IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

Plant Growth-Promoting Bacteria; A Review on Mechanisms and Sustainable Crop Production

Pratik Singh
Amity Institute of Biotechnology, Amity University, Lucknow, Uttar Pradesh, India
pratiksingh281996@gmail.com

Abstract: *The ability of agricultural systems to provide food globally may be limited by growing environmental concerns. The biggest issue the world is now dealing with is climate change. By 2050, food production will need to quadruple to fulfill the world's food demand. In the field of sustainable agriculture, plant growth-promoting bacteria (PGPB) have been shown to have a significant impact. Increasing agricultural yield while using less synthetic chemical fertilizers and pesticides is a major issue in today's world. It has been demonstrated that using PGPB to promote plant development through direct or indirect means is a sustainable method of raising agricultural yields. Among PGPB's processes are the control of hormonal and nutritional balance, the development of resistance against plant diseases, and the solubilization of minerals to facilitate their simple absorption by plants. Moreover, PGPB interact both antagonistically and synergistically with microorganisms in bulk soil and the rhizosphere, which indirectly accelerates plant development. Numerous bacterial species have been reported in the literature to function as PGPR and to effectively enhance plant development. There is a difference, nevertheless, between the PGPR's function as a biofertilizer and its method of action (mechanism) for plant development. Therefore, this analysis fills in the aforementioned void and provides an overview of PGPR's mechanism as a biofertilizer for sustainable agriculture*

Keywords: agricultural systems

I. INTRODUCTION

The world's population, which is now estimated to be about 8 billion, is predicted to rise to almost 8 billion by 2020. It is evident that feeding everyone on the planet will become increasingly difficult in the next ten to twenty years due to the combined effects of the predicted rise in global population and the growing environmental harm caused by ever-increasing levels of industrialization. There is no time to waste; in order to feed the world's expanding population, agriculture output must be significantly increased in a sustainable and ecologically acceptable manner. Reexamining many of the current agricultural practices, which involve the use of chemical fertilizers, herbicides, fungicides, and insecticides, is needed in order to feed the world's expanding population. Rather, transgenic plants (for instance, go to http://www.isaaa.org/inbrief/default.asp) and plant growth promoting bacteria, or PGPB, will probably be used far more in sustainable agriculture [1]. According to estimates, "environmental degradation, coupled with the growth in world population, are (considered to be) major causes behind the rapid (global) increase in human disease" (http://www.sciencedaily.com/releases/2007/08/070813162438.htm) and "water, air, and soil pollution cause about 40% of deaths worldwide." That is to say, the earth's atmospheric, terrestrial, and aquatic systems are no longer enough to absorb and decompose the growing quantity of garbage that humans create as a result of both population growth and industrialization. As a result, a variety of hazardous metals and organic chemicals are finding their way into the environment [2, 4]. Understanding the scope and nature of the issue is a crucial first step. But even if there was no more environmental contamination tomorrow, remediation of all damaged lands and seas would still be necessary. Using phytoremediation-the deliberate use of plants to absorb, concentrate, or degrade a variety of environmental pollutants-as a solution to this issue is one possibility [5-8]. Furthermore, adding PGPB to plants employed in phytoremediation techniques usually results in a considerably more effective remediation process overall [3, 9, 10].

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

II. PLANT GROWTH-PROMOTING BACTERIA (PGPB)

Microorganisms such as bacteria, fungus, actinomycetes, protozoa, and algae are abundant in soil. Approximately 95% of these various microorganisms are bacteria, making them the most prevalent kind. It has long been known that soil has a high concentration of bacteria (usually 108–109 cells per gram of soil) and that the proportion of culturable bacteria to total cells in soil is typically only 1% [11]. However, the quantity of culturable bacteria in stressed-out environments might be as low as 104 cells per gram of soil [12]. Furthermore, microorganisms in soil are typically not dispersed equally. That is, compared to the rest of the soil, the rhizosphere—the area around a plant's roots—generally has a significantly higher concentration of bacteria. This is due to the nutrients found in plant root exudates, which include sugars, amino acids, organic acids, and other tiny molecules and may make up as much as one-third of the carbon fixed by a plant [14–17].

There are three possible ways that bacteria might impact plants, depending on how many are present in a given soil sample. From the plant's point of view, the relationship between soil bacteria and plants might be advantageous, detrimental, or neutral [18]. But if circumstances alter, a given bacterium's impact on a plant may also alter. For instance, when significant amounts of artificial fertilizer are applied to the soil, a bacterium that promotes plant development by supplying either fixed nitrogen or phosphorus—compounds that are frequently present in only limited levels in many soils—is unlikely to assist plants in any way. Furthermore, it is feasible for a single bacteria to have varying effects on several plants. For instance, a mutant of the bacteria Pseudomonas fluorescens BSP53a that produces an excess of IAA enhanced the growth of roots in blackcurrant cuttings but inhibited the same process in cherry cuttings [19]. It is possible to explain this data by supposing that the bacteria increased the inadequate amount of IAA present in the blackcurrant cuttings. However, with the cherry cuttings, the extra IAA that the bacterium delivered became inhibitory since the IAA level was already at its peak when the bacterium was added. With these exceptions, it is typically simple to determine whether a bacteria encourages or hinders plant development.

The term "plant growth-promoting bacteria," or "PGPB," refers to a variety of bacteria that can coexist with plants, form particular symbiotic relationships with them (such as Rhizobia and Frankia species), colonize some or all of the internal tissues of plants, and are known as cyanobacteria (formerly known as blue-green algae). Despite their diversity, these bacteria all make use of the same processes. PGPB can either directly or indirectly stimulate plant growth by reducing the inhibitory effects of different pathogenic agents on plant growth and development, i.e., by functioning as biocontrol bacteria, or by enabling resource acquisition or modifying plant hormone levels [20]. In the past, a great deal of research was done on Rhizobia species from physiological, biochemical, and molecular biological viewpoints before there was a lot of interest in figuring out how to use or comprehend additional PGPB to promote plant development [21–23]. As a result, the conceptual foundation for mechanistic research on PGPB was established by these early investigations. However, research to better understand some of the processes utilized by PGPB have addressed a wide variety of alternative mechanisms since, in contrast to Rhizobia spp., most PGPB fix no nitrogen or only a small quantity of it [13, 20, 24].

2.1. Commercialization

Even while our knowledge of PGPB-plant interactions is currently restricted, some of these bacteria are still employed in the agricultural industry as supplements [1, 25]. PGPB strains that have been commercialized include *Agrobacterium radiobacter, Bacillus licheniformis, Bacillus fimus, Bacillus megaterium, Bacillus mucilaginous, Bacillus pumilus, Bacillus spp., Bacillus subtilis, Bacillus subtilis var. amyloliquefaciens, Burkholderia cepacia, Delfitia acidovorans, Paenobacillus macerans, and Pantoea agglomerans. Serratia entomophilia, Streptomyces griseoviridis, Streptomyces spp., Streptomyces lydicus, and many Rhizobia spp. are among the pseudomonas that include Pseudomonas aureofaciens, Pseudomonas chlororaphis, Pseudomonas fluorescens, Pseudomonas solanacerum, Pseudomonas spp., and Pseudomonas syringae.* But PGPB-inoculated crops only make up a tiny portion of agricultural practices used now in the globe.

Many challenges must be resolved in order to commercialize PGPB strains more widely. These include: (i) identifying the characteristics that are most crucial for effective functioning and then choosing PGPB strains with the right biological activities; (ii) uniformity among regulatory bodies in various nations regarding which strains can be released into the environment and what circumstances make genetically modified strains suitable for environmental use; (iii) a

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

better comprehension of the benefits and drawbacks of using rhizospheric versus endophytic bacteria; (iv) choosing PGPB strains that function optimally under particular environmental conditions (e.g., those that perform well in warm and sandy soils versus organisms better suited to cool and moist environments); (v) the creation of more efficient methods for delivering PGPB to plants in different environments (such as the field as opposed to a greenhouse); (vi) an improved comprehension of the possible interactions between PGPB and other soil fungi, such as mycorrhizae.

III. DIRECT MECHANISMS

3.1. Facilitating Resource Acquisition

The most well-researched methods of bacterial plant growth promotion involve giving plants nutrients and resources that they don't already have, including fixed nitrogen, iron, and phosphorus. Plant development is sometimes subpar in agricultural soils because of a lack of one or more of these chemicals in appropriate amounts. In order to avoid this issue and achieve greater plant yields, farmers have relied more and more on artificial supplies of phosphate and nitrogen.In addition to being expensive, the manufacture of chemical fertilizers puts human and environmental health at risk and uses up nonrenewable resources like natural gas and oil.Clearly, it would be beneficial if at least some of the artificial nitrogen and phosphorus that are presently utilized could be replaced by effective biological methods of giving plants these nutrients.

3.1.1. Nitrogen Fixation

Many free-living bacteria, such as *Azospirillum* spp., may fix nitrogen and supply it to plants in addition to *Rhizobia* spp. [26].Nonetheless, the general consensus is that free-living bacteria only supply a tiny portion of the fixed nitrogen needed by the host plant linked with the bacteria [27]. Genes related to iron molybdenum cofactor biosynthesis, electron donation, structural genes involved in Fe protein activation, and regulatory genes necessary for the manufacture and operation of the enzyme are among the nitrogenase (nif) genes needed for nitrogen fixation. The nif genes, which encode 20 distinct proteins through seven operons, are normally found in a cluster of 20–24 kb in diazotrophic (nitrogen-fixing) bacteria.Genetic techniques to enhance nitrogen fixing have been difficult to implement due to the intricate nature of this system. It was originally thought by some scientists that nitrogen fixation might be genetically engineered to enhance if genes were extracted and described. Furthermore, some people asserted that it could be able to genetically modify plants so they can fix nitrogen on their own. These concepts appear a little naive now.

It would be preferable if bacterial carbon resources were directed toward oxidative phosphorylation, which results in the synthesis of ATP, rather than glycogen synthesis, which results in the storage of energy in the form of glycogen, since the process of nitrogen fixation requires a significant amount of energy in the form of ATP. In one study, a strain of Rhizobium tropici was created with the glycogen synthase gene deleted [28]. Compared to treatment with the wild-type strain, treatment of bean plants with this modified bacteria led to a considerable increase in the number of nodules that developed as well as an increase in the dry weight of the plant. This is one of the extremely few instances when researchers have genetically altered a bacterium's nitrogen fixation system to produce higher amounts of fixed nitrogen. Regretfully, despite the fact that this mutant enhanced plant biomass and nodule number in the field, it is not very resilient in the soil.

Oxygen is necessary for Rhizobium spp. bacteroid respiration, but it also inhibits the enzyme nitrogenase and is a negative regulator of nif gene expression. Bacterial hemoglobin, which binds free oxygen, can be added to the environment to prevent oxygen from impeding nitrogen fixation while yet supplying enough oxygen for the bacteroides inside the nodule to breathe. After Rhizobium etli was transformed with a hemoglobin gene from Vitreoscilla sp., a gram-negative bacteria, the respiratory rate of the rhizobial cells was two to three times greater than that of the nontransformed strain at low concentrations of dissolved oxygen. After being injected with hemoglobin-containing R. etli, bean plants in the greenhouse exhibited 68% higher nitrogenase activity than plants injected with wild-type R. etli.The nitrogen content of the resulting seeds increased by 16% and the nitrogen content of the leaves by 25–30% as a result of this variation [29].Plant ethylene levels frequently rise slightly and locally when legumes become infected with Rhizobium species.This elevated ethylene content has the potential to prevent nodulation and subsequent rhizobial infection [30].By producing a tiny molecule known as rhizobitoxine [31], which chemically inhibits the activity of the

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

enzyme ACC synthase, one of the ethylene biosynthesis enzymes, certain rhizobial strains can limit the rise in ethylene and increase the number of nodules that form on the roots of a host legume. After being injected with hemoglobin-containing R. etli, bean plants in the greenhouse exhibited 68% higher nitrogenase activity than plants injected with wild-type R. etli.The nitrogen content of the resulting seeds increased by 16% and the nitrogen content of the leaves by 25–30% as a result of this variation [29].Plant ethylene levels frequently rise slightly and locally when legumes become infected with Rhizobium species.This elevated ethylene content has the potential to prevent nodulation and subsequent rhizobial infection [30].By producing a tiny molecule known as rhizobitoxine [31], which chemically inhibits the activity of the enzyme ACC synthase, one of the ethylene biosynthesis enzymes, certain rhizobial strains can limit the rise in ethylene and increase the number of nodules that form on the roots of a host legume. On the other hand, certain rhizobial strains generate the enzyme ACC deaminase, which eliminates a portion of ACC, the plant's direct precursor to ethylene, before it can be converted to ethylene [30].Reducing the ethylene concentration in legume hosts can lead to a 25–40% increase in nodule number and plant biomass [32, 33]. Since 1–10% of rhizobial strains found in the field naturally have ACC deaminase [34], it is feasible to engineer Rhizobia strains lacking ACC deaminase with genes (and regulatory regions) isolated from other strains in order to boost their nodulation efficiency. In one case, the number of nodules and biomass of host alfalfa plants were significantly enhanced when an ACC deaminase gene from R. leguminosarum bv. viciae was inserted into the chromosomal DNA of a strain of Sinorhizobium meliloti that did not have this enzyme [33]. However, most governments presently do not allow genetically modified strains of Rhizobia to be used in the field due to political and regulatory reasons.Several commercial inoculant manufacturers have started screening/testing their more recently obtained Rhizobia strains for active ACC deaminase, despite this political/regulatory limitation.

3.1.2. Phosphate Solubilization

Even while the average soil contains a significant quantity of phosphorus (typically 400–1,200 mg kg−1 of soil), the majority of this phosphorus is insoluble and thus not accessible to promote plant development. It can be found as an inorganic mineral like apatite or as one of various organic forms including phosphomonesters, phosphotriesters, and inositol phosphate (soil phytate) [35]. Furthermore, a large portion of the soluble inorganic phosphorus used in chemical fertilizers quickly gets immobilized after application, making it inaccessible to plants and thus lost. The inability to absorb enough phosphorus frequently restricts plant growth because of the element's poor bioavailability from the soil and its need for plant growth [36]. Therefore, phosphate-solubilizing bacteria's ability to solubilize and mineralize phosphorus is a crucial characteristic of both PGPB and fungi that promote plant development, including mychorrizae [37, 38].

Generally, low molecular weight organic acids like citric and gluconic acid—both of which are produced by different soil bacteria—are responsible for the solubilization of inorganic phosphorus [38–40]. Conversely, the process of mineralizing organic phosphorus is brought about by the creation of several phosphatases, which catalyze the hydrolysis of phosphoric esters [38]. It's noteworthy that a single bacterial strain may exhibit both mineralization and phosphate solubilization [41]. Unfortunately, there hasn't been much commercial usage of phosphate-solubilizing PGPB due to inconsistent findings. In particular, when phosphate-solubilizing bacteria are coinoculated with other physiological capacities like N fixation or with mycorrhizal or nonmycorrhizal fungi, the most consistent favorable impacts of the application of these bacteria are observed [42].

3.1.3. Sequestering Iron

Iron is the fourth most abundant element in the universe, but in aerobic soils, neither bacteria nor plants can easily assimilate it because the predominant form of iron, ferric ion or Fe+3, is only very sparingly soluble, leaving very little iron available for assimilation by living things [43]. High levels of iron are necessary for both microorganisms and plants, and getting enough iron becomes increasingly difficult in the rhizosphere where fungus, bacteria, and plants fight with one another for iron [44, 45]. Bacteria create low-molecular mass siderophores (approximately 400–1500 Da) to survive on such a limited iron supply. These molecules have a very high affinity for Fe+3 (Fe+3 ranging from 1023 to 1052) and membrane receptors that can bind the Fe-siderophore complex, which helps microorganisms absorb iron

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[46, 47]. Currently, approximately 500 siderophores are identified; 270 of these compounds have had their chemical structures elucidated [46].

Multiple types of tests have revealed the direct advantages of bacterial siderophores on plant development. For instance, (i) a number of studies using radiolabeled ferric-siderophores as the only source of iron revealed that plants can absorb the labeled iron [48–55]; (ii) mung bean plants grown under ironlimiting conditions and inoculated with the siderophore-producing Pseudomonas strain GRP3 showed reduced chlorotic symptoms and an enhanced chlorophyll level compared to uninoculated plants [56]; (iii) Arabidopsis thaliana plants absorbed the Fe-pyoverdine complex synthesized by Pseudomonas fluorescens C7, increasing the amount of iron inside plant tissues and improving plant growth [57].

It is much more crucial for soil bacteria to provide plants with iron when the plants are under environmental stress, such as heavy metal contamination. In this instance, siderophores aid in reducing the stressors that high soil concentrations of heavy metals place on plants [58–62].

Bacterial communities' organizational structure in the rhizosphere can be impacted by plant iron feeding. For instance, transgenic tobacco has less accessible iron in the rhizosphere than nontransformed tobacco because it overexpresses ferritin and accumulates more iron [63]. Consequently, the bacterial community's composition in the rhizosphere was much different from that of tobacco lines that had not undergone transformation.

3.2. Plant hormone Level Modulation

Plant hormones are essential for both the growth and development of plants as well as how they react to their surroundings[64].Furthermore, a plant is frequently exposed to a variety of nonlethal stressors during its life that may restrict its development until the stress is eliminated or the plant is able to modify its metabolism to withstand the effects of the stress[65].Plants frequently try to modify the amounts of their endogenous phytohormones in response to growth-limiting environmental circumstances, with the goal of lessening the detrimental impacts of the stressors [66].While this tactic can occasionally work, rhizosphere microorganisms can also manufacture or modify phytohormones in vitro [66], allowing numerous phytohormone-producing bacteria (PGPB) to change phytohormone levels and impact the plant's hormonal balance and stress response [65].

3.2.1. Cytokinins and Gibberellins

Numerous investigations have demonstrated that PGPB in particular, as well as many other soil bacteria, are capable of producing gibberellins, cytokinins, or both [67–72].For instance, several strains of Azotobacter spp., Rhizobium spp., Pantoea agglomerans, Rhodospirillum rubrum, Pseudomonas fluorescens, Bacillus subtilis, and Paenibacillus polymyxa have been shown to have cytokinins in their cell-free media. Furthermore, it has been documented that some PGPB that produce gibberellin or cytokinin can promote plant development [73–77]. Nevertheless, a thorough knowledge of the function of hormones produced by bacteria as well as the regulation of the bacterial synthesis of these plant hormones is now lacking.Therefore, a large portion of our understanding of the function of gibberellins and cytokinins generated by bacteria is derived from investigations on plant physiological responses to exogenous administration of pure hormones to developing plants.

Lastly, certain phytopathogen strains have the ability to produce cytokinins. On the other hand, it seems that PGPB create less cytokinins than phytopathogens, which explains why PGPB has a stimulatory impact on plant development whereas pathogen-produced cytokines have an inhibitory effect.

3.2.2: Indoleacetic Acid

Although a number of naturally occurring auxins have been reported in the literature, indole-3-acetic acid, or indoleacetic acid, IAA, is by far the most widely used and researched auxin. In fact, a large portion of the scientific literature regards auxin and IAA as synonymous names [78, 79]. IAA influences photosynthesis, pigment formation, the biosynthesis of various metabolites, resistance to stressful conditions, and lateral and adventitious root formation. It also affects plant cell division, extension, and differentiation, stimulates seed and tuber germination, increases the rate of xylem and root development, controls vegetative growth processes, and initiates lateral and adventitious root formation [80, 81].

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

For over seven decades, it has been shown that the physiology of plants is significantly impacted by varying IAA concentrations. Plant responses to IAA differ depending on the type of plant; some plants are more or less sensitive to IAA than others; depending on the specific tissue involved, such as roots versus shoots (the ideal level of IAA for supporting plant growth is approximately five orders of magnitude lower for roots than for shoots); and depending on the stage at which the plant is developing. On the other hand, the uptake of IAA released by soil bacteria may modify the endogenous pool of plant IAA. In this sense, whether bacterial IAA promotes or inhibits plant development depends on the amount of IAA that the plant synthesizes. Endogenous IAA in plant roots may be either inadequate or ideal for growth [82], and extra IAA absorbed from bacteria may change the IAA level to either optimal or supraoptimal, promoting or inhibiting plant development, respectively.

Plant-bacterial interactions may entail IAA synthesised by bacteria at various stages. IAA specifically affects root nodulation and plant growth promotion. After this strain's IAA-deficient mutant was created, researchers looked into the function of IAA, which was produced by the PGPB Pseudomonas putida GR12-2, in the growth of canola roots [83]. When wild-type P. putida GR12-2 was injected into seeds, the result was the production of roots that were 35–50% longer than those from seeds treated with the IAA-deficient mutant and uninoculated seeds. However, compared to controls [85], mung bean cuttings inoculated with a mutant of the same strain [84] that overproduces IAA resulted in a much higher number of shorter roots.

The combined effects of auxin on growth promotion and ethylene's suppression of root elongation were shown to be responsible for this outcome [86]. The plant's incorporation of bacterial IAA enhanced the activity of ACC synthase, leading to a rise in ACC synthesis [86], which in turn caused an increase in ethylene, which hindered root growth [87]. Overall, bacterial IAA lengthens and increases the surface area of the roots, giving the plant better access to nutrients in the soil. Furthermore, bacterial IAA breaks down the cell walls of plants, which allows for more root exudation and the subsequent supply of extra nutrients that promote the development of rhizosphere bacteria.

The majority of Rhizobium strains that have been studied have been shown to generate IAA [88], and a number of investigations have revealed that auxin levels in the host plant must rise in order for nodules to grow [89]. Bradyrhizobium elkanii mutants with reduced IAA production levels therefore produced fewer nodules on soybean roots than the wild-type strain [90]. Furthermore, it was discovered that the IAA content of nodules produced by low IAA-producing Rhizobium sp. NGR234 mutants was lower than that of nodules induced by the wild-type strain. This finding lends credence to the theory that some of the IAA present in nodules is of prokaryotic origin and that it aids in nodulation [91].

3.2.3. Ethylene

One of the most basic chemicals with biological action is ethylene, the hormone found in plants. The prophet Amos was a “herdsman and a nipper of figs,” according to the Hebrew Bible. This remark suggests that people knew as early as the ninth century BCE that piercing or nipping figs released ethylene gas, which accelerated the ripening process and increased the figs' sweetness.The plant hormone ethylene is active at concentrations as low as 0.05 μL/L and has a wide variety of biological actions; yet, ripening fruit can have ethylene levels as high as around 200 μL/L [92].

Promoting root initiation, inhibiting root elongation, fruit ripening, flower wilting, stimulating seed germination, encouraging leaf abscission, activating the synthesis of other plant hormones, preventing Rhizobia spp. nodule formation, reducing mycorrhizae-plant interaction, and reacting to biotic and abiotic stresses are just a few of the numerous ways that ethylene can influence plant growth and development [92]. The term "stress ethylene" [92] refers to the synthesis of ethylene that occurs in response to a variety of environmental stresses. These include temperature extremes, intense light, flooding, droughts, the presence of organic pollutants and toxic metals, radiation, wounding, insect predation, high salt, and various pathogens, such as bacteria, viruses, and fungi [93]. Under response to a variety of environmental challenges, a greater quantity of ethylene is produced. This increased ethylene can either worsen the symptoms of the stress or cause reactions that improve plant survival under challenging circumstances. A theory that explains this seemingly paradoxical behavior is that when plants are stressed, they swiftly react by releasing a brief peak of ethylene, which starts the plant's protective reaction, such as the transcription of genes encoding defensive proteins [65, 94]. A second, significantly greater peak of ethylene appears, usually a few days later, if the stress is

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

severe or continues.Plant growth and survival may be significantly inhibited by the processes that this second ethylene peak triggers, including senescence, chlorosis, and abscission.

After the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase was found in soil bacteria [95], a number of investigations revealed that this enzyme was a common characteristic of numerous PGPB [96, 97]. Furthermore, a model was developed that detailed this enzyme's function in PGPB-induced plant growth facilitation [98]. According to this hypothesis, PGPB invade a developing plant's seed or root, and in response to tryptophan and other small molecules found in exudates from the seed or root, the bacteria produce and exude IAA [78, 83].In conjunction with endogenous plant IAA, this bacterial IAA has the ability to either promote plant development or trigger the production of the plant enzyme ACC synthase, which transforms the chemical S-adenosyl methionine into ACC, the direct precursor of ethylene in all higher plants. A part of the freshly generated ACC is removed from seeds or plant roots [99], absorbed by the PGPB, and transformed into easily digested chemicals like ammonia and α-ketobutyrate by the enzyme ACC deaminase. The activity of this enzyme directly results in a decrease in the quantity of ethylene that the plant produces.Thus, PGPB that produce ACC deaminase colonize roots or seeds to stop plant ethylene levels from becoming growth inhibitory [20, 98].

Enhancement of plant root elongation is the primary short-term observable result of seed or root inoculation with ACC deaminase-producing bacteria; longer-term investigations often show encouragement of shoot growth [13, 100–107]. Local increases in ethylene levels are also brought about by other processes including the nodulation of legumes and the formation of mycorrhizae in the host plant. Therefore, in a variety of legumes, including pea, alfalfa, mung bean, and chickpea [32, 33, 107, 108] and cucumber [109], ACC deaminase-producing bacteria can increase the extent of both rhizobial nodulation and mycorrhizal colonization by lowering the local ethylene content in these plants.

IV. INDIRECT MECHANISMS

There has been a lot of interest in the capacity of biocontrol bacteria to indirectly stimulate plant growth, with two goals in mind: (i) understanding some of the underlying mechanisms by which the bacteria function, and (ii) using these bacteria commercially to replace chemical pesticides. In actuality, these two goals work best together.In other words, knowing the strategies used by biocontrol bacteria should make it easier to use certain strains of bacteria effectively in the future.

4.1. Lytic Enzymes and Antibiotics

The PGPB property that is most frequently linked to the bacterium's capacity to stop plant pathogens—typically fungi—from proliferating is the production of a variety of different antibiotics [110–115]. A number of these antibiotics, as well as their mechanism of action and specificity, have been thoroughly investigated; some of these biocontrol strains have even gone on sale. An issue with overly relying on bacteria that produce antibiotics as biocontrol agents is that some phytopathogens may become resistant to particular antibiotics as a result of the increased usage of these strains. To prevent this from happening, some researchers have deployed biocontrol strains that synthesize hydrogen cyanide as well as one or more antibiotics. Although hydrogen cyanide may not have much biocontrol action on its own, this strategy works well because it seems to work in concert with antibiotics that are encoded in bacteria. Enzymes such as chitinases, cellulases, β-1,3 glucanases, proteases, and lipases are produced by some biocontrol bacteria and have the ability to partially break down the cell walls of certain dangerous fungus. It has been discovered that PGPB that produce one or more of these enzymes have biocontrol action against a variety of pathogenic fungus, such as Sclerotium rolfsii, Botrytis cinerea, Fusarium oxysporum, Phytophthora spp., Rhizoctonia solani, and Pythium ultimum [116–119].

4.2. Siderophores

Some bacterial strains can function as biocontrol agents by producing siderophores, even if they don't use any other kind of biocontrol. In this instance, siderophores from PGPB may inhibit the capacity of some phytopathogens to multiply by preventing them from obtaining an adequate supply of iron [120, 121]. According to some theories, the reason this mechanism works is that the biocontrol agent, PGPB, produces siderophores with a far higher affinity for iron than do fungal pathogens [122], which prevents the pathogens from proliferating due to a shortage of iron in the

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

rhizosphere of the host plant's roots [123].Fungal pathogens are efficiently outcompeted for available iron in this model by the biocontrol PGPB.

However, because most plants can grow at far lower iron concentrations than most microbes, the depletion of iron in the rhizosphere induced by the siderophores generated by biocontrol PGPB typically has little effect on plant growth[123].Furthermore, a variety of plants have the ability to bind, absorb, and subsequently use the biocontrol PGPB ironsiderophore complex [124, 125].Numerous studies provide experimental data that supports the role of biocontrol PGPB siderophores in the reduction of plant diseases caused by fungal pathogens.For instance, some research using mutants deficient in siderophore synthesis discovered that these strains were less successful than wild type strains in defending plants against fungus infections [126–128]. However, one study found that plants were better protected against fungal infections by siderophore overproducing mutants [129].

4.3. Ethylene

In response to phytopathogens, plants usually produce ethylene under stress, which intensifies the effects of the stress on the plant [92]. Therefore, reducing the plant's ethylene response is one strategy to lessen the harm that a variety of phytopathogens may do to plants [131]. The easiest method for doing this is to apply PGPB that contains ACC deaminase to plants (usually the roots or seeds) [98]. Thus far, studies conducted in growth chambers and greenhouses have demonstrated that this approach reduces the harm inflicted upon castor bean, tomato, carrot, cucumber, and soybean plants [132–136]. Significantly, a variety of phytopathogens, including Pythium ultima, Fusarium oxysporum, Erwinia carotovora, Agrobacterium tumefaciens, Agrobacterium vitis, Sclerotium rolfsii, and Rhizoctonia solani, have been evaluated in these investigations. Furthermore, transgenic plants expressing a bacterial ACC deaminase exhibit a notable degree of protection against different phytopathogen-induced damage [137, 138]. Despite these potentially promising findings, it has not been investigated if PGPB that contains ACC deaminase may lessen pathogen-induced plant damage in the field.This probably indicates that many people are reluctant to cope with the possibly challenging regulatory permission procedure that is involved in doing this kind of field testing.

4.4. Induced Systemic Resistance

Plants can experience a phenomena called induced systemic resistance (ISR) in response to infection by a pathogenic agent. This event is phenotypically comparable to systemic acquired resistance (SAR) [139]. It is suggested that ISR-positive plants are "primed" in order to trigger defensive systems more quickly and potently in response to pathogen assault. ISR doesn't focus on any particular infections. Instead, it could be useful in managing illnesses brought on by certain viruses. ISR is mediated by plant hormones called jasmonate and ethylene, which activate the host plant's defensive mechanisms against several pathogens [140]. The virus and the resistance-inducing PGPB do not need to interact directly for ISR to occur [141]. In addition to ethylene and jasmonate, other bacterial molecules have also been shown to function as indicators for the induction of systemic resistance. These include salicylic acid, pyoverdine, chitin, β-glucans, flagellar proteins, the O-antigenic side chain of the bacterial outer membrane protein lipopolysaccharide, and chitin.

V. REDUCING THE IMPACT OF ENVIRONMENTAL STRESS

In perfect conditions, a lot of a plant's growth and development may be seen as happening in a roughly linear form over time [65]. On the other hand, a variety of biotic and abiotic stressors might impede plant development in the field. Extremes in temperature, bright light, flooding, drought, the presence of hazardous metals and organic pollutants in the environment, radiation, wounding, insect predation, nematodes, excessive salt content, and a variety of pathogens, such as bacteria, fungus, and viruses, are some of these stressors.Plant development is thus always less than it would be in their absence as a result of these numerous diverse environmental pressures.

Throughout addition, a plant may encounter several nonlethal stressors throughout its lifetime that restrict its development until the stress is eliminated or the plant is able to modify its metabolism to withstand the stress. As a result, in real life, plant development usually consists of intervals of peak growth separated by different intensities of growth inhibition. PGPB may use any one or more of a number of distinct mechanistic techniques when they are introduced to plants in an effort to get around this growth inhibition.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

5.1. Ethylene

The majority of the environmental stressors indicated above cause the formation of ethylene stress inhibitory levels. Using PGPB that contains ACC deaminase can help prevent high amounts of ethylene and the harm it causes, as was previously discussed when talking about the stress ethylene produced as a result of phytopathogen infection [142]. Extremes in temperature [143], floods [144], drought [145, 146], metals and metaloids [60, 61, 147–152], hypoxia [153], salt [154–165], and organic pollutants [150, 151, 166–168] are a few abiotic stressors whose impacts can be lessened in this way. According to the aforementioned reports from around the globe, a variety of ACC deaminase-containing PGPB can significantly protect plants from a variety of abiotic stresses. This suggests that the technology is ready for commercial application in the field and that the approach could have a big impact on agricultural practices. ACC deaminase-containing bacteria, however, are probably more likely to find their first large-scale commercial uses as parts of phytoremediation protocols, which use bacteria and plants simultaneously to remove organic contaminants and metals from the environment, given the reluctance in many jurisdictions to use bacteria in agriculture on a large scale [3, 9].

5.2. IAA

A number of findings show that some PGPB, even in the absence of ACC deaminase, can shield plants from the harmful effects of abiotic stressors. According to more recent research, PGPB may aid plants in overcoming abiotic challenges by giving them IAA, which directly promotes plant development even in the presence of substances that would otherwise hinder it [169–176].

Together with the results already stated, several other research have revealed that the bacteria that shield plants from a variety of stressors are also those that generate both ACC and IAA deaminase [65, 177–179]. Tryptophan is an amino acid that is rejected by plant roots and then taken up by PGPB attached to the roots, where it is transformed into IAA. This is one hypothesis that explains how IAA and ACC deaminase work together to promote plant development [20, 65, 178]. Together with the plant's own supply of IAA, the bacterially generated IAA is released, absorbed by plant cells, and initiates an auxin signal transduction pathway that includes a number of auxin response proteins.Plant cells multiply and grow as a result. Meanwhile, some of the IAA stimulates transcription of the gene encoding the enzyme ACC synthase, increasing the concentration of ACC and ultimately ethylene (which is catalyzed by the enzyme ACC oxidase since ACC is the direct precursor of ethylene).

Different biotic and abiotic stressors can also either promote the transcription of the ACC synthase gene or enhance the synthesis of IAA.When a bacterium with the ACC deaminase enzyme is present, some ACC may be taken up by the plant-bound PGPB and broken down into ammonia and N-ketobutyrate.As a result, an ACC deaminase-containing PGPB functions as a sink for ACC, which has the effect of reducing the amount of ethylene that the plant produces and its stress response to an environmental stress.Auxin response factor transcription is suppressed in plants with elevated ethylene levels [65, 180–182]. When bacterial ACC deaminase is absent, ethylene inhibits the transcription of auxin response factors, which in turn restricts cell development and proliferation. Furthermore, ethylene decreases IAA stimulation of ethylene production, which is crucial for plant survival. Less ethylene is produced when ACC deaminase is present.Therefore, the presence of ACC deaminase prevents the inhibition of auxin response factor transcription, allowing IAA to promote cell growth and proliferation without also contributing to the accumulation of ethylene. As a result, in the presence or absence of plant stress, ACC deaminase both reduces the ethylene-induced restriction of plant development and permits IAA to optimally enhance plant growth.

5.3. Cytokinin

Named for its capacity to stimulate plant cell division, or cytokinesis, cytokinins are substances with an adenine-like structure (Sakakibara 2006).Plants, several yeast strains, and certain soil bacteria, including PGPB, all generate them [66, 68]. Transgenic plants that overproduce cytokinins are considerably shielded against the harmful consequences of abiotic stress, particularly when such stressors occur [183]. Regretfully, no conclusive research has been done to determine if cytokinins generated by bacteria may also shield plants from abiotic stressors. This would include a thorough analysis of the biological activities of PGPB-producing cytokinin-minus mutants and cytokinin-producing PGPB.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

5.4. Trehalose

Trehalose is a nonreducing disaccharide found in many forms in nature. It is a α,-1,1-glucoside made up of two molecules of α-glucose. Bacteria, yeast, fungus, plants, insects, and invertebrates all contain it. Elevated trehalose levels can serve as a buffer against a variety of abiotic stressors, such as excessive salinity, drought, and temperature fluctuations. Trehalose is a very stable molecule that may form a gel phase when cells dry, replenishing water and reducing the harm caused by salt and dehydration. Trehalose is resistant to both acid and high temperatures. Trehalose can also stop some of the aggregation and degradation of proteins that frequently happen in response to stressors from hot and low temperatures. Treating plants with PGPB that have been modified to overproduce trehalose is one method of giving them resistance to drought and other stresses [184, 185]. Therefore, compared to plants inoculated with wild-type Rhizobium etli, plants treated with the symbiotic bacterium that had been genetically modified to overproduce trehalose had more nodules, fixed more nitrogen, had more biomass, and recovered from drought stress to a greater extent [185]. Similarly, plants treated with PGPB Azospirillum brasilense, which had been genetically engineered to overproduce trehalose, were shown to be more resistant to drought and to yield higher biomass than plants treated with wild-type A. brasilense [184]. While it is feasible to genetically modify plants such that they generate excessive amounts of trehalose, using genetically modified PGPB is a far easier way to accomplish the same goal. Furthermore, a variety of agricultural plants may be successfully protected by a single modified bacterial strain.

List of plant growth promotion rhizobacteria

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
Azoarcus	Nitrogen fixation	rice	Plants were grown gnotobiotically with a mutant of strain BH72 expressing the b-glucuronidase gene constitutively.	The presence of *Azoarcus* in the stele, especially in the stelar tissue of culms, suggests that these bacteria might spread systemically *in situ*, and underline their endophytic life style.	[195]
Azobacter	Cytokinin synthesis	Cucumber	-	-	[196]
Azorhizobium	Nitrogen fixation	Wheat	2 mL of rhizobial culture were added four times to each wheat plant, once during the planting of the seeds, and subsequently three times at one-week intervals.	Five weeks after inoculation with *A. caulinodans* IRBG314, there were approximately five times more short lateral roots, each up to 3 mm in length, present on inoculated wheat.	[197]
Azospirillum	Nitrogen fixation	sugar cane	-	-	[198,199,200,201]
Azotobacter	Nitrogen fixation	Wheat, barley, oats,	-	-	[202]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
		rice, sunflowers, maize, line, beetroot, tobacco, tea, coffee and coconuts			
Bacillus	Auxin synthesis	Potato	Seed-dipping (108 mL^{-1} cfu)	Both the strains enhanced the auxin content of inoculated plants up to 71.4% and 433%, respectively, as compared to non-inoculated plants.	[203]
Bacillus	Cytokinin synthesis	Cucumber	Seed-dipping 106 cells/mL (106 CFU/mL)	Cucumber seedlings subjected to bacterization had well developed lateral roots.	[204]
Bacillus	Gibberelin synthesis	Pepper	-	-	[205]
Bacillus	Potassium solubilization	pepper, cucumber	Seedling was inoculated with 1 mL of inoculum containing around 108 cells.	The results showed that there was a relatively higher availability of P and K in soils planted with pepper than with cucumber.	[206,207]
Bacillus	Induction of plant stress resistance	Peanuts Maize	Plants were inoculated with 1 mL of a 108 cfu suspension Seed-dipping for 30 min	Increasing salt concentrations, biological N fixation may be competitive, becoming a more economic and sustainable alternative to chemical fertilization. The bacterial inoculants increased the total N, P, and K contents of the shoot and root of maize in calcisol soil from 16% to 85% significantly as	[208,209]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
				compared to the control counterpart.	
Bacillus	Antibiotic production	Alfalfa	Seedling was inoculated	Filtrates of cultures suppressed alfalfa disease caused by *P. medicaginis* and inhibited the growth of the pathogen in an agar plate assay.	[210]
Bacillus	Siderophore production	Maize, pepper	-	-	[211]
Beijerinckia	Nitrogen fixation	Sugar cane	-	-	[198,212]
Burkholderia	Nitrogen fixation	Rice	-	-	[213,214]
Chryseobacterium	Siderophore production	Tomato	Soil drenched	Siderophore production increased as bacterial biomass increased after 16 h of culture	[215]
Frankia	Nitrogen fixation	*Alnus*	-	-	[216]
Gluconacetobacter	Nitrogen fixation	Sugar cane	Root-dipping of seedlings for 1 h	The endophytic establishment of *G. diazotrophicus* within stems of sugarcane was confirmed by the scanning electron microscopy.	[217]
Herbaspirillum	Nitrogen fixation	rice	Seed was inoculated	GFP-tagged cells of *Herbaspirillum* sp. strain B501*gfp*1 were apparently localized in intercellular spaces of shoot tissues of 7-day-old seedlings of *O. officinalis* W0012.	[218]
Mycobacterium	Induction of plant stress resistance	Maize	-	-	[208]
Paenibacillus	Indole acetic acid	Lodgepole pine	-	-	[219]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
	synthesis				
Paenibacillus	Potassium solubilization	Black pepper	-	-	[220]
Phyllobacterium	Phosphate solubilization	Strawberries	The strawberry seedlings were inoculated with 1 mL of 108 CFU/mL suspensions.	Strain PEPV15 was able to solubilize moderate amounts of phosphate (5mm radius around the colonies).	[221]
Phyllobacterium	Siderophore production	Strawberries	The strawberry seedlings were inoculated with 1 mL of 108 CFU/mL suspensions.	The strain grew on the CAS indicator medium where the colonies were surrounded by a yellow-orange halo (3.5 mm radius around colonies) indicative of the siderophore production.	[221]
Pseudomonas	Chitinase and β-glucanases production	Several crops	-	-	[222]
Pseudomonas	ACC deaminase synthesis	Mung beans, wheat	-	-	[223,224]
Pseudomonas	Induction of plant stress resistance	Cotton, Maize	-	-	[208,225]
Pseudomonas	Antibiotic production	Wheat	-	-	[226]
Pseudomonas	Chitinase and β-glucanases production	Pigeon pea	The method of Weller and Cook (1983) was adopted for seed bacterization	P. fluorescens LPK2 and S. fredii KCC5 showed chitinase activity on chitinase minimal medium. b-1,3-glucanase activity was more pronounced in the fluorescent pseudomonads strains.	[227]
Pseudomonas	Siderophore production	Potato, maize	-	-	[211]
Rhizobia	Nitrogen	Legumes	-	-	[228]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
	fixation				
Rhizobia	Induction of plant stress resistance	Peanuts	-	-	[209]
Rhizobia	Hydrogen Cyanide Production	Legumes	-	-	[229]
Rhizobium	Nitrogen fixation	Rice	-	-	[230]
Rhizobium	Indole acetic acid synthesis	Pepper, tomato, lettuce, carrot	Seed Inoculation Seedlings were inoculated with 250 µL plant^{-1} of a bacterial suspension with a turbidity of 5 in McFarland standards (1.5 × 109 CFUmL^{-1}).	The dry weight of the inoculated seedlings (shoots and roots) was more than twice with respect to the un-inoculated seedlings. Concentrations of N, P, and Ca were significantly higher in inoculated plants, indicating that they had higher potential for nutrient uptake than control plants.	[231,232]
Rhizobium	ACC deaminase synthesis	Pepper, tomato mung beans,	-	-	[223,231]
Rhizobium	Siderophore production	Tomato, pepper, Carrot, lettuce,	Seed Inoculation Seedlings were inoculated with 250 lL plant^{-1} of a bacterial suspension with a turbidity of 5 in McFarland standards (1.5 × 109 CFU/mL^{-1}).	The colonies of strain TPV08 were surrounded by a yellow-orange halo (3.5 mm radium around colonies) indicative of siderophore production.	[231,232]
Sinorhizobium	Chitinase and β-glucanases production	Pigeon pea	-	-	[222]
Sphingomonas	Gibberelin synthesis	Tomato	-	-	[233]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

PGPR	PGPR Mechanisms	Crops	Application Mode	Observation/Findings	Ref.
Streptomyces	Indole acetic acid synthesis	Indian lilac	-	-	[234]
Streptomyces	Siderophore production	Indian lilac	-	-	[234]

VI. CONCLUSION

The technology whose time has come is the incorporation of PGPB as a fundamental aspect of agricultural operations. Many underdeveloped nations now effectively employ these microorganisms, and it is anticipated that this practice will spread. The application of PGPB fills a little but expanding niche in the advancement of organic agriculture in the more industrialized countries, where agricultural chemicals are still comparatively affordable. Furthermore, it seems sense to anticipate seeing PGPB used in a greater number of phytoremediation techniques.

Encouragement should be provided to the application of PGPB in agriculture because of its favorable effects on biofertilization, biocontrol, and bioremediation—all of which have a positive impact on crop yield and ecosystem functioning. With luck, technology will advance to the point where successful research and development is possible. PGPB utilization will then become a reality and play a key role in the vital processes that guarantee the productivity and stability of agro-ecosystems, guiding us in the direction of the perfect agricultural system.

REFERENCES

[1]. M. Lucy, E. Reed, and B. R. Glick, "Applications of free living plant growth-promoting rhizobacteria," Antonie van Leeuwenhoek, vol. 86, no. 1, pp. 1–25, 2004.
[2]. C. T. de Rosa, B. L. Johnson, M. Fay, H. Hansen, and M. M. Mumtaz, "Public health implications of hazardous waste sites: findings, assessment and research," Food and Chemical Toxicology, vol. 34, no. 11-12, pp. 1131–1138, 1996.
[3]. B. R. Glick, "Using soil bacteria to facilitate phytoremediation," Biotechnology Advances, vol. 28, no. 3, pp. 367–374, 2010.
[4]. J. Ziegler, "Health risk assessment research: the OTA report," Environmental Health Perspectives, vol. 101, no. 5, pp. 402–406, 1993.
[5]. I. Alkorta and C. Garbisu, "Phytoremediation of organic contaminants in soils," Bioresource Technology, vol. 79, no. 3, pp. 273–276, 2001.
[6]. E. Pilon-Smits, "Phytoremediation," Annual Review of Plant Biology, vol. 56, pp. 15–39, 2005.
[7]. E. Pilon-Smits and J. L. Freeman, "Environmental cleanup using plants: biotechnological advances and ecological considerations," Frontiers in Ecology and the Environment, vol. 4, no. 4, pp. 203–210, 2006.
[8]. D. E. Salt, M. Blaylock, N. P. B. A. Kumar et al., "Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants," Nature Biotechnology, vol. 13, no. 5, pp. 468–474, 1995.
[9]. E. Gamalero and B. R. Glick, "Plant growth-promoting bacteria and metal phytoremediation," in Phytotechnologies, N. A. Anjum, M. E. Pereira, I. Ahmad, A. C. Duarte, S. Umar, and N. A. Khan, Eds., pp. 359–374, Taylor & Francis, Boca Raton, Fla, USA, 2012.
[10]. B. R. Glick and J. C. Stearns, "Making phytoremediation work better: maximizing a plant's growth potential in the midst of adversity," International Journal of Phytoremediation, vol. 13, no. 1, pp. 4–16, 2011.
[11]. L. Schoenborn, P. S. Yates, B. E. Grinton, P. Hugenholtz, and P. H. Janssen, "Liquid serial dilution is inferior to solid media for isolation of cultures representative of the phylum-level diversity of soil bacteria," Applied and Environmental Microbiology, vol. 70, no. 7, pp. 4363–4366, 2004.
[12]. S. Timmusk, V. Paalme, T. Pavlicek et al.,"Bacterial distribution in the rhizosphere of wild barley under contrasting microclimates," PLoS One, vol. 6, no. 3, Article ID e17968, 2011.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[13]. B. R. Glick, C. L. Patten, G. Holguin, and D. M. Penrose, Biochemical and Genetic Mechanisms Used by Plant Growth Promoting Bacteria, Imperial College Press, London, UK, 1999.
[14]. D. V. Badri, T. L. Weir, D. van der Lelie, and J. M. Vivanco, "Rhizosphere chemical dialogues: plant-microbe interactions," Current Opinion in Biotechnology, vol. 20, no. 6, pp. 642–650, 2009.
[15]. D. V. Badri and J. M. Vivanco, "Regulation and function of root exudates," Plant, Cell and Environment, vol. 32, no. 6, pp. 666–681, 2009.
[16]. H. P. Bais, T. L. Weir, L. G. Perry, S. Gilroy, and J. M. Vivanco, "Role role of root exudates in rhizosphere interactions with plants and other organisms," Annual Review of Plant Biology, vol. 57, pp. 233–266, 2006.
[17]. J. M. Whipps, "Carbon utilization," in the Rhizosphere,, J. M. Lynch, Ed., pp. 59–97, Wiley-Interscience, Chichester, UK, 1990.
[18]. J. M. Lynch, Ed., the Rhizosphere, Wiley-Interscience, Chichester, UK, 1990.
[19]. A. N. Dubeikovsky, E. A. Mordukhova, V. V. Kochetkov, F. Y. Polikarpova, and A. M. Boronin, "Growth promotion of blackcurrant softwood cuttings by recombinant strain Pseudomonas fluorescens BSP53a synthesizing an increased amount of indole3-acetic acid," Soil Biology and Biochemistry, vol. 25, no. 9, pp. 1277–1281, 1993.
[20]. A. R. Glick, "The enhancement of plant growth by free-living bacteria," Canadian Journal of Microbiology, vol. 41, no. 2, pp. 109–117, 1995.
[21] R. O. D. Dixon and C. T. Wheeler, Nitrogen Fixation in Plants, Blackie and Son, Glasgow, UK, 1986.
[22] H. M. Fischer,"Genetic regulation of nitrogen fixation in rhizobia," Microbiological Reviews, vol. 58, no. 3, pp. 352–386, 1994.
[23] S. R. Long, W. J. Buikema, and F. M. Ausubel, "Cloning of Rhizobium meliloti nodulation genes by direct complementation of Nod− mutants," Nature, vol. 298, no. 5873, pp. 485–488, 1982.
[24] J. W. Kloepper, R. Lifshitz, and R. M. Zablotowicz, "Free-living bacterial inocula for enhancing crop productivity," Trends in Biotechnology, vol. 7, no. 2, pp. 39–44, 1989.
[25] M. R. Banerjee, L. Yesmin, and J. K. Vessey, "Plant-growthpromoting rhizobacteria as biofertilizers and biopesticides," in Handbook of Microbial Biofertilizers, M. K. Rai, Ed., pp. 137–181, Food Products Press, Binghamton, NY, USA, 2006.
[26] Y. Bashan and H. Levanony, "Current status of Azospirillum inoculation technology: Azospirillum as a challenge for agriculture," Canadian Journal of Microbiology, vol. 36, no. 9, pp. 591–608, 1990.
[27] E. K. James and F. L. Olivares, "Infection and colonization of sugar cane and other graminaceous plants by endophytic diazotrophs," Critical Reviews in Plant Sciences, vol. 17, no. 1, pp. 77–119, 1997.
[28] S. Marroquí, A. Zorreguieta, C. Santamaría et al., "Enhanced symbiotic performance by Rhizobium tropici glycogen synthase mutants," Journal of Bacteriology, vol. 183, no. 3, pp. 854–864, 2001.
[29] M. Ramírez, B. Valderrama, R. Arredondo-Peter, M. Soberón, J. Mora, and G. Hernández, "Rhizobium etli genetically engineered for the heterologous expression of Vitreoscilla sp. hemoglobin: effects on free-living and symbiosis," Molecular Plant-Microbe Interactions, vol. 12, no. 11, pp. 1008–1015, 1999.
[30] W. Ma, D. M. Penrose, and B. R. Glick, "Strategies used by rhizobia to lower plant ethylene levels and increase nodulation," Canadian Journal of Microbiology, vol. 48, no. 11, pp. 947–954, 2002.
[31] K. I. Yuhashi, N. Ichikawa, H. Ezura et al., "Rhizobitoxine production by Bradyrhizobium elkanii enhances nodulation and competitiveness on Macroptilium atropurpureum," Applied and Environmental Microbiology, vol. 66, no. 6, pp. 2658–2663, 2000.
[32] W. Ma, F. C. Guinel, and B. R. Glick, "Rhizobium leguminosarum biovar viciae 1-aminocyclopropane-1-carboxylate deaminase promotes nodulation of pea plants," Applied and Environmental Microbiology, vol. 69, no. 8, pp. 4396–4402, 2003. 10 Scientifica
[33] W. Ma, T. C. Charles, and B. R. Glick, "Expression of an exogenous 1-aminocyclopropane-1-carboxylate deaminase gene in Sinorhizobium meliloti increases its ability to nodulate alfalfa," Applied and Environmental Microbiology, vol. 70, no. 10, pp. 5891–5897, 2004.
[34] J. Duan, K. M. Müller, T. C. Charles, S. Vesely, and B. R. Glick, "1-Aminocyclopropane-1-carboxylate (ACC) deaminase genes in rhizobia from southern saskatchewan," Microbial Ecology, vol. 57, no. 3, pp. 423–436, 2009.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[35] M. S. Khan, A. Zaidi, and P. A. Wani, "Role of phosphatesolubilizing microorganisms in sustainable agriculture—a review," Agronomy for Sustainable Development, vol. 27, no. 1, pp. 29–43, 2007.
[36] K. Feng, H. M. Lu, H. J. Sheng, X. L. Wang, and J. Mao, "Effect of organic ligands on biological availability of inorganic phosphorus in soils," Pedosphere, vol. 14, no. 1, pp. 85–92, 2004.
[37] A. E. Richardson, "Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants," Functional Plant Biology, vol. 28, no. 9, pp. 897–906, 2001.
[38] H. Rodríguez and R. Fraga, "Phosphate solubilizing bacteria and their role in plant growth promotion," Biotechnology Advances, vol. 17, no. 4-5, pp. 319–339, 1999.
[39] B. Y. Bnayahu, "Root excretions and their environmental effects: influence on availability of phosphorus," in Plant Roots: the Hidden Half, Y. Waisel, A. Eshel, and U. Kafkafi, Eds., pp. 529–557, Marcel Dekker, New York, NY, USA, 1991.
[40] H. Rodriguez, T. Gonzalez, I. Goire, and Y. Bashan, "Gluconic acid production and phosphate solubilization by the plant growth-promoting bacterium Azospirillum spp," Nature-wissenschafen, vol. 91, no. 11, pp. 552–555, 2004.
[41] G. C. Tao, S. J. Tian, M. Y. Cai, and G. H. Xie, "Phosphatesolubilizing and -mineralizing abilities of bacteria isolated from soils1 1 project supported by the Scientific Research Foundation for the Returned Overseas Chinese Scholars, the Ministry of Education of the P.R. China," Pedosphere, vol. 18, no. 4, pp. 515–523, 2008.
[42] A. Rojas, G. Holguin, B. R. Glick, and Y. Bashan, "Synergism between Phyllobacterium sp. (N2-fixer) and Bacillus licheniformis (P-solubilizer), both from a semiarid mangrove rhizosphere," FEMS Microbiology Ecology, vol. 35, no. 2, pp. 181–187, 2001.
[43] J. F. Ma, "Plant root responses to three abundant soil minerals: silicon, aluminum and iron," Critical Reviews in Plant Sciences, vol. 24, no. 4, pp. 267–281, 2005.
[44] M. L. Guerinot and Y. Ying, "Iron: nutritious, noxious, and not readily available," Plant Physiology, vol. 104, no. 3, pp. 815–820, 1994.
[45] J. E. Loper and J. S. Buyer, "Siderophores in microbial interactions on plant surfaces," Molecular Plant-Microbe Interactions, vol. 4, pp. 5–13, 1991.
[46] R. C. Hider and X. Kong, "Chemistry and biology of siderophores," Natural Product Reports, vol. 27, no. 5, pp. 637–657, 2010.
[47] J. B. Neilands, "Iron absorption and transport in microorganisms," Annual Review of Nutrition, vol. 1, pp. 27–46, 1981.
[48] D. E. Crowley, C. P. P. Reid, and P. J. Szaniszlo, "Utilization of microbial siderophores in iron acquisition by oat," Plant Physiology, vol. 87, pp. 685–688, 1988.
[49] B. J. Duijff, P. A. H. M. Bakker, and B. Schippers, "Ferric pseudobactin 358 as an iron source for carnation," Journal of Plant Nutrition, vol. 17, no. 12, pp. 2069–2078, 1994.
[50] B. J. Duijff, W. J. de Kogel, P. A. H. M. Bakker, and B. Schippers, "Influence of pseudobactin 358 on the iron nutrition of barley," Soil Biology and Biochemistry, vol. 26, no. 12, pp. 1681–1688, 1994.
[51] C. W. Jin, Y. F. He, C. X. Tang, P. Wu, and S. J. Zheng, "Mechanisms of microbially enhanced Fe acquisition in red clover (Trifolium pratense L.)," Plant, Cell and Environment, vol. 29, no. 5, pp. 888–897, 2006.
[52] A. Robin, G. Vansuyt, P. Hinsinger, J. M. Meyer, J. F. Briat, and P. Lemanceau, "Iron dynamics in the rhizosphere. Consequences for plant health and nutrition," Advances in Agronomy, vol. 99, pp. 183–225, 2008.
[53] H. Siebner-Freibach, Y. Hadar, and Y. Chen, "Siderophores sorbed on Ca-montmorillonite as an iron source for plants," Plant and Soil, vol. 251, no. 1, pp. 115–124, 2003
[54] A. Walter, V. Römheld, H. Marschner, and D. E. Crowley, "Iron nutrition of cucumber and maize: effect of Pseudomonas putida YC 3 and its siderophore," Soil Biology and Biochemistry, vol. 26, no. 8, pp. 1023–1031, 1994.
[55] Z. Yehuda, M. Shenker, V. Römheld, H. Marschner, Y. Hadar, and Y. Chen, "□e role of ligand exchange in the uptake of iron from microbial siderophores by gramineous plants," Plant Physiology, vol. 112, no. 3, pp. 1273–1280, 1996.
[56] A. Sharma, B. N. Johri, A. K. Sharma, and B. R. Glick, "Plant growth-promoting bacterium Pseudomonas sp. strain GRP3 influences iron acquisition in mung bean (Vigna radiata L. Wilzeck)," Soil Biology and Biochemistry, vol. 35, no. 7, pp. 887–894, 2003.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[57] G. Vansuyt, A. Robin, J. F. Briat, C. Curie, and P. Lemanceau, "Iron acquisition from Fe-pyoverdine by Arabidopsis thaliana," Molecular Plant-Microbe Interactions, vol. 20, no. 4, pp. 441– 447, 2007.
[58] A. A. Belimov, N. Hontzeas, V. I. Safronova et al., "Cadmiumtolerant plant growth-promoting bacteria associated with the roots of Indian mustard (Brassica juncea L. Czern.)," Soil Biology and Biochemistry, vol. 37, no. 2, pp. 241–250, 2005.
[59] A. Braud, K. Jézéquel, E. Vieille, A. Tritter, and T. Lebeau, "Changes in extractability of Cr and Pb in a polycontaminated soil after bioaugmentation with microbial producers of biosurfactants, organic acids and siderophores," Water, Air, and Soil Pollution, vol. 6, no. 3-4, pp. 261–279, 2006.
[60] G. I. Burd, D. G. Dixon, and B. R. Glick, "A plant growthpromoting bacterium that decreases nickel toxicity in seedlings," Applied and Environmental Microbiology, vol. 64, no. 10, pp. 3663–3668, 1998.
[61] G. I. Burd, D. G. Dixon, and B. R. Glick, "Plant growthpromoting bacteria that decrease heavy metal toxicity in plants," Canadian Journal of Microbiology, vol. 46, no. 3, pp. 237–245, 2000.
[62] L. Diels, N. van der Lelie, and L. Bastiaens, "New developments in treatment of heavy metal contaminated soils," Reviews in Environmental Science and Biotechnology, vol. 1, no. 1, pp. 75–82, 2002.
[63] A. Robin, C. Mougel, S. Siblot, G. Vansuyt, S. Mazurier, and P. Lemanceau, "Effect of ferritin overexpression in tobacco on the structure of bacterial and pseudomonad communities associated with the roots," FEMS Microbiology Ecology, vol. 58, no. 3, pp. 492–502, 2006.
[64] P. J. Davies, Plant Hormones: Biosynthesis, Signal Transduction, Action!, Kluwer Academic, Dordrecht, Netherlands, 2004.
[65] B. R. Glick, Z. Cheng, J. Czarny, and J. Duan, "Promotion of plant growth by ACC deaminase-producing soil bacteria," Scientifica 11 European Journal of Plant Pathology, vol. 119, no. 3, pp. 329– 339, 2007.
[66] I. E. G. Salamone, R. K. Hynes, and L. M. Nelson, "Role of cytokinins in plant growth promotion by rhizosphere bacteria," in PGPR: Biocontrol and Biofertilization, Z. A. Siddiqui, Ed., pp. 173–195, Springer, Amsterdam, Netherlands, 2005.
[67] K. F. Nieto and W. T. Frankenberger Jr., "Biosynthesis of cytokinins by Azotobacter chroococcum," Soil Biology and Biochemistry,vol.21, no.7, pp. 967–972, 1989.
[68] I. E. G. Salamone, R. K. Hynes, and L. M. Nelson, "Cytokinin production by plant growth promoting rhizobacteria and selected mutants," Canadian Journal of Microbiology, vol. 47, no. 5, pp. 404–411, 2001.
[69] B. J. Taller and T. Y.Wong, "Cytokinins inAzotobacter vinelandii culture medium," Applied and Environmental Microbiology, vol. 55, pp. 266–267, 1989.
[70] T. Tien, M. Gaskin, and D. Hubbel, "Plant growth substances produced by Azospirillum brasilense and their effect on the growth of pearl millet (Pennisetum americanum L.)," Applied and Environmental Microbiology, vol. 37, pp. 1016–1024, 1979.
[71] S. Timmusk, B. Nicander, U. Granhall, and E. Tillberg, "Cytokinin production by Paenibacillus polymyxa," Soil Biology and Biochemistry, vol. 31, no. 13, pp. 1847–1852, 1999.
[72] P. M. Williams and M. S. de Mallorca, "Abscisic acid and gibberellin-like substances in roots and root nodules of Glycine max," Plant and Soil, vol. 65, no. 1, pp. 19–26, 1982.
[73] R. Atzorn, A. Crozier, C. T. Wheeler, and G. Sandberg, "Production of gibberellins and indole-3-acetic acid by Rhizobium phaseoli in relation to nodulation of Phaseolus vulgaris roots," Planta, vol. 175, no. 4, pp. 532–538, 1988.
[74] G. J. Joo, Y. M. Kim, J. T. Kim, I. K. Rhee, J. H. Kim, and I. J. Lee, "Gibberellins-producing rhizobacteria increase endogenous gibberellins content and promote growth of red peppers," Journal of Microbiology, vol. 43, no. 6, pp. 510–515, 2005.
[75] S. M. Kang, G. J. Joo, M. Hamayun et al., "Gibberellin production and phosphate solubilization by newly isolated strain of Acinetobacter calcoaceticus and its effect on plant growth," Biotechnology Letters, vol. 31, no. 2, pp. 277–281, 2009.
[76] M. A. Lorteau, B. J. Ferguson, and F. C. Guinel, "Effects of cytokinin on ethylene production and nodulation in pea (Pisum sativum) cv. Sparkle," Physiologia Plantarum, vol. 112, no. 3, pp. 421–428, 2001.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[77] E. Yahalom, Y. Okon, and A. Dovrat, "Possible mode of action of Azospirillum brasilense strain Cd on the root morphology and nodule formation in burr medic (Medicago polymorpha)," Canadian Journal of Microbiology, vol. 36, no. 1, pp. 10–14, 1990.
[78] C. L. Patten and B. R. Glick, "Bacterial biosynthesis of indole3-acetic acid," Canadian Journal of Microbiology, vol. 42, no. 3, pp. 207–220, 1996.
[79] S. Spaepen, J. Vanderleyden, and R. Remans, "Indole-3-acetic acid in microbial and microorganism-plant signaling," FEMS Microbiology Reviews, vol. 31, no. 4, pp. 425–448, 2007.
[80] S. Spaepen and J. Vanderleyden, "Auxin and plant-microbe interactions," Cold Spring Harbor perspectives in biology, vol. 3, no. 4, 2011.
[81] E. A. Tsavkelova, S. Y. Klimova, T. A. Cherdyntseva, and A. I. Netrusov, "Microbial producers of plant growth stimulators and their practical use: a review," Applied Biochemistry and Microbiology, vol. 42, no. 2, pp. 117–126, 2006.
[82] P. E. Pilet and M. Saugy, "Effect on root growth of endogenous and applied IAA and ABA," Plant Physiology, vol. 83, pp. 33–38, l987.
[83] C. L. Patten and B. R. Glick, "Role of Pseudomonas putida indoleacetic acid in development of the host plant root system," Applied and Environmental Microbiology, vol. 68, no. 8, pp. 3795–3801, 2002.
[84] H. Xie, J. J. Pasternak, and B. R. Glick, "Isolation and characterization of mutants of the plant growth-promoting rhizobacterium Pseudomonas putida GR12-2 that overproduce indoleacetic acid," Current Microbiology, vol. 32, no. 2, pp. 67–71, 1996.
[85] S. Mayak, T. Tirosh, and B. R. Glick, "Effect of wild-type and mutant plant growth-promoting rhizobacteria on the rooting of mung bean cuttings," Journal of Plant Growth Regulation, vol. 18, no. 2, pp. 49–53, 1999.
[86] M. B. Jackson, "Ethylene in root growth and development," in □e Plant Hormone Ethylene, A. K. Mattoo and J. C. Suttle, Eds., pp. 169–181, CRC Press, Boca Raton, Fla, USA, 1991.
[87] J. Riov and S. F. Yang, "Ethylene and auxin-ethylene interaction in adventitious root formation in mung bean (Vigna radiata) cuttings," Journal of Plant Growth Regulation, vol. 8, no. 2, pp. 131–141, 1989.
[88] J. Badenoch-Jones, R. E. Summons, B. G. Rolfe, and D. S. Letham, "Phytohormones, Rhizobium mutants, and nodulation in legumes. IV. Auxin metabolites in pea root nodules," Journal of Plant Growth Regulation, vol. 3, no. 1-3, pp. 23–39, 1984.
[89] U. Mathesius, H. R. M. Schlaman, H. P. Spaink, C. Sautter, B. G. Rolfe, and M. A. Djordjevic, "Auxin transport inhibition precedes root nodule formation in white clover roots and is regulated by flavonoids and derivatives of chitin oligosaccharides," Plant Journal, vol. 14, no. 1, pp. 23–34, 1998.
[90] H. Fukuhara, Y. Minakawa, S. Akao, and K. Minamisawa, "□e involvement of indole-3-acetic acid produced by Bradyrhizobium elkanii in nodule formation," Plant and Cell Physiology, vol. 35, no. 8, pp. 1261–1265, 1994.
[91] Meunis, IAA biosynthesis in rhizobia and its potential role in symbiosis [Ph.D. thesis], Universiteit Antwerpen, 2005.
[92] F. B. Abeles, P. W. Morgan, and M. E. Saltveit Jr., Ethylene in Plant Biology, Academic Press, New York, NY, USA, 2nd edition, 1992.
[93] P. W. Morgan and M. C. Drew, "Ethylene and plant responses to stress," Physiologia Plantarum, vol. 100, no. 3, pp. 620–630, 1997.
[94] J. A. Ciardi, D. M. Tieman, S. T. Lund, J. B. Jones, R. E. Stall, and H. J. Klee, "Response to Xanthomonas campestris pv. vesicatoria in tomato involves regulation of ethylene receptor gene expression," Plant Physiology, vol. 123, no. 1, pp. 81–92, 2000.
[95] M. Honma and T. Shimomura, "Metabolism of 1-aminocyclopropane-1-carboxylic acid," Agricultural and Biological Chemistry, vol. 42, no. 10, pp. 1825–1831, 1978.
[96] D. Blaha, C. Prigent-Combaret, M. S. Mirza, and Y. MoënneLoccoz, "Phylogeny of the 1-aminocyclopropane-1-carboxylic acid deaminase-encoding gene acdS in phytobeneficial and pathogenic Proteobacteria and relation with strain biogeography," FEMS Microbiology Ecology, vol. 56, no. 3, pp. 455–470, 2006.
[97] B. R. Glick, B. Todorovic, J. Czarny, Z. Cheng, J. Duan, and B. McConkey, "Promotion of plant growth by bacterial ACC deaminase," Critical Reviews in Plant Sciences, vol. 26, no. 5-6, pp. 227–242, 2007. 12

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[98] B. R. Glick, D. M. Penrose, and J. Li, "A model for the lowering of plant ethylene concentrations by plant growth-promoting bacteria," Journal of Biology, vol. 190, no. 1, pp. 63–68, 1998.
[99] D. M. Penrose and B. R. Glick, "Levels of ACC and related compounds in exudate and extracts of canola seeds treated with ACC deaminase-containing plant growth-promoting bacteria," Canadian Journal of Microbiology, vol. 47, no. 4, pp. 368–372, 2001.
[100] C. Contesto, G. Desbrosses, C. Lefoulon et al., "Effects of rhizobacterial ACC deaminase activity on Arabidopsis indicate that ethylene mediates local root responses to plant growthpromoting rhizobacteria," Plant Science, vol. 175, no. 1-2, pp. 178–189, 2008.
[101] R. Dey, K. K. Pal, D. M. Bhatt, and S. M. Chauhan, "Growth promotion and yield enhancement of peanut (Arachis hypogaea L.) by application of plant growth-promoting rhizobacteria," Microbiological Research, vol. 159, no. 4, pp. 371–394, 2004.
[102] J. A. Hall, D. Peirson, S. Ghosh, and B. R. Glick, "Root elongation in various agronomic crops by the plant growth promoting rhizobacterium Pseudomonas putida GR12-2," Israel Journal of Plant Sciences, vol. 44, no. 1, pp. 37–42, 1996.
[103] F. Nascimento, C. Brígido, L. Alho, B. R. Glick, and S. Oliveira, "Enhanced chickpea growth promotion ability of a mesorhizobia expressing an exogenous ACC deaminase gene," Plant and Soil, vol. 353, no. 1-2, pp. 221–230, 2012.
[104] M. Naveed, Z. A. Zahir, M. Khalid, H. N. Asghar, M. J. Akhtar, and M. Arshad, "Rhizobacteria containing acc-deaminase for improving growth and yield of wheat under fertilized conditions," Pakistan Journal of Botany, vol. 40, no. 3, pp. 1231–1241, 2008.
[105] J. Onofre-Lemus, I. Hernández-Lucas, L. Girard, and J. Caballero-Mellado, "ACC (1-aminocyclopropane-1-carboxylate) deaminase activity, a widespread trait in Burkholderia species, and its growth-promoting effect on tomato plants," Applied and Environmental Microbiology, vol. 75, no. 20, pp. 6581–6590, 2009.
[106] S. Shah, J. Li, B. A. Moffatt, and B. R. Glick, "Isolation and characterization of ACC deaminase genes from two different plant growth-promoting rhizobacteria," Canadian Journal of Microbiology, vol. 44, no. 9, pp. 833–843, 1998.
[107] B. Shaharoona, M. Arshad, and Z. A. Zahir, "Effect of plant growth promoting rhizobacteria containing ACC-deaminase on maize (Zea mays L.) growth under axenic conditions and on nodulation in mung bean (Vigna radiata L.)," Letters in Applied Microbiology, vol. 42, no. 2, pp. 155–159, 2006.
[108] F. X. Nascimento, C. Brígido, B. R. Glick, S. Oliveira, and L. Alho, "Mesorhizobium ciceri LMS-1 expressing an exogenous ACC deaminase increases its nodulation abilities and chickpea plant resistance to soil constraints," Letters in Applied Microbiology, vol. 55, pp. 15–21, 2012.
[109] E. Gamalero, G. Berta, N. Massa, B. R. Glick, and G. Lingua, "Synergistic interactions between the ACC deaminaseproducing bacterium Pseudomonas putida UW4 and the AM fungus Gigaspora rosea positively affect cucumber plant growth," FEMS Microbiology Ecology, vol. 64, no. 3, pp. 459–467, 2008.
[110] S. Compant, B. Duffy, J. Nowak, C. Clément, and E. Ait Barka, "Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects," Applied and Environmental Microbiology, vol. 71, no. 9, pp. 4951–4959, 2005.
[111] D. Haas and C. Keel, "Regulation of antibiotic production in root-colonizing Pseudomonas spp. and relevance for biological control of plant disease," Annual Review of Phytopathology, vol. 41, pp. 117–153, 2003.
[112] S. Mazurier, T. Corberand, P. Lemanceau, and J. M. Raaijmakers, "Phenazine antibiotics produced by fluorescent pseudomonads contribute to natural soil suppressiveness to Fusarium wilt," ISME Journal, vol. 3, no. 8, pp. 977–991, 2009.
[113] K. K. Pal and B. McSpadden Gardener, "Biological control of plant pathogens," The Plant Health Instructor. In press http:// www.apsnet.org / edcenter / advanced/topics/Documents/PHIBiologicalControl.pdf.
[114] J. M. Raaijmakers, M. Vlami, and J. T. de Souza, "Antibiotic production by bacterial biocontrol agents," Antonie van Leeuwenhoek, vol. 81, no. 1–4, pp. 537–547, 2002.
[115] J. M. Whipps, "Microbial interactions and biocontrol in the rhizosphere," Journal of Experimental Botany, vol. 52, pp. 487–511, 2001.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[116] J. Frankowski, M. Lorito, F. Scala, R. Schmid, G. Berg, and H. Bahl, "Puriﬁcation and properties of two chitinolytic enzymes of Serratia plymuthica HRO-C48," Archives of Microbiology, vol. 176, no. 6, pp. 421–426, 2001.
[117] Y. C. Kim, H. Jung, K. Y. Kim, and S. K. Park, "An effective biocontrol bioformulation against Phytophthora blight of pepper using growth mixtures of combined chitinolytic bacteria under different ﬁeld conditions," European Journal of Plant Pathology, vol. 120, no. 4, pp. 373–382, 2008.
[118] A. Ordentlich, Y. Elad, and I. Chet, "□e role of chitinase of Serratia marcescens in biocontrol of Sclerotium rolfsii," Phytopathol, vol. 78, pp. 84–88, 1988.
[119] P. P. Singh, Y. C. Shin, C. S. Park, and Y. R. Chung, "Biological control of Fusarium wilt of cucumber by chitinolytic bacteria," Phytopathology, vol. 89, no. 1, pp. 92–99, 1999.
[120] D. N. Dowling, R. Sexton, A. Fenton et al., "Iron regulation in plant-associated Pseudomonas fluorescens M114: implications for biological control," in Molecular Biology of Pseudomonads, T. Nakazawa, K. Furukawa, D. Haas, and S. Silver, Eds., pp. 502–511, American Society for Microbiology Press, Washington, DC, USA, 1996.
[121] J. W. Kloepper, J. Leong, M. Teintze, and M. N. Schroth, "Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria," Nature, vol. 286, no. 5776, pp. 885–886, 1980.
[122] B. Schippers, A. W. Bakker, and A. H. M. Bakker, "Interactions of deleterious and beneficial rhizosphere microorganisms and the effect of cropping practice," Annual Review of Phytopathology, vol. 25, pp. 339–358, 1987.
[123] D. J.Sullivan and F. Gara, "Traits of fluorescent Pseudomonas spp. involved in suppression of plant root pathogens," Microbiological Reviews, vol. 56, no. 4, pp. 662–676, 1992.
[124] E. Bar-Ness, Y. Chen, Y. Hadar, H. Marschner, and V. Römheld, "Siderophores of Pseudomonas putida as an iron source for dicot and monocot plants," in Iron Nutrition and Interactions in Plants,, Y. Chen and Y. Hadar, Eds., pp. 271–281, Kluwer Academic, Dordrecht, □e Netherlands, 1991.
[125] Y. Wang, H. N. Brown, D. E. Crowley, and P. J. Szaniszlo, "Evidence for direct utilization of a siderophore, ferrioxamine B, in axenically grown cucumber," Plant, Cell & Environment, vol. 16, pp. 579–585, 1993.
[126] S. Buysens, K. Heungens, J. Poppe, and M. Hö□e, "Involvement of pyochelin and pyoverdin in suppression of Pythium-induced Scientiﬁca 13 damping-off of tomato by Pseudomonas aeruginosa 7NSK2," Applied and Environmental Microbiology, vol. 62, no. 3, pp. 865–871, 1996.
[127] M. Elsherif and F. Grossmann, "Comparative investigations on the antagonistic activity of ﬂuorescent pseudomonads against Gaeumannomyces graminis var. tritici in vitro and in vivo," Microbiological Research, vol. 149, no. 4, pp. 371–377, 1994.
[128] G. Martinetti and J. E. Loper, "Mutational analysis of genes determining antagonism of Alcaligenes sp. strain MFA1 against the phytopathogenic fungus Fusarium oxysporum," Canadian Journal of Microbiology, vol. 38, no. 3, pp. 241–247, 1992.
[129] P. A. Vandenbergh and C. F. Gonzalez, "Method for protecting the growth of plants employing mutant siderophore producing strains of Pseudomonas putida," United States Patent Number: 4, 479, 936, 1984.
[131] B. R. Glick and Y. Bashan, "Genetic manipulation of plant growth-promoting bacteria to enhance biocontrol of phytopathogens," Biotechnology Advances, vol. 15, no. 2, pp. 353–378, 1997.
[132] Y. Hao, T. C. Charles, and B. R. Glick, "ACC deaminase from plant growth-promoting bacteria affects crown gall development," Canadian Journal of Microbiology, vol. 53, no. 12, pp. 1291–1299, 2007.
[133] Y. Hao, T. C. Charles, and B. R. Glick, "An ACC deaminase containing A. tumefaciens strain D3 shows biocontrol activity to crown gall disease," Canadian Journal of Microbiology, vol. 57, no. 4, pp. 278–286, 2011.
[134] E. Husen, A. T. Wahyudi, A. Suwanto, and Giyanto, "Growth enhancement and disease reduction of soybean by 1-aminocyclopropane-1-carboxylate deaminase-producing Pseudomonas," American Journal of Applied Sciences, vol. 8, no. 11, pp. 1073–1080, 2011.
[135] N. Toklikishvili, N. Dandurishvili, M. Tediashvili et al., "Inhibitory effect of ACC deaminase-producing bacteria on crown gall formation in tomato plants infected by Agrobacterium tumefaciens or A. vitis," Plant Pathology, vol. 59, no. 6, pp. 1023–1030, 2010.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[136] C. Wang, E. Knill, B. R. Glick, and G. Défago, "Effect of transferring 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase genes into Pseudomonas fluorescens strain CHA0 and its gacA derivative CHA96 on their growth-promoting and diseasesuppressive capacities," Canadian Journal of Microbiology, vol. 46, no. 10, pp. 898–907, 2000.
[137] S. T. Lund, R. E. Stall, and H. J. Klee, "Ethylene regulates the susceptible response to pathogen infection in tomato," Plant Cell, vol. 10, no. 3, pp. 371–382, 1998.
[138] M. M. Robison, S. Shah, B. Tamot, K. P. Pauls, B. A. Moffatt, and B. R. Glick, "Reduced symptoms of Verticillium wilt in transgenic tomato expressing a bacterial ACC deaminase," Molecular Plant Pathology, vol. 2, no. 3, pp. 135–145, 2001.
[139] C. M. J. Pieterse, A. Leon-Reyes, S. van der Ent, and S. C. M. van Wees, "Networking by small-molecule hormones in plant immunity," Nature Chemical Biology, vol. 5, no. 5, pp. 308–316, 2009.
[140] B. W. M. Verhagen, J. Glazebrook, T. Zhu, H. S. Chang, L. C. van Loon, and C. M. J. Pieterse, "The transcriptome of rhizobacteria-induced systemic resistance in Arabidopsis," Molecular Plant-Microbe Interactions, vol. 17, no. 8, pp. 895–908, 2004.
[141] P. A. H. M. Bakker, C. M. J. Pieterse, and L. C. van Loon, "Induced systemic resistance by fluorescent Pseudomonas spp," Phytopathology, vol. 97, no. 2, pp. 239–243, 2007.
[142] B. R. Glick, "Bacterial ACC deaminase and the alleviation of plant stress," Advances in Applied Microbiology, vol. 56, pp. 291–312, 2004.
[143] B. R. Glick, C. Liu, S. Ghosh, and E. B. Dumbroff, "Early development of canola seedlings in the presence of the plant growth-promoting rhizobacterium Pseudomonas putida GR12- 2," Soil Biology and Biochemistry, vol. 29, no. 8, pp. 1233–1239, 1997.
[144] V. P. Grichko and B. R. Glick, "Amelioration of flooding stress by ACC deaminase-containing plant growth-promoting bacteria," Plant Physiology and Biochemistry, vol. 39, no. 1, pp. 11–17, 2001.
[145] S. Mayak, T. Tirosh, and B. R. Glick, "Plant growth-promoting bacteria that confer resistance to water stress in tomatoes and peppers," Plant Science, vol. 166, no. 2, pp. 525–530, 2004.
[146] Z. A. Zahir, A. Munir, H. N. Asghar, B. Shaharoona, and M. Arshad, "Effectiveness of rhizobacteria containing ACC deaminase for growth promotion of peas (Pisum sativum) under drought conditions," Journal of Microbiology and Biotechnology, vol. 18, no. 5, pp. 958–963, 2008.
[147] Z. Cheng, Y. Y. C. Wei, W. W. L. Sung, B. R. Glick, and B. J. McConkey, "Proteomic analysis of the response of the plant growth-promoting bacterium Pseudomonas putida UW4 to nickel stress," Proteome Science, vol. 7, article 18, 2009.
[148] A. J. Farwell, S. Vesely, V. Nero et al., "The use of transgenic canola (Brassica napus) and plant growth-promoting bacteria to enhance plant biomass at a nickel-contaminated field site," Plant and Soil, vol. 288, no. 1-2, pp. 309–318, 2006.
[149] L. Nie, S. Shah, A. Rashid, G. I. Burd, D. G. Dixon, and B. R. Glick, "Phytoremediation of arsenate contaminated soil by transgenic canola and the plant growth-promoting bacterium Enterobacter cloacae CAL2," Plant Physiology and Biochemistry, vol. 40, no. 4, pp. 355–361, 2002.
[150] M. L. E. Reed and B. R. Glick, "Growth of canola (Brassica napus) in the presence of plant growth-promoting bacteria and either copper or polycyclic aromatic hydrocarbons," Canadian Journal of Microbiology, vol. 51, no. 12, pp. 1061–1069, 2005.
[151] M. L. E. Reed, B. G. Warner, and B. R. Glick, "Plant growthpromoting bacteria facilitate the growth of the common reed Phragmites australis in the presence of copper or polycyclic aromatic hydrocarbons," Current Microbiology, vol. 51, no. 6, pp. 425–429, 2005.
[152] V. I. Safronova, V. V. Stepanok, G. L. Engqvist, Y. V. Alekseyev, and A. A. Belimov, "Root-associated bacteria containing 1- aminocyclopropane-1-carboxylate deaminase improve growth and nutrient uptake by pea genotypes cultivated in cadmium supplemented soil," Biology and Fertility of Soils, vol. 42, no. 3, pp. 267–272, 2006.
[153] J. Li, J. Sun, Y. Yang, S. Guo, and B. R. Glick, "Identification of hypoxic-responsive proteins in cucumber using a proteomic approach," Plant Physiology and Biochemistry, vol. 51, pp. 74–80, 2012. 14 Scientifica

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[154] M. Ahmad, Z. A. Zahir, H. N. Asghar, and M. Asghar, "Inducing salt tolerance in mung bean through coinoculation with rhizobia and plant-growthpromoting rhizobacteria containing 1- aminocyclopropane-1-carboxylate deaminase," Canadian Journal of Microbiology, vol. 57, no. 7, pp. 578–589, 2011.
[156] Z. Cheng, O. Z. Woody, B. J. McConkey, and B. R. Glick, "Combined effects of the plant growth-promoting bacterium Pseudomonas putida UW4 and salinity stress on the Brassica napus proteome," Applied Soil Ecology, vol. 61, pp. 255–263, 2012.
[157] E. Gamalero, G. Berta, N. Massa, B. R. Glick, and G. Lingua, "Interactions between Pseudomonas putida UW4 andGigaspora rosea BEG9 and their consequences for the growth of cucumber under salt-stress conditions," Journal of Applied Microbiology, vol. 108, no. 1, pp. 236–245, 2010.
[158] F. Jalili, K. Khavazi, E. Pazira et al., "Isolation and characterization of ACC deaminase-producing uorescent pseudomonads, to alleviate salinity stress on canola (Brassica napus L.) growth," Journal of Plant Physiology, vol. 166, no. 6, pp. 667–674, 2009. [
159] S. Mayak, T. Tirosh, and B. R. Glick, "Plant growth-promoting bacteria confer resistance in tomato plants to salt stress," Plant Physiology and Biochemistry, vol. 42, no. 6, pp. 565–572, 2004.
[160] S. M. Nadeem, Z. A. Zahir, M. Naveed, and M. Arshad, "Preliminary investigations on inducing salt tolerance in maize through inoculation with rhizobacteria containing ACC deaminase activity," Canadian Journal of Microbiology, vol. 53, no. 10, pp. 1141–1149, 2007.
[161] M. Sadrnia, N. Maksimava, E. Khromsova, S. Stanislavich, P. Owilia, and M. Arjomandzadegan, "Study the effect of bacterial 1-aminocyclopropane-1-carboxylatedeaminase (ACC deaminase) on resistance to salt stress in tomato plants," Anals of University of Oradea, vol. 18, pp. 120–123, 2011.
[162] D. Saravanakumar and R. Samiyappan, "ACC deaminase from Pseudomonas uorescens mediated saline resistance in groundnut (Arachis hypogea) plants," Journal of Applied Microbiology, vol. 102, no. 5, pp. 1283–1292, 2007.
[163] M. A. Siddikee, P. S. Chauhan, R. Anandham, G. H. Han, and T. Sa, "Isolation, characterization, and use for plant growth promotion under salt stress, of ACC deaminase-producing halotolerant bacteria derived from coastal soil," Journal of Microbiology and Biotechnology, vol. 20, no. 11, pp. 1577–1584, 2010.
[164] M. A. Siddikee, B. R. Glick, P. S. Chauhan, W. J. Yim, and T. Sa, "Enhancement of growth and salt tolerance of red pepper seedlings (Capsicum annuum L.) by regulating stress ethylene synthesis with halotolerant bacteria containing 1-aminocyclopropane-1-carboxylic acid deaminase activity," Plant Physiology and Biochemistry, vol. 49, no. 4, pp. 427–434, 2011.
[165] H. T. Yue, W. P. Mo, C. Li, Y. Y. Zheng, and H. Li, "e salt stress relief and growth promotion effect of Rs-5 on cotton," Plant and Soil, vol. 297, no. 1-2, pp. 139–145, 2007.
[166] J. Gurska, W. Wang, K. E. Gerhardt et al., "ree year eld test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste," Environmental Science and Technology, vol. 43, no. 12, pp. 4472–4479, 2009.
[167] X. D. Huang, Y. El-Alawi, D. M. Penrose, B. R. Glick, and B. M. Greenberg, "A multi-process phytoremediation system for removal of polycyclic aromatic hydrocarbons from contaminated soils," Environmental Pollution, vol. 130, no. 3, pp. 465–476, 2004.
[168] X. D. Huang, Y. El-Alawi, J. Gurska, B. R. Glick, and B. M. Greenberg, "A multi-process phytoremediation system for decontamination of persistent total petroleum hydrocarbons (TPHs) from soils," Microchemical Journal, vol. 81, no. 1, pp. 139–147, 2005.
[169] C. Bianco and R. Defez, "Medicago truncatula improves salt tolerance when nodulated by an indole-3-acetic acidoverproducing Sinorhizobium melilotistrain," Journal of Experimental Botany, vol. 60, no. 11, pp. 3097–3107, 2009.
[170] C. Bianco and R. Defez, "Improvement of phosphate solubilization and Medicago plant yield by an indole-3-acetic acidoverproducing strain of Sinorhizobium meliloti," Applied and Environmental Microbiology, vol. 76, no. 14, pp. 4626–4632, 2010.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[171] L. E. de-Bashan, J. P. Hernandez, K. N. Nelson, Y. Bashan, and R. M. Maier, "Growth of quailbush in acidic, metalliferous desert mine tailings: effect of Azospirillum brasilense Sp6 on biomass production and Rhizosphere community structure," Microbial Ecology, vol. 60, no. 4, pp. 915–927, 2010.
[172] D. Egamberdieva, "Alleviation of salt stress by plant growth regulators and IAA producing bacteria in wheat," Acta Physiologiae Plantarum, vol. 31, no. 4, pp. 861–864, 2009.
[173] M. Rajkumar, R. Nagendran, K. J. Lee, W. H. Lee, and S. Z. Kim, "Influence of plant growth promoting bacteria and Cr6+ on the growth of Indian mustard," Chemosphere, vol. 62, no. 5, pp. 741–748, 2006.
[174] X. F. Sheng and J. J. Xia, "Improvement of rape (Brassica napus) plant growth and cadmium uptake by cadmium-resistant bacteria," Chemosphere, vol. 64, no. 6, pp. 1036–1042, 2006.
[175] P. A. Wani, M. S. Khan, and A. Zaidi, "Effect of metal tolerant plant growth promoting Bradyrhizobium sp. (vigna) on growth, symbiosis, seed yield and metal uptake by greengram plants," Chemosphere, vol. 70, no. 1, pp. 36–45, 2007.
[176] P. A. Wani, M. S. Khan, and A. Zaidi, "Effect of metal-tolerant plant growth-promoting Rhizobium on the performance of pea grown in metal-amended soil," Archives of Environmental Contamination and Toxicology, vol. 55, no. 1, pp. 33–42, 2008.
[177] D. Egamberdieva and Z. Kucharova, "Selection for root colonising bacteria stimulating wheat growth in saline soils," Biology and Fertility of Soils, vol. 45, no. 6, pp. 563–571, 2009.
[178] E. Gamalero and B. R. Glick, "Bacterial ACC deaminase and IAA: interactions and consequences for plant growth in polluted environments," in Handbook of Phytoremediation, I. A. Golubev, Ed., pp. 763–774, Nova Science, New York, NY, USA, 2010.
[179] V. Sgroy, F. Cassán, O. Masciarelli, M. F. Del Papa, A. Lagares, and V. Luna, "Isolation and characterization of endophytic plant growth-promoting (PGPB) or stress homeostasisregulating (PSHB) bacteria associated to the halophyte Prosopis strombulifera," Applied Microbiology and Biotechnology, vol. 85, no. 2, pp. 371–381, 2009.
[180] J. C. Czarny, S. Shah, and B. R. Glick, "Response of canola plants at the transcriptional level to expression of a bacterial ACC deaminase in the roots," in Advances in Plant Ethylene Research, A. Ramina, C. Chang, J. Giovannoni, H. Klee, P. Perata, and E. Woltering, Eds., pp. 377–382, Springer, Dordrecht, □e Netherlands, 2007. Scienti□ca 15
[181] N. Dharmasiri and M. Estelle, "Auxin signaling and regulated protein degradation," Trends in Plant Science, vol. 9, no. 6, pp. 302–308, 2004.
[182] J. C. Stearns, O. Z. Woody, B. J. McConkey, and B. R. Glick, "Effects of bacterial ACC deaminase on Brassica napus gene expression measured with an Arabidopsis thaliana microarray," Molecular Plant-Microbe Interactions, vol. 25, pp. 668–676, 2012.\
[183] R. M. Rivero, M. Kojima, A. Gepstein et al., "Delayed leaf senescence induces extreme drought tolerance in a □owering plant," Proceedings of the National Academy of Sciences of the United States of America, vol. 104, no. 49, pp. 19631–19636, 2007.
[184] J. Rodríguez-Salazar, R. Suárez, J. Caballero-Mellado, and G. Iturriaga, "Trehalose accumulation in Azospirillum brasilense improves drought tolerance and biomass in maize plants," FEMS Microbiology Letters, vol. 296, no. 1, pp. 52–59, 2009.
[185] R. Suárez, A.Wong, M. Ramírez et al., "Improvement of drought tolerance and grain yield in common bean by overexpressing trehalose-6-phosphate synthase in rhizobia," Molecular PlantMicrobe Interactions, vol. 21, no. 7, pp. 958–966, 2008.
[186] B. R. Glick and Y. C. Skof, "Environmental implications of recombinant DNA technology," Biotechnology Advances, vol. 4, no. 2, pp. 261–277, 1986.
[187] J. G. Duman and T. M. Olsen, "□ermal hysteresis protein activity in bacteria, fungi, and phylogenetically diverse plants," Cryobiology, vol. 30, no. 3, pp. 322–328, 1993.
[188] X. Sun, M. Griffith, J. J. Pasternak, and B. R. Glick, "Low temperature growth, freezing survival, and production of antifreeze protein by the plant growth promoting rhizobacterium Pseudomonas putida GR12-2," Canadian Journal of Microbiology, vol. 41, no. 9, pp. 776–784, 1995.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[189] H. Xu, M. Griffith, C. L. Patten, and B. R. Glick, "Isolation and characterization of an antifreeze protein with ice nucleation activity from the plant growth promoting rhizobacterium Pseudomonas putida GR12-2," Canadian Journal of Microbiology, vol. 44, no. 1, pp. 64–73, 1998.

[191] J. A. Gilbert, P. L. Davies, and J. Laybourn-Parry, "A hyperactive, Ca2+-dependent antifreeze protein in an Antarctic bacterium," FEMS Microbiology Letters, vol. 245, no. 1, pp. 67–72, 2005.

[192] J. A. Gilbert, P. J. Hill, C. E. R. Dodd, and J. Laybourn-Parry, "Demonstration of antifreeze protein activity in Antarctic lake bacteria," Microbiology, vol. 150, no. 1, pp. 171–180, 2004.

[193] H. Kawahara, Y. Iwanaka, S. Higa et al., "A novel, intracellular antifreeze protein in an antarctic bacterium, Flavobacterium xanthum," Cryo-Letters, vol. 28, no. 1, pp. 39–49, 2007.

[194] N. Muryoi, M. Sato, S. Kaneko et al., "Cloning and expression of afpA, a gene encoding an antifreeze protein from the arctic plant growth-promoting rhizobacterium Pseudomonas putida GR12- 2," Journal of Bacteriology, vol. 186, no. 17, pp. 5661–5671, 2004.

[195]. Reinhold-Hurek B., Hurek T. Interactions of gramineous plants with *Azoarcus* spp. and other diazotrophs: Identification, localization, and perspectives to study their function. *Crit. Rev. Plant Sci.* 1998;17:29–54. doi: 10.1016/S0735-2689(98)00355-4.

[196]. Aloni R., Aloni E., Langhans M. Role of cytokinin and auxin in shaping root architecture: Regulating vascular differentiation, lateral root initiation, root apical dominance and root gravitropism. *Ann. Bot.* 2006;97:883–893. doi: 10.1093/aob/mcl027.

[197]. Sabry S.R.S., Saleh S.A., Batchelor C.A. Endophytic establishment of *Azorhizobium caulinodans* in wheat. *Proc. Biol. Sci.* 1997;264:341–346. doi: 10.1098/rspb.1997.0049.

[198]. De Felipe M.R. Fijación biológica de dinitrógeno atmosférico en vida libre. In: Bedmar E., Gonzálo J., Lluch C., et al., editors. *Fijación de Nitrógeno: Fundamentos y Aplicaciones. Granada: Sociedad Española de Microbiología.* Sociedad Española de Fijación de Nitrógeno; Granada, Spain: 2006. pp. 9–16.

[199]. Tejera N., Lluch C., Martínez-Toledo M.V. Isolation and characterization of Azotobacter and *Azospirillum* strains from the sugarcane rhizosphere. *Plant Soil.* 2005;270:223–232. doi: 10.1007/s11104-004-1522-7.

[200]. Sahoo R.K., Ansari M.W., Pradhan M. Phenotypic and molecular characterization of native *Azospirillum* strains from rice fields to improve crop productivity. *Protoplasma.* 2014;251:943–953. doi: 10.1007/s00709-013-0607-7.

[201]. Berg R.H., Tyler M.E., Novick N.J. Biology of *Azospirillum*-sugarcane association: Enhancement of nitrogenase activity. *Appl. Environ. Microbiol.* 1980;39:642–649

[202]. Wani S.A., Chand S., Ali T. Potential Use of Azotobacter Chroococcum in Crop Production: An Overview. *Curr. Agric. Res. J.* 2013;1:35–38. doi: 10.12944/CARJ.1.1.04.

[203]. Ahmed A., Hasnain S. Auxin producing *Bacillus* sp.: Auxin quantification and effect on the growth Solanum tuberosum. *Pure Appl. Chem.* 2010;82:313–319. doi: 10.1351/PAC-CON-09-02-06.

[204]. Sokolova M.G., Akimova G.P., Vaishlia O.B. Effect of phytohormones synthesized by rhizosphere bacteria on plants. *Prikl Biokhim Mikrobiol.* 2011;47:302–307. doi: 10.1134/S0003683811030148.

[205]. 37. Joo G.J., Kim Y.M., Kim J.T. Gibberellins-producing rhizobacteria increase endogenous gibberellins content and promote growth of red peppers. *J. Microbiol.* 2005;43:510–515.

[206]. 38. Han H.S., Lee K.D. Phosphate and Potassium Solubilizing Bacteria Effect on Mineral Uptake, Soil Availability and Growth of Eggplant. *Res. J. Agric. Biol. Sci.* 2005;1:176–180.

[207]. 39. Han H.S., Supanjani S., Lee K.D. Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. *Plant Soil Environ.* 2006;52:130–136.

[208]. 40. Egamberdiyeva D. The effect of plant growth promoting bacteria on growth and nutrient uptake of maize in two different soils.*Appl. Soil Ecol.* 2007;36:184–189. doi: 10.1016/j.apsoil.2007.02.005.

[209]. 41. El-Akhal M.R., Rincon A., Coba de la Peña T., Lucas M.M., El Mourabit N., Barrijal S., Pueyo J.J. Effects of salt stress and rhizobial inoculation on growth and nitrogen fixation of three peanut cultivars. *Plant Biol.* 2013;15:415–421. doi: 10.1111/j.1438-8677.2012.00634.x.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[210]. Silo-Suh L.A., Lethbridge B.J., Raffel S.J. Biological activities of two fungistatic antibiotics produced by *Bacillus cereus* UW85. *Appl. Environ. Microbiol.* 1994;60:2023–2030.

[211]. Beneduzi A., Ambrosini A., Passaglia L.M. Plant growth-promoting rhizobacteria (PGPR): Their potential as antagonists and biocontrol agents. *Genet. Mol. Biol.* 2012;35:1044–1051. doi: 10.1590/S1415-47572012000600020.

[212]. Dobereiner J. Nitrogen-fixing bacteria of the genus *Beijerinckia* Derx in the rhizosphere of sugar cane. *Plant Soil.* 1961;15:211–216. doi: 10.1007/BF01400455.

[213]. Govindarajan M., Balandreau J., Kwon S.W. Effects of the inoculation of Burkholderia vietnamensis and related endophytic diazotrophic bacteria on grain yield of rice. *Microb. Ecol.* 2007;55:21–37. doi: 10.1007/s00248-007-9247-9.

[214]. Kao C.M., Chen S.C., Chen Y.S. Detection of Burkholderia pseudomallei in rice fields with PCR-based technique. *Folia Microbiol.* 2003;48:521–524. doi: 10.1007/BF02931334.

[215]. Radzki W., Gutierrez Manero F.J., Algar E. Bacterial siderophores efficiently provide iron to iron-starved tomato plants in hydroponics culture. *Antonie Van Leeuwenhoek.* 2013;104:321–330. doi: 10.1007/s10482-013-9954-9

[216]. Simonet P., Normand P., Moiroud A. Identification of Frankia strains in nodules by hybridization of polymerase chain reaction products with strain-specific oligonucleotide probes. *Arch. Microb.* 1990;153:235–240. doi: 10.1007/BF00249074.

[217]. Muñoz-Rojas J., Caballero-Mellado J. Population dynamics of Gluconacetobacter diazotrophicus in sugarcane cultivars and its effect on plant growth. *Microb. Ecol.* 2003;46:454–464. doi: 10.1007/s00248-003-0110-3.

[218]. Elbeltagy A., Nishioka K., Sato T. Endophytic colonization and in planta nitrogen fixation by a *Herbaspirillum* sp. isolated from wild rice species. *Appl. Environ. Microbiol.* 2001;67:5285–5293. doi: 10.1128/AEM.67.11.5285-5293.2001.

[219]. Bent E., Tuzun S., Chanway C.P. Alterations in plant growth and in root hormone levels of lodgepole pines inoculated with rhizobacteria. *Can. J. Microbiol.* 2001;47:793–800. doi: 10.1139/w01-080.

[220]. Sangeeth K.P., Bhai R.S., Srinivasan V. Paenibacillus glucanolyticus, a promising potassium solubilizing bacterium isolated from black pepper (*Piper nigrum* L.) rhizosphere. *J. Spices Aromat. Crops.* 2012;21:118–124

[221]. Flores-Felix J.D., Silva L.R., Rivera L.P. Plants probiotics as a tool to produce highly functional fruits: The case of Phyllobacterium and vitamin C in strawberries. *PLoS ONE.* 2015;10:e0122281. doi: 10.1371/journal.pone.0122281.

[222]. Arora N.K., Khare E., Oh J.H. Diverse mechanisms adopted by *Pseudomonas* fluorescent PGC2 during the inhibition of Rhizoctonia solani and Phytophthora capsici. *World J. Microbiol. Biotechnol.* 2008;24:581–585. doi: 10.1007/s11274-007-9505-5.

[223]. Ahmad M., Zahir Z.A., Khalid M. Efficacy of *Rhizobium* and *Pseudomonas* strains to improve physiology, ionic balance and quality of mung bean under salt-affected conditions on farmer's fields. *Plant Physiol. Biochem.* 2013;63:170–176. doi: 10.1016/j.plaphy.2012.11.024.

[224]. Shaharoona B., Naveed M., Arshad M. Fertilizer-dependent efficiency of *Pseudomonas* for improving growth, yield, and nutrient use efficiency of wheat (*Triticum aestivum* L.) *Appl. Microbiol. Biotechnol.* 2008;79:147–155. doi: 10.1007/s00253-008-1419-0.

[225]. Yao L., Wu Z., Zheng Y. Growth promotion and protection against salt stress by *Pseudomonas putida* Rs-198 on cotton. *Eur. J. Soil Biol.* 2010;46:49–54. doi: 10.1016/j.ejsobi.2009.11.002. 58. Mazzola M., Fujimoto D.K., Thomashow L.S. Variation in Sensitivity of Gaeumannomyces graminis to Antibiotics Produced by Fluorescent *Pseudomonas* spp. and Effect on Biological Control of Take-All of Wheat. *Appl. Environ. Microbiol.* 1995;61:2554–2559.

[226]. Kumar H., Bajpai V.K., Dubey R.C. Wilt disease management and enhancement of growth and yield of *Cajanus cajan* (L) var. Manak by bacterial combinations amended with chemical fertilizer. *Crop Protect.* 2010;29:591–598. doi: 10.1016/j.cropro.2010.01.002.

[227]. Young J.P.W., Haukka K.E. Diversity and phylogeny of rhizobia. *New Phytol.* 1996;133:87–94.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 2, June 2024

[228]. Thamer S., Schädler M., Bonte D. Dual benefit from a belowground symbiosis: Nitrogen fixing rhizobia promote growth and defense against a specialist herbivore in a cyanogenic plant. *Plant Soil.* 2011;341:209–219. doi: 10.1007/s11104-010-0635-4.

[229]. Yanni Y., Rizk R., Abd-El Fattah F. The beneficial plant growth-promoting association of *Rhizobium leguminosarum* bv. trifolii with rice roots. *Aust. J. Plant Physiol.* 2001;28:845–870.

[230]. Garcia-Fraile P., Carro L., Robledo M. Rhizobium promotes non-legumes growth and quality in several production steps: Towards a biofertilization of edible raw vegetables healthy for humans. *PLoS ONE.* 2012;7:e38122. doi: 10.1371/journal.pone.0038122.

[231]. Flores-Felix J.D., Menendez E., Rivera L.P. Use of *Rhizobium leguminosarum* as a otential biofertilizer for Lactuca sativa and Daucus carota crops. *J. Plant Nutr. Soil Sci.* 2013;176:876–882. doi: 10.1002/jpln.201300116.

[232]. Khan A.L., Waqas M., Kang S.M. Bacterial endophyte Sphingomonas sp. LK11 produces gibberellins and IAA and promotes tomato plant growth. *J. Microbiol.* 2014;52:689–695. doi: 10.1007/s12275-014-4002-7.

[233]. Verma V.C., Singh S.K., Prakash S. Bio-control and plant growth promotion potential of siderophore producing endophytic *Streptomyces* from *Azadirachta indica* A. Juss. *J. Basic Microb.* 2011;51:550–556. doi: 10.1002/jobm.201000155.