Review on Mechanisms and Applications of Plant Growth-Promoting Bacteria

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ABSTRACT: The sad result of global growth in both environmental degradation and human population pressure is that global food production may soon be inadequate to feed the whole world's population. As a result, substantial increases in agricultural production are required during the next several decades. As a result, agricultural practices are shifting toward a more ecologically friendly and sustainable approach. It encompasses both the growing usage of transgenic plants and plant growth-promoting microorganisms in conventional agriculture. A variety of methods used by plant growth-promoting microorganisms are addressed and examined in this paper. Plant growth-promoting bacteria (PGPB) are expected to replace the usage of pesticides in agriculture, horticulture, silviculture, and environmental cleaning techniques in the not-too-distant future. While there may not be a single straightforward approach that may successfully stimulate plant development in all circumstances, several of the tactics described so far have shown tremendous promise.

KEYWORDS: Agriculture, Bacteria, Fertilizers, Fungi, PGPB.

1. INTRODUCTION

The world's population is presently estimated to be about 7 billion people, with this number projected to rise to roughly 8 billion by 2020. When one considers both the expected global population increase and the increasing environmental damage caused by ever higher levels of industrialization, it is clear that feeding all of the world's people will be a significant challenge in the next ten to twenty years, a problem that will only get worse. There is no time to waste; in order to feed the world's increasing population, agriculture production must be significantly increased, and in a sustainable and ecologically acceptable way. To feed an expanding world, many current agricultural practices, such as the usage of chemical fertilizers, herbicides, fungicides, and insecticides, must be re-examined. Instead, transgenic plants and plant growth promoting bacteria, or PGPB, will likely play a larger role in sustainable agriculture.

It is estimated that “environmental degradation, coupled with the growth in world population, are (considered to be) major causes behind the rapid (global) increase in human disease” and that “environmental degradation, coupled with the growth in world population, are (considered to be) major causes behind the rapid (global) increase in human disease.” That is, the earth's atmospheric, terrestrial, and aquatic systems are no longer adequate to absorb and break down the growing quantity of garbage that humans generate as a result of both expanding population and industrialisation. As a consequence, a variety of hazardous metals and organic chemicals are becoming more prevalent in the environment. Recognizing the problem's nature and scope is a critical first step. Even if all environmental pollution were to stop tomorrow, it would still be necessary to repair all polluted lands and waterways. Phytoremediation, or the intentional use of plants to take up and concentrate or degrade a broad variety of environmental contaminants, is one method to solve this issue. Furthermore, adding PGPB to plants used in phytoremediation methods usually improves the efficacy of the whole remediation process [1], [2].

2. PLANT GROWTH-PROMOTING BACTERIA (PGPB)

Bacteria, fungus, actinomycetes, protozoa, and algae are among the tiny life forms found in soil. Bacteria are by far the most prevalent of these microorganisms (about 95%). For a long time, scientists have known that soil contains a high number of bacteria (usually about 108 to 109 cells per gram of soil) and that the amount of culturable bacterial cells in soil is only around 1% of the total number of cells present. The amount of culturable bacteria in environmentally challenged soils, on the other hand, may be as low as 104 cells per gram of soil. The quantity and kind of bacteria present in various soils are affected by soil factors such as temperature, moisture, salt, and other chemicals, as well as the number and species of plants found in particular soils. Furthermore, bacteria are not uniformly dispersed in soil. That is, the concentration of bacteria found around plant roots (i.e., in the rhizosphere) is usually considerably higher than in the rest of the soil. This is due to the availability of nutrients from plant root exudates such as sugars, amino acids, organic acids, and other tiny molecules, which may account for up to a third of the carbon fixed by a plant.

Bacteria may impact plants in one of three ways, regardless of the quantity of bacteria in a soil sample. The relationship between soil bacteria and plants may be helpful, detrimental, or neutral from the plant's viewpoint. However, depending on the circumstances, the impact of a specific bacteria on a plant may vary. When large quantities of chemical fertilizer are applied to the soil, a bacterium that promotes plant development by supplying either fixed nitrogen or phosphorus, chemicals that are frequently present in very limited levels in many soils, is unlikely to offer much advantage to plants. Furthermore, a single bacteria may have a variety of effects on various plants. For example, in blackcurrant cuttings, an IAA overproducing mutant of the bacteria Pseudomonas fluorescents BSP53a promoted root growth while inhibited root development in cherry cuttings. This finding may be taken as suggesting that the blackcurrant cuttings had a low amount of IAA that was boosted by the bacterium's presence. The IAA level in the cherry cuttings, on the other hand, was optimum before the bacteria was added, and the extra IAA supplied by the bacterium turned inhibitory. Despite these limitations, determining whether a bacteria supports or hinders plant development is generally a simple process. Free-living bacteria, those that establish specialized symbiotic relationships with plants (e.g., Rhizobia spp. and Frankia spp.), bacterial endophytes that may colonize some or all of a plant's inner tissues, and cyanobacteria are among the bacteria that can promote plant growth, or PGPB (formerly called blue-green algae). Despite their variations, these bacteria all use the same methods to survive. PGPB may enhance plant growth either directly by enabling resource acquisition or indirectly by reducing the inhibitory effects of different pathogenic agents on plant growth and development, i.e. by functioning as a biocontrol bacterium. Before considerable attention was exhibited in attempting to understand or use other PGPB to promote plant development, Rhizobia spp. were intensively researched from physiological, biochemical, and molecular biology viewpoints. As a result, these early investigations served as a conceptual foundation for PGPB mechanistic research. However, since most PGPB fix little or a small amount of nitrogen, unlike Rhizobia spp., research to better understand some of the processes employed by PGPB have focused on a variety of mechanisms [3]–[7].

2.1. Commercialization:

Despite the fact that there is currently a lack of knowledge of PGPB-plant interactions, a number of these bacteria are utilized commercially as agricultural supplements. Agrobacterium radiobacter, Azospirillum brasilense, Azospirillum lipoferum, Azotobacter chroococcum, Bacillus fimus, Bacillus licheniformis, Bacillus megaterium, Bacillus mucilaginous, Bacillus pumilus, Bacillus pumilus, Bacillus spp., Bacillus subtilis, Bacillus subtilis var. amyl Pseudomonas aureofaciens, Pseudomonas chlororaphis, Pseudomonas fluorescens, Pseudomonas syringae, Serratia entomophilia, Streptomyces griseoviridis, Streptomyces spp., Streptomyces lydicus, and a variety of Rhizobia spp. However, PGPB-inoculated crops account for a tiny percentage of contemporary agricultural practice throughout the globe.

1. A number of problems must be solved before PGPB strains may be widely commercialized. These include the following:
2. Identification of the most essential characteristics for effective functioning and subsequent selection of PGPB strains with the necessary biological activity;
3. Consistency among regulatory authorities in various countries in terms of which strains may be released into the environment and under what circumstances genetically modified strains are acceptable for usage in the environment;
4. A better knowledge of the benefits and drawbacks of employing rhizospheric bacteria rather than endophytic bacteria;
5. Selection of PGPB strains that perform well under particular environmental circumstances (e.g., organisms that thrive in warm, sandy soils vs organisms that thrive in cold, moist settings);
6. Improved methods for applying PGPB to plants in different environments (e.g., in the field vs in the greenhouse);
7. A deeper knowledge of PGPB's possible interactions with mycorrhizae and other soil fungi.

3. DIRECT MECHANISMS

3.1. Making Resource Acquisition Easier

Providing plants with resources/nutrients that they need, such as fixed nitrogen, iron, and phosphorus, is one of the well-studied methods of bacterial plant growth promotion. Many agricultural soils are deficient in one or more of these chemicals, resulting in poor plant development. Farmers have grown more reliant on artificial supplies of nitrogen and phosphorus to avoid this issue and increase plant yields. Chemical fertilizer manufacturing is not only expensive, but it also depletes nonrenewable resources, such as the oil and natural gas needed to make them, and presents health and environmental risks. It would clearly be beneficial if effective biological methods of supplying nitrogen and phosphorus to plants could be utilized to replace at least some of the artificial nitrogen and phosphorus now used [8].

3.1.1. Fixation of nitrogen:

A variety of free-living bacteria, such as Azospirillum spp., may fix nitrogen and supply it to plants in addition to Rhizobia spp. Free-living bacteria, on the other hand, are thought to supply just a tiny portion of the fixed nitrogen that the bacterially-associated host plant needs. Structural genes, genes involved in Fe protein activation, iron molybdenum cofactor biosynthesis, electron donation, and regulatory genes needed for the production and activity of nitrogenase (nif) are among the genes required for nitrogen fixation. Nif genes are usually found in a cluster of approximately 20–24 kb in diazotrophic (nitrogen-fixing) bacteria, with seven operons encoding 20 distinct proteins. Genetic methods to enhance nitrogen fixation have proven difficult due to the system's complexity. Once the nif genes were identified and described, some scientists thought it might be feasible to genetically engineer advances in nitrogen fixation. A few people have suggested that genetically engineering plants to fix their own nitrogen may be feasible. These views now seem to be a little naive.

Because nitrogen fixation requires a significant quantity of ATP, it would be preferable if bacterial carbon resources were directed toward oxidative phosphorylation, which results in ATP synthesis, rather than glycogen synthesis, which results in energy storage in the form of glycogen. In one experiment, a Rhizobium tropici strain was created with a deletion in the glycogen synthase gene. In compared to the wild-type strain, treatment of bean plants with this modified bacterium resulted in a substantial increase in both the number of nodules that developed and the plant dry weight. This is one of the rare instances of scientists genetically altering a bacterium's nitrogen fixation machinery to achieve higher amounts of fixed nitrogen. Unfortunately, although this mutant enhanced the number of nodules and plant biomass in the field, it did not fare well in the soil [9].

3.1.2. Solubilization of Phosphate:

Despite the fact that phosphorus levels in soil are typically high (between 400 and 1,200 mg kg^{-1}), the majority of this phosphorus is insoluble and therefore unable to promote plant development. Insoluble phosphorus may be found as an inorganic mineral like apatite or as an organic form like inositol phosphate (soil phytate), phosphomonesters, and phosphotriesters. Furthermore, most of the soluble inorganic phosphorus used as a chemical fertilizer gets immobilized shortly after application, rendering it inaccessible to plants and therefore wasting it.

Due to the low bioavailability of phosphorus from the soil and the fact that this element is required for plant development, insufficient phosphorus is often a limiting factor in plant growth. Phosphate solubilization and mineralization by phosphate-solubilizing bacteria is therefore an essential feature in PGPB and plant growth-promoting fungi like mychorrizae.

Inorganic phosphorus is often solubilized as a result of the action of low molecular weight organic acids like gluconic and citric acid, which are both produced by different soil bacteria. The mineralization of organic phosphorus, on the other hand, happens via the production of a range of phosphatases that catalyze the hydrolysis of phosphoric esters. Phosphate solubilization and mineralization may coexist in the same bacterial strain, which is significant.

Unfortunately, the commercial use of phosphate-solubilizing PGPB has been restricted due to mixed findings. In fact, when phosphate-solubilizing bacteria are coinoculated with bacteria that have other physiological capacities, such as N fixation, or with mycorrhizal or nonmycorrhizal fungi, the most consistent beneficial effects are observed [10].

3.2. Phytohormone Levels Modulation:

Plant hormones play an important part in plant growth and development, as well as plant reaction to their surroundings. Furthermore, a plant is often exposed to a variety of nonlethal stressors during its lifespan, which may restrict its development until the stress is removed or the plant is able to alter its metabolism to counteract the stress's effects. When plants are confronted with growth-limiting environmental circumstances, they often try to alter the levels of their endogenous phytohormones to mitigate the detrimental impacts of the stressors. While this approach may be effective in certain cases, rhizosphere microbes can also generate or regulate phytohormones in vitro, allowing numerous PGPB to change phytohormone levels and therefore influence the plant's hormonal balance and stress response.

3.2.1. Gibberellins and Cytokinins:

Several investigations have shown that various soil bacteria, including PGPB, may generate either cytokinins or gibberellins, or both. Some species of Azotobacter spp., Rhizobium spp., Pantoea agglomerans, Rhodospirillum rubrum, Pseudomonas fluorescens, Bacillus subtilis, and Paenibacillus polymyxa, for example, have been shown to produce cytokinins in their cell-free media. Furthermore, certain cytokinin- or gibberellin-producing PGPB has been shown to promote plant growth. However, there is presently no comprehensive knowledge of the function of bacterially produced hormones and how bacterial synthesis of these plant hormones is controlled. Much of our understanding of the function of bacterially generated cytokinins and gibberellins is based on plant physiological investigations after exogenous administration of pure hormones to developing plants. Finally, certain phytopathogen strains have the ability to produce cytokinins. However, PGPB seems to generate lower amounts of cytokinin than phytopathogens, suggesting that PGPB has a stimulatory impact on plant development whereas pathogen cytokinins have an inhibiting effect.

3.2.2 Indoleacetic Acid:

Although many naturally occurring auxins have been reported in the literature, indole-3-acetic acid (indoleacetic acid, IAA) is by far the most prevalent and researched auxin, with auxin and IAA being used interchangeably in most of the scientific literature. IAA affects plant cell division, extension, and differentiation; stimulates seed and tuber germination; increases the rate of xylem and root development; controls vegetative growth processes; initiates lateral and adventitious root formation; mediates responses to light, gravity, and fluorescence; affects photosynthesis, pigment formation, biosynthesis of various metabolites, and stomatal resistance.

4. DISCUSSION

A significant part of a plant's growth and development may be conceived of as occurring in a more or less linear manner over time under ideal conditions. In the field, however, a variety of biotic and abiotic stressors may stifle plant development. Extremes of temperature, high light, floods, drought, the presence of toxic metals and organic pollutants in the environment, radiation, wounding, insect predation, nematodes, excessive salt, and different diseases such as viruses, bacteria, and fungus are all examples of these stressors. As a result of these many environmental stressors, plant development is always lower than it would be if they were not there. A plant may also be exposed to a variety of nonlethal stressors throughout its life that restrict its development until the stress is removed or the plant is able to alter its metabolism to overcome the stress. Plant growth usually consists of times of maximum growth interspersed with periods of different degrees of growth inhibition in practice. In order to overcome this growth inhibition, PGPB may use one or more of many distinct mechanistic methods when given to plants.

5. CONCLUSION

The use of PGPB as an essential part of agricultural practice is a technology that has reached its peak. These microorganisms are already being utilized effectively in a number of poor nations, and the trend is likely to continue. The usage of PGPB occupies a small but increasing niche in the development of organic agriculture in the more industrialized countries, since agricultural chemicals remain relatively cheap. Furthermore, a rise in the utilization of PGPB in different phytoremediation methods is likely. However, if PGPB becomes more widely used, a number of problems will need to be solved. In the first instance, transitioning from laboratory and greenhouse studies to field trials and large-scale commercial field usage would need a variety of novel methods to bacteria growth, storage, shipping, formulation, and application. Second, the public will need to be educated about the widespread usage of PGPB in agriculture. Much popular mythology promotes thinking of microorganisms only as disease-causing agents. Before the public accepts the intentional release of helpful bacteria into the environment on a broad scale, this misunderstanding must be dispelled. Third, while the initial PGPB strains are likely to be non-transformed bacterial strains that have been selected for certain positive traits, scientists will likely genetically engineer more efficacious strains in the future as they gain a better understanding of the mechanisms at work in bacterial plant growth stimulation. Scientists will have to demonstrate to the public and regulatory authorities across the globe that genetically modified PGPB pose no additional dangers or concerns. Fourth, scientists must decide whether future research should focus on creating rhizospheric or endophytic PGPB, and fifth, scientists must better understand and then maximize the interaction between PGPB and mychorrhizae.

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