World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Review Article)

Check for updates

Rhizospheric Bacteria: A Potential Source of Biofertilizer: A review

Ayoola Nike Daniel * and Smart Obumneme Obiekezie

Department of Microbiology, Faculty of Natural and Applied Science, Nasarawa State University, Keffi, Nigeria.

World Journal of Advanced Research and Reviews, 2026, 29(02), 466-479

Publication history: Received on 20 December 2025; revised on 05 February 2026; accepted on 07 February 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.2.0320

Abstract

Rhizospheric bacteria are one of the microorganisms found in rhizosphere of plant. These bacteria have demonstrated their ability to promote plant growth either directly or indirectly. Over the years, the use of chemical fertilizers has been widely employed to increase the yield of plants. Nevertheless, it negative impact on plants cannot be overlooked as it continues to pose several health risk. There is a need to shift from this culture into a more suitable means, of achieving the same goal on a healthier note. Rhizospheric bacteria have shown their ability to formulate biofertilizers by providing plants with the nutrients needed for their growth. This could be through nitrogen fixation, phosphate solubilization, among others. This paper aims to support the use of rhizospheric bacteria in promoting the growth of plants; hence, it will review rhizospheric bacteria as a potential source of biofertilizer.

Keywords: Rhizospheric bacteria; Nitrogen fixation; Enzymatic activity; Farmer; Human health; Environment; Biofertilizer; Plant growth promotion

1. Introduction

The rhizosphere is a source of various microorganisms that play a role in the growth and development of plants. Rhizospheric bacteria are one of the major microorganisms found in the plant Rhizosphere. These bacteria have demonstrated their ability in the formulation of biofertilizers in the agricultural sector, providing plants with the nutrients required to enhance their growth, increase yield, manage abiotic and biotic stress, and prevent phytopathogen attacks [1]. In addition, rhizospheric bacteria promote plant growth and its development by certain processes [2]. These include phosphate solubilization, siderophore production, ammonia production, hydrogen cyanide production, biological nitrogen fixation, among others [3, 1, 4]. They can also increase plant growth indirectly by suppressing known diseases or by reducing the deleterious effects of minor pathogens and developing systemic resistance [4, 5, 2].

The use of biofertilizers is reportedly growing in countries such as Canada, Argentina, China, India, Europe, and the United States of America [6, 7]. Nigeria should not be an exception.

Examples of plant growth promoting rhizospheric bacteria (PGPR) that can be used for the production of biofertilizers may include; *Azotobacter sp, Azospirillum* sp, *Rhizobium* sp, *Bacillus* sp, *Pseudomomas* sp, *Enterobacter* sp, *Aerobacter* sp, *Bradyrhizobium, Azotobacter, Streptomyces* sp, *Arthobacter, Alkaligens, Azospirillum, Pseudomonas, Serratia, Acinetobacter* among others [8, 1, 9, 10, 11, 12, 7], among several others.

However, chemical fertilizer is the most common agricultural method used to increase crop yield [13, 14]. Several health risk / harmful effects has been associated with the use of Chemical fertilizers [15]. These chemicals can cause a change in the natural components of the soil, it can cause environmental degradation, pollution, among others [16, 17, 12]. Owning to the deleterious effects that may arise from chemical fertilizers, there is need to device a more suitable and

* Corresponding author: Ayoola Nike Daniel

cost effective means to satisfy the needs of farmers for more crop yield or increase but on a healthier note, for the betterment of the plants, human and environmental health.

Therefore, this paper will review Rhizospheric Bacteria as a Potential source of Biofertilizer.

1.1. Rhizosphere

The rhizosphere is the region of the soil that includes the area immediately around plant roots and large number of microorganisms [18, 12] with high microbial activity and high turnover of nutrients where essential macro- and micronutrients are gotten [19, 20, 12].

1.2. Microorganisms in the Rhizosphere

The Rhizosphere is composed of several microorganisms. The kind of microorganisms present in the rhizosphere is determined by the kind and amount of organic nutrients released, root system architecture, root branching order and the root chemistry. Some example of microorganisms present in the Rhizosphere includes; Bacteria, Fungi, Acticomycetes, Protozoa, and Algae [19, 21, 22, 23, 12].

1.3. Rhizospheric Bacteria

Bacteria are microscopic organism, which exist as one of the natural component of the soil. They are the most abundant organism present in the rhizosphere [24, 19]. Bacteria living in the rhizosphere of plant can be called Rhizospheric bacteria. These bacteria develop specific communication pathways with the plant and may influence plant physiology [25, 12]. Some Rhizospheric bacteria are known for promoting plant growth. Some example of the plant growth promoting Rhizospheric bacteria includes the genera of *Azospirillum, Pseudomonas, Azotobacter, Rhizobium, Bacillus, Serratia, Enterobacter, Klebsiella and Acinetobacter* [12].

1.4. Chemical fertilizers

Fertilizers are substances, either synthetic or natural, that are added to soils to provide vital nutrients for plant growth [15].

Chemical fertilizers are the most common agricultural measure used to increase crop yield [13, 14]. Some examples of chemical fertilizers used on plants are; Urea, NPK fertilizers, liquid fertilizers, etc.

Although, chemical fertilizers as been employed for increasing crop yield/production, attention has not been paid on the adverse effect it has on the soil, crop, environment and the consumers.

The use of chemical fertilizers for more yield/crop production as led to some harmful effects on human health and the environment. The components of chemical fertilizers may include heavy metals like Mercury (Hg), Cadmium (Cd), Arsenic (As), Lead (Pb), Copper (Cu), Nickel (Ni), and Chloride, Cobalt etc, which has deleterious effects on the environment and human health [15].

Problems like high cost, environmental degradation, destruction of soil quality, groundwater pollution, deterioration of soil microbial community and several others have been associated with the use of Chemical fertilizers [15, 17, 26, 27, 14] which in turn affects human health.

Some health challenges associated with the use of Chemical fertilizer includes; eye and skin irritation, nausea, vomiting, Irritation of the nose, throat, and lungs through inhalation. Excess nitrogen in plants causes an infant disease, amines produced from the nitrogenous fertilizer can cause cancer in humans, among others [15].

1.5. Disadvantages of Chemical fertilizers

The excessive use of chemical fertilizers may lead to the following;

- Environmental deterioration
- Reduced plant quality
- Destruction of soil structure /quality.
- Disruption of soil microbial community
- Ground water pollution
- Can lead to the loss of plant

- Health challenges in human and other consumers.

2. The need for Biofertilizer

Biofertilizers are microbial formulants used to enhance the growth of plant. Just as chemical fertilizers, biofertilizers are employed for the purpose of more crop yield but on a healthy note, to improve soil and plant quality. Biofertilizers are needed as a replacement to chemical fertilizers to address the effects of chemical fertilizers on the soil, plant, the consumers and the ecosystem.

There are various types of biofertilizers depending on their functions in plant rhizospheres. A biofertilizer can have one single strain of plant growth promoting rhizospheric bacteria with single or multiple plant growth promoting traits while another may have more than one rhizospheric bacteria with various promoting traits. The different types of biofertilizers normally work together to give an effective and environmentally-friendly solution to ensure food security and minimize environmental impacts [7].

3. Rhizospheric bacteria as Biofertilizers

Plant growth promoting organisms can be considered as biofertilizers because of their positive influences to stimulate the growth of plant [7]. Rhizospheric bacteria such as *Rhizobium* sp, *Bradyrhizobium, Bacillus* sp, *Azospirillum, Azotobacter, Acinetobacter, Pseudomonas, Streptomyces* sp, *Arthobacter, Alkaligens, Azospirillum* sp among others have been identified as plant growth promoters [8, 1, 9, 7]. Some have been successfully formulated into commercial biofertilizers [10, 7] due to their ability to fix atmospheric nitrogen, solubilize Phosphate, Zinc and other compound which stimulates plant growth. Plant growth promoting bacteria modulate the level of phytohormones in plant tissues and increase plant biotic or abiotic stress tolerance [21, 12].

Moreso, the application of some microbial strains in the formulation of biofertilizer to enhance plant yeild can protect plant against diseases directly by proliferation of plants Pathogens or indirectly by competition for nutrients.

The major components of biofertilizers are the plant growth promoting Rhizospheric bacteria whose activities positively contributes to the enhancement of plant growth and are able access plant nutrients in the rhizosphere.

Herridge et al., [28] reported that rhizobial inoculants can reduce the cost of annual Nitrogen fertilizer by approximately USD 29 ha−1, signifying the importance of nitrogen fixing rhizospheric bacteria as biofertilizers [7]. Another study reported the use of Rhizospheric bacteria to significantly enhance the uptake of zinc in wheat among several others [29, 7]. The consumption of biofertilizers is reportedly growing in countries like Canada, Argentina, China, India, Europe, and the United States of America, due to tax exemptions, and input subsidies [6, 7]. There are more success stories of legume inoculants in different parts of the world [30, 31, 32, 7].

Examples of Rhizospheric bacteria used for the production of biofertilizers include; *Bacillus* sp, *Pseudomomas* sp, *Azotobacter* sp, *Azospirillum* sp, *Rhizobium* sp, *Enterobacter* sp, *Aerobacter* sp, [10, 11, 12, 7], among several others still in discovery or yet to be discovered.

4. Mechanism of Rhizospheric bacteria in promoting plant growth

The Mechanism of Rhizospheric bacteria in promoting plant growth includes those factors responsible for the stilmuation of plant growth. Rhizospheric bacteria promotes plant growth and development by exhibiting the following trait; ammonia production, hydrogen cyanide production, indole acetic acid production, phosphate solubilization, biological nitrogen fixation, siderophore production among others either directly or indirectly;

The mechanisms of Plant growth promoting bacteria can be separated into two which includes; direct and indirect mechanism.

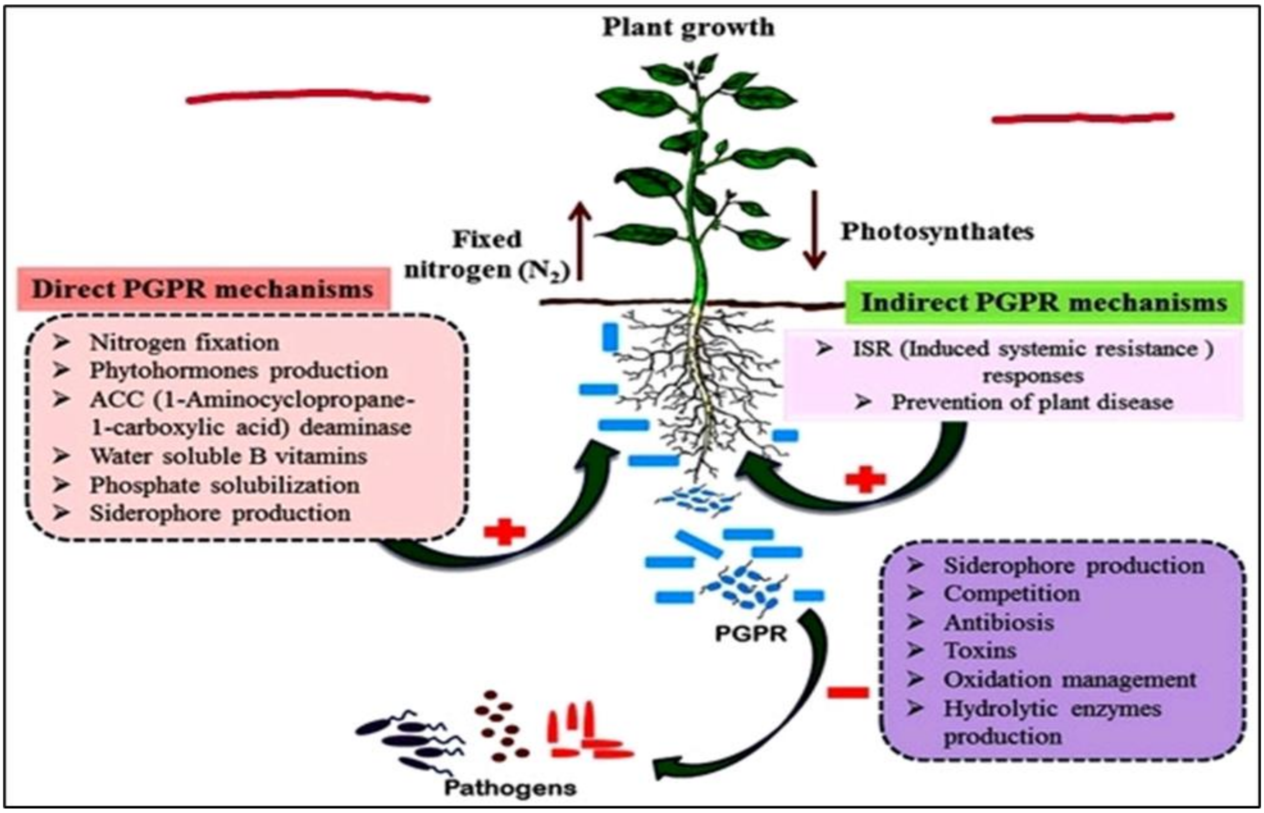

Figure 1 Mechanism of plant growth promotion by Rhizospheric bacteria [33]

4.1. Direct Mechanism

This involves the direct production of substances needed for plant growth by the specific microorganisms. This microorganisms enhance soil fertility by bringing out essential nutrients or minerals [34, 35] needed in the soil for the plant growth.

The direct mechanisms in plant growth may include; phytohormone production, biological nitrogen fixation, phosphorus solubilization, biofertilization, stimulation of root growth, rhizoremediation, Hydrogen Cyanide production, plant stress control among others [36, 35].

5. Phytohormone Production

Phytohormones allows the growth of plant and its development by tolerating different stress conditions [37, 35]. Some rhizospheric bacteria plays a role in several plant growth processes through its ability to produce phytohormones like auxins, gibberellins, cytokinins, ethylene among others [33, 38, 39, 35].

5.1. Auxins

Auxins are hormones produced by different microorganisms. This hormone is essential for the cell division, fruit development and leaves of plants [40].

Indole acetic acid (IAA) is one of the most essential auxins that stimulates the development of plants; the leaves, flowers and the roots development [41, 42]. Some bacteria like *Bacillus subtilis, Aeromonas punctate, Burkholderia phytofirmans* and *Azospirillum brasilense* have shown the ability to efficiently produce Indole acetic acid [43, 44, 45, 46, 47, 48, 49, 35].

Indole acetic acid (IAA) is a responsible part of the communication and signaling system between rhizospheric bacteria and plants [50, 35]. A plant inoculated with isolates capable of producing IAA will significantly increase the plant yield [51, 36]. Most rhizospheric bacteria can produce indole acetic acid.

Biosynthesis pathways of IAA have been identified using several biochemical and genetic methods. However, a small set of genes and enzymes involved in these pathways have been characterized [52, 35]. The main precursor for the synthesis of IAA is the tryptophan [50]. The biosynthesis of tryptophan starts in a five step reaction encoded by trp genes from the metabolic nodes [53]. The pathways of tryptophan-dependent include indole-3- acetamide, indole-3-pyruvate, indole-3-acetonitrile pathways and tryptamine [50], though some intermediaries may differ as mentioned by Patten and Glick, [43]; Woodward and Bartel, [54], most pathways show similarity to those described in plant. The amount of IAA produced by rhizobacteria is quantified by Salkowski method [55, 56]. Many bacteria, both beneficial and harmful have the ability to produce IAA. This can affect plant growth in both favourable and unfavorable way. Too much amounts of IAA produced can be deleterious to plant growth. Therefore, IAA must be carefully regulated to avoid inhibitory effects caused by overdosing [47, 35].

5.2. Cytokinins

Cytokinins are phytohormone responsible for the formation of shoots, improvement of cell division, root development and inhibition of root elongation [57, 58, 35].

Several types of cytokines like zeatin and kinetin can be produced by rhizospheric bacteria [59]. Rhizospheric bacteria are able to produce zeatin in two seperate ways either directly and indirectly. The synthesis of dimethylalyl diphosphate and isopentenyl adenosine monophosphate involves the direct pathway while cis-zeatin that contains tRNA go through the indirect pathway to release cytokinins [60, 35].

Examples of rhizobateria capable of producing cytokinin includes; *Azotobacter* sp, *Rhizobium* sp, *Pseudomonas fluorescens, B. subtilis, Pantoea agglomerans, Rhodospirillum rubrum* etc [61, 62, 35].

5.3. Gibberellins

Gibberellin is another example of phytohormones that acts throughout the life cycle of plant. It produces many physical effects like; stem elongation, seed germination, flower induction, etc [63, 64]. Gibberellins are released by rhizospheric bacteria, they regulate cell division and elongation, stimulating the growth of the hypocotyl and stem, having a good effect on leaf meristem size and the plant root [65]. Gibberellin are also good at promoting xylem increase and shoot growth [66, 67].

Some studies have shown some plants with gibberellin producing rhizobacteria to exhibits better growth rates [68, 69, 35]. The first report of gibberellin characterization in bacteria was reported using physico-chemical methods by Atzorn *et al.,* [70], he demonstrated the presence of GA1, GA3, GA4 and GA20 in gnotobiotic cultures of *Rhizobium meliloti*. Production of gibberellins by rhizospheric bacteria has been confirmed in several studies [35]. They include examples like *Acetobacter diazotrophicus, Sphingomonas sp, Enterococcus faecium, Herbaspirillum seropedicae,* and *Bacillus* sp, among others [71, 35].

5.4. Ethylene

Ethylene is another phytohormones proven to be very active promoting many growth parameters like seed germination, leaf maturation, flower initiation, fruit maturation, root elongation and branching, nodule formation, among others [72, 35]. Though, overproduction of this hormone can cause inhibitory effects on root development of the plant which may lead to abnormal growth of the plant. Therefore, ethylene level in plant should be controlled for healthy plants growth and root development [73, 63]. Some bacteria; *Bacillus, Azotobacter* and *Pseudomonas* [74, 75 76, 77, 78, 35] as been identified to be able to synthesize '1-aminocyclopropane -1-carboxylate deaminase (ACCD), an enzyme that bind to ACC (ethylene precursors in plant), able to reduce or control levels of ethylene produced in plant to level considered to be nontoxic [35, 63].

6. Biological Nitrogen Fixation

Nitrogen is used by plants to produce vitamins, amino acids, nucleic acids, and other nitrogenous compounds [12]. The most limiting nutrient for plant development is nitrogen but can be taken in from the soil in the form of ammonia, nitrate and nitrite [79, 35]. Nitrogen forms (ammonia, nitrate and nitrite) are not abundant in most soils [80]. Nitrogen -fixing microorganisms are capable of fixing nitrogen from the atmosphere into the soil making it available for plant to use.

The Nitrogen -fixing microorganisms are classified into two groups: symbiotic microorganisms and free-living microorganisms [79]. Bacteria that perform symbiosis act by forming nodules on the roots of a plant converting atmospheric nitrogen into ammonia, which can be used by the plant as a source of Nitrogen [81, 35]. Examples of symbiotic nitrogen fixing bacteria are the family of Rhizobiaceae which includes; *Rhizobium, Bradyrhizobium, Sinorhizobium* among others. Rhizobium helps fixes atmospheric nitrogen in leguminous plants which makes the use of chemical nitrogen fertilizers not necessary [12].

Free-living bacteria are able to interact with roots; they live close to them so that the nitrogen fixed by these bacteria can be easily taken in by plants while the bacteria feed on root exudate (amino acids, peptides, proteins, enzymes, vitamins, and hormones [60]. Examples of free-living N-fixing bacteria may include; *Azotobacter, Azospirillum, Paenibacillus, Clostridium, Enterobacter, Burkholderia, Corynebacterium, Bacillus, Pseudomomas* etc. [82, 83, 84, 36, 85, 86, 35]. Azotobacter is able to fix nitrogen under aerobic conditions and can act as control agent [12]. Azospirillum strains promotes growth in plants through the production of phytohormones e.g auxins [12].

Biological Nitrogen Fixation is carried out by a specific gene product called nif, which, together with other structural genes, participates in protein iron activation, electron transfer biosynthesis of the molybdenum iron cofactor and many other regulatory processes required for enzyme synthesis and activity [87, 35]. All nitrogen fixing bacteria use the same enzyme called Nitrogenase [88, 12].

7. Phosphorus Solubilization

Phosphorus an essential nutrient for plant growth. It plays an important role in almost all major metabolic processes like respiration, signal transduction, energy transfer, photosynthesis, [89, 35]. Phophorus present in the soil are majorly in form of insoluble compound which cannot be absorbed, this makes it limited for plant growth. Plants absorb phosphate only in the form of monobasic and dibasic ions [80, 35].

Rhizobacteria can solubilize inorganic phosphate source to enhance the growth of plant in the soil [33]. Bacteria able to solubilize phosphate are called Phosphate solubilizing bacteria. This bacteria play a key role in solubilizing and mineralizing Phosphate in the soil [90] to enhance plant growth. Some examples of phosphate solubilizing bacteria may include; *Bacillus, Enterobacter, Arthrobacter, Burkholderia, Pseudomonas, Beijerinckia Rhizobium, Erwinia, Microbacterium* etc. [90, 12, 33].

The ability of plant growth promoting rhizospheric bacteria to solubize phosphate has been of major interest to the agricultural microbiologist because of it's ability to enhance the availability of phosphorus in the soil for effective growth of plant. The synthesis of organic acids by rhizosphere microorganism could be possible reason for solubilization of inorganic phosphate in the soil [33].

8. Hydrogen Cyanide production

Hydrogen cyanide is produced by some rhizospheric bacteria in plant seedlings. The production of cyanide by rhizospheric bacteria is an environmentally friendly mechanism used to control weeds /undesired plants biologically, to reduce it harmful effects on the growth of desired plants [91, 71].

Hydrogen cyanide is formed during the early stationary growth phase but does not take part in growth or primary metabolism. It is considered to be a secondary metabolite that confers a selective advantage on the producer strains [92, 71].

Cyanide occurs as a free cyanide solution which includes cyanide anion and non –dissociated hydrogen cyanide [71]. Cyanide is a phytotoxic agent capable of inhibiting enzymes involved in major metabolic processes. It is seen as one of the important characters of deleterious rhizobacterial isolates [93]. It's applications in areas of biocontrol is gaining increase [94, 71].

Some cyanogenic rhizobacteria are typically host specific and associated with the roots of their host plants. Some examples of rhizospheric bacteria with cyanogenic traits includes; *Bacillus, Pseudomomas* [95, 71, 2].

9. Indirect Mechanism

The indirect mechanism of plant growth promotion in rhizospheric bacteria is done majorly by acting as biocontrol agents [62, 33]. This mechanism of biological control for rhizospheric bacteria works by reducing the impact of diseases by means of antagonistic activity against phytopathogenic microorganisms, inducing plant systemic resistance responses among others [35].

9.1. Antagonism/ Biocontrol potential of Rhizospheric bacteria in plants

Antagonism also known as 'biocontrol', is a process by which living organisms are used to mitigate the growth of plant pathogens [96, 97].

One of the major factors that affects plant productivity is the attack of on the plants by plant pathogens. The application of essential microorganisms that produces high antimicrobial substances helps in reducing the attack from phytopathogen. Antagonism/biocontrol potential is a method of plant growth promotion carried out by rhizospheric bacteria to suppress the occurrence of diseases in plants [98].

Microorganisms with biocontrol potential are called Antagonist. These organisms can suppress a wide range of bacteria, fungi and nematode diseases and provide protection against viral diseases [36]. They are eco-friendly in nature as they do not cause harm to man, animals while consuming the crops and the environment they live in [97].

The biological control of plant pathogens may occur through the production of antimicrobial compounds, lytic enzymes, competition for space, nutrients, among others [99, 100, 101, 102, 35].

Examples of Rhizospheric bacteria with biocontrol or antagonistic potential includes; *Pseudomomas florescence, Bacillus sp* etc. *Pseudomomas florescence* has been characterise with the ability to colonize the rhizosphere and protect it from wide range of important agronomic disease like black root rot, pea and wheat rot [36]. *Pseudomonas florescence* showed strong antifungal activity against *Pyricularia oryzae* through the production of antifungal metabolites such as antibiotics, phytohormones, siderophore, hydrogen cyanide etc [36]. These organisms can be introduced to the plants roots during the seedling stage of plant to ensure beneficial relationship between the plant, to improve plant health and enhance plant growth.

The mechanism of antagonism of biological agents is direct antagonism including predation and hyperparasitism, indirect antagonism includes induction of host resistance and competition while mixed antagonism includes antibiotics and lytic enzymes which are capable of causing chemical and physical disruption of pathogens [103, 104].

9.2. Enzymatic Activity of Plant Growth Promoting Rhizospheric Bacteria

Several bacteria found in the Rhizospheres are known to produce enzymes. The activity of rhizospheric bacteria in the rhizosphere is mainly noticed by the production of hydrolytic enzymes such as Β- glucanases, Chitinase, Protease, Cellulase, Amylase among others. These enzymes can cause cell injuries to a fungi [105, 98] or bacteria cell wall which may result to the death of such organism. In other words, the antagonistic potential of a rhizobacteria to a pathogen is noticed by its ability to lyse bacteria or fungi cell wall. For example, *Pseudomomas stutzeri* produces extracellular enzymes like chitinase which breaks down the mycelia of *Fusarium solani* [36]. The enymatic activity of the rhizospheric bacteria is a function of it antagonistic /biocontrol potential against test organism.

10. Some Enzymatic activity of Rhizospheric bacteria

Amylase production: Amylase are catalysts enzymes of starch hydrolysis [98]. This enzymes can be produced by some rhizospheric bacteria for their ability to hydrolyze starch into smaller sugars. The action of Amylase on soil makes glucoside bonds of starch hydrolyze, releasing molecules of maltose and glucose at the end of the hydrolysis. This is important for the activity of microorganisms in the soil for nutrient cycling and the maintainance of plant or soil system [106, 98].

Protease production: Protease are enzymes responsible for protein degradation by releasing many amino acids that can undergo deamination. The capacity of the enzyme is dependent on the microbial activity [106, 98]. *Bacillus lueiferensis* was reported to reduce the phytophthora blight of pepper by protecting it from infection through enhanced root colonization and protease production [36]. Proteolytic enzyme activity is essential for nutrient cycling and promotes plant growth by releasing essential nutrients like nitrogen from dead organic matter. Protease producing Rhizospheric organism act as biocontrol agents against disease causing organism. Proteases from microbial sources are preferred over the enzymes from plant or animal sources since they possess almost all the characteristics desired for their biotechnological applications [107].

Cellulose production: Cellulase is an enzyme system consisting of a mixture of several enzymes, which are primarily classifed into into three main types: β-glucosidase, exo-β-1,4-glucanases, and endo-β-1,4- glucosidases [108]. Bacteria is one of the primary organism in soil capable of degrading cellulose [109]. Cellulose enzymes are lytic enzymes that degrade the cell walls of pathogenic fungi in plants [5, 104]. Some studies like Bhattacharyya et al., [5] has reported the isolation of Rhizosphere bacteria with cellulase activity. Some example of cellulose degrading bacteria include; *Bacillus sphaericus* BS-5 [110], Bacillus cereus, Bacillus thuringiensis, etc [5].

Chitinase production: Chitinase is composed of structural polysaccharides β–1,4–N–acetyl–D–glucosamine. Chitin is one of the most common biodegradable polymers after cellulose [111, 112, 104]. Chitin is abundant in the shells of crustaceans, insect exoskeletons, and some fungi. The chitinase enzyme is capable of degrading chitin in the cell walls of fungi and insect exoskeletons. Microorganisms that produce chitinase can be used as potential agents for the biological control of plant diseases caused by various insect pests and pathogenic fungi. They can be used instead of chemical pesticides [113, 104]. Other antagonistic potential of rhizospheric bacteria may include; the competition of nutrients, production of antibiotics among others [114, 98].

10.1. Induced Systemic Resistance (ISR)

The Interaction of some rhizospheric bacteria with the plant roots can result in plant resistance against some pathogenic bacteria, fungi, and viruses through a process called the Induced systemic resistance [33]. This process describes the defensive capability of plants in response to various pathogens induced by beneficial microorganisms present in the rhizosphere [115, 35]. Induced systemic resistance can also be caused by specific environmental stimuli that leads to the up regulation of plants' innate defenses against biotic situations which allows plants to respond fast against further attack by pathogens [116, 35]. Induced Systemic Resistance (ISR) can be stimulated by non-pathogenic microorganisms which begins from the plant roots and extends to its shoots [117]. It initiates the defense mechanisms of plants and protects the unexposed parts of plants from further pathogenic attacks. ISR defense response depends on the signaling of ethylene and jasmonic acid within the plant [118, 119, 35] and these hormones are able to stimulate the host plant's defense responses against several plant pathogens [62, 33]. Many individual bacterial components induce systemic resistance, such as; siderophores, cyclic lipopeptides, lipopolysaccharides (LPS), 2,4-diacetylphloroglucinol, flagella, homoserine lactones, and volatiles such as; 2,3-butanediol and acetoin [120, 33].

10.2. Advantages of Rhizospheric bacteria as biofertilizers in plant growth.

- Rhizospheric bacteria are eco-friendly [17, 121, 12, 122].
- They increases crop yeilds and enhances plant growth.
- Rhizospheric bacteria with nitrogen fixing abilities promotes plant growth by converting atmospheric nitrogen into the soil, making it available for plant to use.
- They help manage biotic and abiotic stress [1].
- Some rhizospheric bacteria are good antagonist against plants pathogens thereby preventing the invasion of plant pathogens and reduces the spread of diseases in the plant while promoting the plant growth.
- They are cost efficient means of enhancing soil fertility, they repair and enrich the soil rhizosphere.
- They address any adverse effect caused by chemicals fertilizer in the soil.
- Biofertilizers has no deleterious effects on plant growth or consumers health [17].
- They are reliable for agricultural development [122].

11. Conclusion

Owing to the deleterious effect of chemical fertilizers on the environment and human health, the use of Rhizospheric bacteria to produce biofertilizers cannot be over emphasized as it has been proven to promote plant growth, prevent plant pathogens /diseases and has no deleterious effect on human health. This review supports the study of Kumar and Dev, (2017), who suggested the adoption of a new agricultural technology that switches from the use of chemical fertilizers to the use of organic inputs like biofertilizers. The use of biofertilizer is a good approach to employ and safe in promoting plant growth.

Compliance with ethical standards

Disclosure of conflict of interest

The Authors disclose no conflict of interest.

References

[1] Singh R, Prasad MP. Isolation and screening of Rice Rhizosphere Soil microorganisms for the production of IAA. Int. J. Curr. Microbiol. App. Sci. 2014; 3(9): 993-998.

[2] Kumar V, Indu, Richa, Kumar S, Sehajpal D. Isolation and Screening of Plant Growth Promoting Rhizobacteria from the Rhizospheric Soil of Wheat (Triticum aestivum) from Lower Western Himalayan Zone of Himachal Pradesh. Int. J. Curr. Microbiol. App.Sci. 2021; 10(11): 23-34.

[3] Han J, Sun L, Dong X, Cai Z, Sun X, Yang H, Wang Y, Song W. Characterization of a novel plant growth-promoting bacteria strain Delftia tsuruhatensis HR4 both as a diazotroph and a potential biocontrol agent against various plant pathogens. Syst Appl Microbiol ; 2005 28(1): 66-76.

[4] Nour KAM, Hager IT. Evaluation Impact of Some Plant Growth Promoting Microorganisms on the Growth and Productivity of Cowpea. Middle East Journal of Agriculture Research. 2015; 4 (03); 532-544.

[5] Bhattacharyya C, Banerjee S, Acharya U, Mitra A, Mallick I, Haldar A, Haldar A, Ghosh A, Ghosh A. Evaluation of plant growth promotion properties and induction of antioxidative defense mechanism by tea rhizobacteria of Darjeeling, India. Scientific Reports ; 2020; 10:15536.

[6] Markets and Markets. Biofertilizer market by form (liquid, carrier-based), mode of application (soil treatment, seed treatment), crop type, type (nitrogenfixing, phosphates solubilizing and mobilizing, potash solubilizing and mobilizing), region-global forecast to 2025. Available at: https://www.marketsandmarkets.com/Market-Reports/compound-biofertilizers-customized-fertilizers-market-856. html (Accessed September 1, 2020; August, 2025).

[7] 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.

[8] Kloepper JW, Lifshitz R, Zablotowicz, RM. Free-living bacterial inocula for enhancing crop productivity. Trends Biotechnol. 1989; 7, 39 43.

[9] Hanirah R, Piakong MT, Syaufi L. Isolation, characterization and screening of rhizospheric bacteria of Pittosferum resiniferum Hemsl. Middle East Journal of Agriculture Research. IOP Conf. Ser.: Mater. Sci. Eng. 2015; 78 012036.

[10] Adeleke RA, Raimi AR, Roopnarain A, Mokubedi SM. "Status and prospects of bacterial inoculants for sustainable Management of Agroecosystems" in Biofertilizers for Sustainable Agriculture and Environment. eds. B. Giri, R. Prasad, Q. S. Wu and A. Varma (Cham: Springer International Publishing). 2019; 137–172.

[11] Odoh CK, Eze CN, Akpi UK, Unah VU. Plant growth promoting rhizobacteria (PGPR): a novel agent for sustainable food production. Am. J. Agric. Biol. Sci. 2019; 14, 35–54.

[12] Fasusi OA, Cruz C, Babalola OO. Agricultural Sustainability: Microbial Biofertilizers in Rhizosphere Management. Agriculture. 2021; 11, 163.

[13] Sedri MH, Niedbala G, Roohi E, Niazian M, Szulc P, Rahmani HA, Feiziasl V. Comparative analysis of plant growthpromoting rhizobacteria (PGPR) and chemical fertilizers on quantitative and qualitative characteristics of rainfed wheat. Agronomy. 2022; 12, 1524.

[14] Song Y, Chen Q, Hua J, Zhang S, Luo S. The IAA-Producing Rhizobacterium Bacillus sp. SYM-4 Promotes Maize Growth and Yield. Plants. 2025; 14, 1587.

[15] Kumar R, Dev KK. Effects of Chemical Fertilizers on Human Health and Environment: A Review. International Advanced Research Journal in Science, Engineering and Technology. 2017; (4) 6.

[16] Kloepper JW, Zablotowick RM, Tipping EM, Lifshitz R. Plant growth promotion mediated by bacterial rhizosphere colonizers. In: Keister DL, Cregan PB (eds). The rhizosphere and plant growth. Kluwer, Netherlands. 1991; 315–326.

[17] Makut MD, Ishaya IO, Ombugadu A, Onawola OO, Abikoye ET, Mohammed SA. Isolation, Identification and Screening of Pseudomonas fluorescens from soil environment of Keffi, Nasarawa state - Nigeria for the production of Biofertilizer. Science Park Journals of Applied Microbiology Research. 2019; 4(1); 017-028. DOI: 10.14412/.28.

[18] Hu L, Robert CA, Cadot S, Zhang X, Ye M, Li B, Manzo D, Chervet N, Steinger T, Van Der Heijden MG. Root exudate metabolites drive plant-soil feedbacks on growth and defense by shaping the rhizosphere microbiota. Nat. Comm. 2018; 9, 1–13.

[19] Vejan P, Abdullah R, Khadiran T, Ismail S, Boyce AN. Role of Plant Growth Promoting Rhizobacteria in Agricultural Sustainability—A Review. Molecules. 2016; 21, 573.

[20] Enagbonma BJ, Babalola OO. Environmental sustainability: A review of termite mound soil material and its bacteria. Sustainability. 2019; 11, 3847.

[21] Yadav AN, Verma P, Singh B, Chauhan V, Suman A, Saxena AK. Plant growth promoting bacteria: Biodiversity and multifunctional attributes for sustainable agriculture. Adv. Biotechnol. Microbiol. 2017; 5, 1–16.

[22] Meena VS, Maurya BR, Meena SK, Mishra PK, Bisht JK, Pattanayak A. Potassium solubilization: Strategies to mitigate potassium deficiency in agricultural soils. Glob. J. Biol. Agric. Health Sci. 2018; 7, 1–3.

[23] Pervaiz ZH, Contreras J, Hupp BM, Lindenberger JH, Chen D, Zhang Q, Wang C, Twigg P, Saleem M. Root microbiome changes with root branching order and root chemistry in peach rhizosphere soil. Rhizosphere. 2020; 16.

[24] Kaymak DC. Potential of PGPR in agricultural innovations. In Plant Growth and Health Promoting Bacteria; Maheshwari, DK., Ed.; Springer-Verlag: Berlin/Heidelberg, Germany.2010

[25] Javeria S, Kumar V, Sharma P, Prasad L, Kumar M, Varma A. Mycorrhizal symbiosis: Ways underlying plant–fungus interactions. In Mycorrhiza-Eco-Physiology, Secondary Metabolites, Nanomaterials; Springer. 2017; 183–207.

[26] Zeng QW, Ding XL, Wang JC, Han XJ, Iqbal HMN, Bilal M. Insight into soil nitrogen and phosphorus availability and agricultural sustainability by plant growth-promoting rhizobacteria. Environ. Sci. Pollut. Res. 2022; 29, 45089–45106.

[27] Qasim M, Ju J, Zhao HT, Bhatti SM, Saleem G, Memon SP, Ali S, Younas, MU, Rajput N, Jamali, ZH. Morphological and physiological response of tomato to sole and combined application of vermicompost and chemical fertilizers. Agronomy. 2023; 13, 1508.

[28] Herridge DF, Peoples MB, Boddey RM. Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil . 2008; 311, 1–18.

[29] 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, 449–454.

[30] El-Wakeil NE, El-Sebai TN. Role of biofertilizer on faba bean growth, yield, and its effect on bean aphid and the associated predators. Arch. Phytopathol. Plant Prot. 2009; 42, 1144–1153.

[31] Ngakou A, Megueni C, Ousseni H, Massai A. Study on the isolation and characterization of rhizobia strains as biofertilizer tools for growth improvement of four grain legumes in Ngaoundéré-Cameroon. Int. J. Biol. Chem. 2009; 3, 1078–1089.

[32] Gomare K, Mese M, Shetkar Y. Isolation of rhizobium and cost effective production of biofertilizer. Indian J. Life Sci. 2013; 2:49.

[33] Nazir N, Kamili AN, Shah D. Mechanism of Plant Growth Promoting Rhizobacteria (PGPR) in enhancing plant growth – A Review. International Journal of Management, Technology and Engineering. 2018; 8 (6). 2249-7455.

[34] Naik K, Mishra S, Srichandan H, Singh PK, Sarangi PK. Plant growth promoting microbes: potential link to sustainable agriculture and environment. Biocatal. Agric. Biotechnol. 2019; 21:101326.

[35] dos Santos RM, Diaz PAE, Lobo LLB, Rigobelo EC. Use of Plant Growth-Promoting Rhizobacteria in Maize and Sugarcane: Characteristics and Applications. Front. Sustain. Food Syst. 2020; 4:136. doi: 10.3389/fsufs.2020.00136

[36] Sivasakthi S, Usharani G, Saranraj P. Biocontrol potentiality of plant growth promoting bacteria (PGPR) - Pseudomonas fluorescens and Bacillus subtilis: A review. African Journal of Agricultural Research Review. 2014; 9(16);1265-1277. DOI: 10.5897/AJAR2013.7914.

[37] Shaterian J, Waterer D, De Jong H, Tanin KK. Differential stress responses to NaCl salt application in early- and late-maturing diploid potato (Solanum sp.) clones. Environ. Exp. Bot. 2005; 54, 202–212.

[38] Glick BR. Bacteria with ACC deaminase can promote plant growth and help to feed the world. Microbiol. Res. 2014; 169, 30–39.

[39] Kaur H, Kaur J, Gera R. Plant growth promoting rhizobacteria: a boon to agriculture. Int. J. Cell Sci. Biotechnol. 2016; 5, 17–22.

[40] McSteen P. Auxin and monocot development. Cold Spring Harb. Perspect. Biol. 2010; 2:a001479.

[41] Phillips KA, Skirpan AL, Liu X, Christensen A, Slewinski TL, Hudson C, Barazesh S, Cohen JD, Malcomber S, McSteen P. Vanishing tassel encodes a grass-specific tryptophan aminotransferase required for vegetative and reproductive development in maize. Plant Cell. 2011; 23, 550–566.

[42] Karnwal A. Isolation and identifi cation of plant growth promoting rhizobacteria from maize (Zea mays L.) rhizosphere and their plant growth promoting eff ect on rice (Oryza sativa L.). Journal of Plant Protection Research. 2017; 57 (2): 144–151.

[43] Patten CL, Glick BR. Bacterial biosynthesis on indole-3-acetic acid. Can. J. Microbiol. 1996; 42: 207–220.

[44] Khalid A, Arshad M, Zahir ZA. Screening plant growthpromoting rhizobacteria for improving growth and yield of wheat. J. Appl. Microbiol. 2004a; 96, 473–480.

[45] Iqbal A, Hasnain S. Auxin producing Pseudomonas strains: biological candidates to modulate the growth of Triticum aestivum beneficially. Am. J. Plant Sci. 2013; 4, 1693–1700.

[46] Camilios-Neto D, Bonato P, Wassem R, Tadra-Sfeir MZ, Brusamarello-Santos LCC, Valdameri G, Donatti L, Faoro H, Weiss VA, Chubatsu LS, Pedrosa FO, Souz EM. Dual RNA-seq transcriptional analysis of wheat roots colonized by Azospirillum brasilense reveals up-regulation of nutrient acquisition and cell cycle genes. BMC Genomics. 2014; 15 (1):378.

[47] Duca D, Lorv J, Patten CL, Rose D, Glick BR. Indole-3-acetic acid in plant-microbe interactions. Antonie Van Leeuwenhoek. 2014; 106, 85–125.

[48] Poupin MJ, Greve M, Carmona V, Pinedo I. A complex molecular interplay of auxin and ethylene signaling pathways is involved in arabidopsis growth promotion by Burkholderia phytofirmans PsJN. Front. Plant Sci. 2016; 7:16.

[49] Tahir HAS, Gu Q, Wu HJ, Raza W, Hanif A, Wu L, Colman MV, Gao X. Plant growth promotion by volatile organic compounds produced by Bacillus subtilis SYST2. Front. Microbiol. 2017; 8:171.

[50] Spaepen S, Vanderleyden J, Remans R. Indole-3-acetic acid in microbial and microorganism-plant signaling. FEMS Microbiol. Rev. 2007; 31, 425–448.

[51] Farzana Y, Radizah O. Influence of rhizobacterial inoculation on growth of the sweet potato cultivar. Online J. Biol. Sci. 2005; 1(3):176-179.

[52] Spaepen S, Vanderleyden J. Auxin and plant-microbe interactions. Cold Spring Harb. Perspect. Biol. 2011; 3, 1–13.

[53] Merino E, Jensen RA, Yanofsky C. Evolution of bacterial trp operons and their regulation. Curr. Opin. Microbiol. 2008; 11, 78–86.

[54] Woodward AW, Bartel B. Auxin: Regulation, action, and interaction. Ann. Bot. 2005; 95, 707–735.

[55] Dubey RC, Maheshwari DK. Practical microbiology and microbial physiology. (2006).

[56] Rani MU, Arundhathi Reddy G. Screening of rhizobacteria containing plant growth promoting (PGPR) traits in rhizosphere soils and their role in enhancing growth of pigeon pea. African Journal of Biotechnology. 2012; 11(32) : 8085-8091.

[57] Porcel R, Zamarreno AM, Garcia-Mina JM, Aroca R. Involvement of plant endogenous ABA in Bacillus megaterium PGPR activity in tomato plants. BMC Plant Biol. 2014; 14:36.

[58] Jha CK, Saraf M. Plant growth promoting rhizobacteria (PGPR): a review. J. Agric. Res. Dev. 2015, 108–119.

[59] O'Brien JA, Benkova E. Cytokinin cross-talking during biotic and abiotic stress responses. Front. Plant Sci. 2013; 4:451.

[60] Tabassum B, Khan A, Tariq M, Ramzan M, Iqbal Khan MS, Shahid N Aaliya K. Bottlenecks in Commercialisation and Future Prospects of PGPR. Applied Soil Ecology. 2017; 121, 102-117.

[61] De Salamone IEG, Hynes RK, Nelson LM. Cytokinin production by plant growth promoting rhizobacteria and selected mutants. Can. J. Microbiol. 2001; 47, 404–411.

[62] Glick BR. Plant Growth-Promoting Bacteria: Mechanisms and Applications. Hindawi Publishing Corporation, Scientifica. 2012. doi: 10.6064/2012/963401.

[63] Ngoma L, Babalola OO, Ahmad F. Ecophysiology of plant growth promoting bacteria. Scientific Research and Essays. Academic Journals. 2012; 7(47); 4003-4013.

[64] Boemke C, Tudzynski B (2009). Diversity, regulation, and evolution of the gibberellin biosynthetic pathway in fungi compared to plants and bacteria. Phytochem. 70:1876-1893.

[65] Martínez C, Espinosa-Ruiz A, Prat S. Gibberellins and plant vegetative growth. Annu Plant Rev Online. 2018; 49, 285–322.

[66] Guo HY, Wang YC, Liu HZ, Hu P, Jia YY, Zhang CR, et al. Exogenous GA(3) application enhances xylem development and induces the expression of secondary wall biosynthesis related genes in Betula platyphylla. Int. J. Mol. Sci. 2015; 16, 22960–22975.

[67] Wang GL, Que F, Xu ZS, Wang F, Xiong AS. Exogenous gibberellin altered morphology, anatomic and transcriptional regulatory networks of hormones in carrot root and shoot. BMC Plant Biol. 2015; 15:290.

[68] Poupin MJ, Timmermann T, Vega A, Zuniga A, Gonzalez B. Effects of the plant growth-promoting bacterium Burkholderia phytofirmans PsJN throughout the life cycle of Arabidopsis thaliana. PLoS ONE. 2013; 8:e69435.

[69] Vacheron J, Desbrosses G, Bouffaud ML, Touraine B, Moenne-Loccoz Y, Muller D, et al. Plant growth-promoting rhizobacteria and root system functioning. Front. Plant Sci. 2013; 4:19.

[70] Atzorn R, Crozier A, Wheeler C, Sandberg G. Production of gibberellins and Indole 3-acetic acid by Rhizobium phaseoli in relation to nodulation of Phaseolus vulgaris roots. Planta. 1988; 175: 532–538.

[71] Chaitanya KJ, Meenu SM. Plant growth promoting Rhizobacteria (PGPR): A review. Journal of Agricultural Research and Development. 2015; 5(2). 0108-0119.

[72] Reid MS. "The role of ethylene in flower senescence," in: IV International Symposium on Postharvest Physiology of Ornamental Plants. 1988; 261.

[73] Saleem M, Arshad M, Hussain S, Bhatti AS (2007). Perspective of plant growth promoting rhizobacteria (PGPR) containing ACC deaminase in stress agriculture. J. Ind. Microbiol. Biotechnol. 34:635-648

[74] Belimov AA, Safronova VI, Sergeyeva TA, Egorova TN, Matveyeva VA, Tsyganov VE, Borisov AY, Tikhonovich IA, Kluge C, Priestfeld A, Dietz KJ, Stepanok VV. Characterization of plant growth promoting rhizobacteria isolated from polluted soils and containing 1-aminocyclopropane-1-carboxylate deaminase. Can. J. Microbiol. 2001; 47: 642–652.

[75] Dubey RC, Maheshwari DK, Kumar V, Pandey RR. Growth enhancement of Sesamum indicum L. by rhizosphere-competent Azotobacter chroococcum AZO2 and its antagonistic activity against Macrophomina phaseolina. Arch. Phytopathol. Plant Protect. 2012; 45, 437–454.

[76] Farajzadeh D, Yakhchali B, Aliasgharzad N, Sokhandan-Bashir N, Farajzadeh M. Plant growth promoting characterization of indigenous azotobacteria isolated from soils in Iran. Curr. Microbiol. 2012; 64, 397–403.

[77] Sandhya V, Ali SZ, Grover M, Reddy G, Venkateswarlu B. Effect of plant growth promoting Pseudomonas spp. on compatible solutes, antioxidant status and plant growth of maize under drought stress. Plant Growth Regul. 2010; 62, 21–30.

[78] Kamran MA, Eqani SAMAS, Bibi S, Xu RK, Monis MFH, Katsoyiannis A, et al. Bioaccumulation of nickel by E. sativa and role of plant growth promoting rhizobacteria (PGPRs) under nickel stress. Ecotoxicol. Environ. Saf. 2016; 126, 256–263.

[79] Gopalakrishnan S, Srinivas V, Samineni S. Nitrogen fixation, plant growth and yield enhancements by diazotrophic growth-promoting bacteria in two cultivars of chickpea (Cicer arietinum L.). Biocatal. Agric. Biotechnol. 2017; 11, 116–123.

[80] Perez-Montano F, Alias-Villegas C, Bellogin R A, del Cerro P, Espuny M R, Jimene Guerrero I, López-Baena F J, Ollero F J, Cubo T. Plant growth promotion in cereal and leguminous agricultural important plants: from microorganism capacities to crop production. Microbiol. Res. 2014; 169, 325–336.

[81] Murray JD. Invasion by invitation: rhizobial infection in legumes. Mol. Plant Microbe Interact. 2011; 24, 631–639.

[82] Huang CJ, Tsay JF, Chang SY, Yang HP, Wu WS, Chen, CY. Dimethyl disulfide is an induced systemic resistance elicitor produced by Bacillus cereus C1L. Pest Manag. Sci. 2012; 68, 1306–1310.

[83] Anand R, Grayston S, Chanway C. N-2-fixation and seedling growth promotion of lodgepole pine by endophytic Paenibacillus polymyxa. Microb. Ecol. 2013; 66, 369–374.

[84] Habibi S, Djedidi S, Prongjunthuek K, Mortuza MF, Ohkama-Ohtsu N, Sekimoto H, Yokoyoma T. Physiological and genetic characterization of rice nitrogen fixer PGPR isolated from rhizosphere soils of different crops. Plant Soil. 2014; 379, 51–66.

[85] Geddes BA, Ryu MH, Mus F, Costas AG, Peters JW, Voigt CA Poole P. Use of plant colonizing bacteria as chassis for transfer of N-2-fixation to cereals. Curr. Opin. Biotechnol. 2015; 32, 216–222.

[86] Goswami D, Thakker JN, Dhandhukia PC. Portraying mechanics of plant growth promoting rhizobacteria (PGPR): a review. Cogent Food Agric. 2016.

[87] Reed SC, Cleveland CC, Townsend AR. "Functional ecology of free-living nitrogen fixation: a contemporary perspective," in Annual Review of Ecology, Evolution, and Systematics. 2011; 42.

[88] Saha B, Saha S, Das A, Bhattacharyya PK, Basak N, Sinha AK, Poddar P. Biological nitrogen fixation for sustainable agriculture. In Agriculturally Important Microbes for Sustainable Agriculture; Springer. 2017; 81–128.

[89] Anand K, Kumari B, Mallick MA. Phosphate solubilizing microbes: an effective and alternative approach as biofertilizers. J. Pharm. Pharm. Sci. 2016; 8, 37–40.

[90] Oteino N, Lally RD, Kiwanuka S, Lloyd A, Ryan D, Germaine KJ, Dowling DN. Plant growth promotion induced by phosphate solubilizing endophytic Pseudomonas isolates. Front. Microbiol. 2015; 6:745.

[91] Kremer RJ, Souissi T. Cyanide production by rhizobacteria and potential for suppression of weed seedling growth. Curr Microbiol. 2001; 43: 182–186.

[92] Vining LC. Functions of secondary metabolites. Ann Rev Microbiol. 1990; 44: 395-427.

[93] Bakker AW, Schippers P. Microbial cyanide production in the rhizosphere in relation to potato yield reduction and Pseudomonas spp.-mediated plant growth-stimulation. Soil Biol. Biochem. 1987; 19, 451–457.

[94] Devi K, Nidhi S, Shalini K, David K. Hydrogen cyanide producing rhizobacteria kill subterranean termite Odontotermes obesus (Rambur) by cyanide poisoning under in vitro conditions. Curr Microbiol. 2007; 54: 74-78.

[95] Ahmad F, Ahmad I, Khan MS. Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities. Microbiological Research. 2008; 163; 173—181., ACC

[96] Fernezandez-San MA, Larraya L, Farran I, Ancin M, Veramendi J. Successful Biocontrol of major post harvest and soil-born plant pathogenic fungi by antagonistic yeasts. Biol. Control. 2021; 160, 104683.

[97] Adedayo AA, Babalola OO. Fungi That Promote Plant Growth in the Rhizosphere Boost Crop Growth. J. Fungi. 2023; 9, 239.

[98] Paula GFD, Demétrio GB, Matsumoto LS. Biotechnological potential of soybean plant growth promoting rhizobacteria. Rev. Caatinga, Mossoró. 2021; 34 (2); 328 – 338.

[99] Antoun H, Kloepper JW. Plant Growth Promoting Rhizobacteria. Encyclopedia of Genetics. London: Academic Press. 2001.

[100] Chaiharn M, Chunhaleuchanon S, Kozo A, Lumyong S. Screening of rhizobacteria for their plant growth promoting activities. KMITL Sci.Tech. J. 2008; 8:1.

[101] Wang Y, Zeng Q, Zhang Z. Antagonistic bioactivity of an endophytic bacterium H-6. African Journal of Biotechnology. 2010; (9) : 37. 6140-6145

[102] Resti Z, Reflin, Gani S. Antagonistic and Plant Growth Promoting Potentials of Indigenous Endophytic Bacteria of Shallots. International Journal of Science and Applied Technology. 2017; (2): 2.

[103] Pal KK, Brian, MSG. Biological control of plant pathogensAPSnet. Plant Heal. Instr. 2006; Corpus ID 16033129 1–25.

[104] Minarseh L, Kuswinanti T. Organic rice rhizosphere fungi produce cellulase and chitinase as a biological control agent. IOP Conf. Ser.: Earth Environ. Sci. 2023; 1230012104.

[105] Neeraja C, Anil K, Purushotham P, Suma K, Sarma P, Moerschbacher BM, Podile AR. Biotechnological approaches to develop bacterial chitinases as a bioshield against fungal diseases of plants. Critical Reviews. Biotechnology. 2010; 30: 231-241.

[106] Balota EL, Marco N, Mendes IDC, Hungria M, Fagotti DSL, Melo G, Souza RC, de Melo WJ. Enzimas e seu papel na qualidade do solo. Tópicos em Ciência do Solo. 2013; 8: 221-278.

[107] Dharti K, Jhanvi C, Ratnakar C. Proteolytic Activity of Microbial Isolates from Plant Rhizosphere. Int. J. Curr. Microbiol. App.Sci. 2025; 14(04): 128-137.

[108] Uzuner S, Cekmecelioglu D. Enzymes in the beverage industry. Enzymes in Food Biotechnology. 2019; 29–43.

[109] Ma D, Chen H, Liu D, Feng C, Hua Y, Gu T, Guo X, Zhou Y, Wang H, Tong G, Li H, Zhang K. Soil-derived cellulose-degrading bacteria: screening,identifcation, the optimization of fermentation conditions, and their wholegenome sequencing. Front. Microbiol. 2024; 15:1409697. doi: 10.3389/fmicb.2024.1409697.

[110] Xu J, Gao Z, Wu B, He B. Lactose-inducted production of a complete lignocellulolytic enzyme system by a novel bacterium Bacillus sp. BS-5 and its application for saccharifcation of alkali-pretreated corn cob. Cellulose. 2017; (24); 2059–2070.

[111] Patil RS, Vandana G, Mukund VD. Chitinolytic enzymes: An exploration reetarani. Elsevier Enzym. Microb. Technol. 2000; 26 473–483.

[112] Adrangi S, Mohammad AF. From bacteria to human: A journey into the world of chitinases. Elsevier Biotechnol. Adv. 2013; 31 1–10.

[113] Rathore AS, Gupta RD. Chitinases from bacteria to human : Properties, applications, and future perspectives. Hindawi Enzym. Res. 2015; 791907. 1-8.

[114] Maksimov IV, Abizgil'dina RR, Pusenkova LI. Plant growth promoting rhizobacteria as alternative to chemical crop protectors from pathogens. Applied Biochemistry and Microbiology. 2011; 47: 333-345.

[115] Conrath U, Beckers GJM, Langenbach CJG, Jaskiewicz MR. "Priming for Enhanced Defense," in Annual Review of Phytopathology,, ed. N. K. VanAlfen (Palo Alto: Annual Reviews). 2015; (53): 97–119.

[116] Van Loon LC. Induced resistance in plants and the role of pathogenesis-related proteins. Eur. J. Plant Pathol. 1997; 103, 753–765.

[117] Solano BR, Maicas JB, Mañero FG. "Physiological and molecular mechanisms of plant growth promoting rhizobacteria (PGPR)," in PlantBacteria Interactions: Strategies and Techniques to Promote Plant Growth, eds.I. Ahmad, J. Pichtel, and S. Hayat (Weinheim: Wiley), 2008; 41–52.

[118] van Loon LC. Plant responses to plant growth-promoting rhizobacteria. Eur. J. Plant Pathol. 2007; 119, 243–254.

[119] Pieterse CMJ, Van der Does D, Zamioudis C, Leon-Reyes A, Van Wees SCM. "Hormonal modulation of plant immunity," the in Annual Review of Cell and Developmental Biology, ed. R. Schekman (Palo Alto: Annual Reviews). 2012; (28): 489–521.

[120] Arshad M, Saleem M, Hussain S. Perspectives of bacterial ACC deaminase in phytoremediation, Trends Biotechnol, 25, 2007, 356–362.

[121] Glick BR. Introduction to plant growth-promoting bacteria. In Beneficial Plant-Bacterial Interactions; Springer: Berlin/Heidelberg, Germany. 2020; 1–37.

[122] Shen M, Li J, Dong Y, Liu H, Peng J, Hu Y, Sun Y. Profiling of Plant Growth-Promoting Metabolites by Phosphate-Solubilizing Bacteria in Maize Rhizosphere. Plants. 2021; 10, 1071.