Review paper
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THE IMPORTANCE OF PLANT GROWTH PROMOTING RHIZOBACTERIA (PGPR) IN HEALTH AND PRODUCTIVITY OF AGRO-ECOSYSTEMS

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Abstract

Excessive application of chemical fertilizers lead to several environmental hazards, causing damages to human, animal and ecosystem health. Their chemical remnants in both aqueous and non-aqueous (soil ecosystems) environments could potentially interrupt natural ecosystem balance which consequently results in several critical health issues and numerous side-effects to agricultural productivity in agro-ecosystems. Such environmental, agricultural and health crises call us for serious attention toward the production and application of environmentally friendly bio-fertilizers. Plant growth promoting rhizobacteria lodging around or in the plant roots have several functional activities such as increasing the nutrient availability to plants (biofertilizers), promoting plant growth via phytohormones as plant growth regulators (phytostimulators), degrading organic pollutants like xenobiotic compounds (rhizoremediators), controlling plant diseases and protecting them from phytopathogens (biopesticides), improving soil structure and fertility(bioremidiators). In close future, they are expected to substitute by chemical fertilizers, artificial growth – dependent regulators and pesticides.

Keywords: *Plant Growth Promoting Rhizobacteria, bio-fertilizer, stable agriculture, yield*

Introduction

Believing in a reality known as “Population Growth” requires mankind to produce more agricultural products and to inevitably move towards increased production per unit area. This won’t be achieved but through the production of more fertilizers. Since fertilizer management is considered as one of the main factors of sustainable agriculture, gradual replacement of chemical fertilizers, especially phosphorus and nitrogenous ones with biological fertilizers is quite inevitable due to their advantages and cost-effectiveness. The history of plant inoculation with useful bacteria goes back to many centuries ago. For instance, by experience, farmers knew that if the soil in which legumes were planted was mixed with the soil for non-legume crops, it resulted in an increased crop yield. In late 19th century, the first license for producing a biological fertilizer known as Nitragin was issued for the production of rhizobium inoculants and after that, inoculation of legumes started to be practiced in many countries using rhizobium fertilizers (Bagnasco et al., 1998). Rhizobiums are among the most useful rhizobacteria, whose global usage as a nitrogenous bio-fertilizer (Bio-N fertilizer) in planting legumes and forage legume crops has always been a common practice (Kirchner et al., 1993). Though it’s been a century that rhizobiums’ useful role in stabilizing molecular nitrogen has been known, unfortunately, this significant group of rhizobacteria has not been practically used except in legumes. Of the beneficial activities of these bacteria which have led to putting them in the plant growth promoting rhizobacteria group (PGPR), production of plant growth promoting hormones, specifically Auxins, the ability to solve organic and mineral phosphates, producing Ionophores, especially Siderophores, their positive effects on root growth and morphology, improving symbiotic relationship with host legume crops and the induction of mycorrhizal symbiosis can be mentioned (Rodriguez and Fraga, 1999). As a whole, rhizobacteria are blessings that up until now, except for their useful and productive relationships with plants, no reports on any disease or microbial contamination caused by them either in human beings or other creatures have been submitted.

Plant Growth-Promoting Rhizobacteria

Rhizosphere is a narrow zone where the interaction between soil, plants and microorganisms occurs. Different bacterial genera that are widely involved in many biological activities such as sustainability of soil ecosystems and nutrient turn over are called Rhizobacteria (Ahemad and Kibret, 2014). Those types of them which positively affect crop growth and yield are called plant growth-promoting rhizobacteria (PGPR). The term was first introduced by Klopper and Schroth in 1978 and for the years that followed, it was only used to refer to some specific rhizosphere bacterial genera that indirectly provided conditions required for plant growth through controlling phytopathogenic factors and helping to maintain plant health (Ahemad and Kibret, 2014). In other words, PGPRs as bio-control agents improve the plant growth and development directly by either regulating plant hormones or acquisition of essential elements or indirectly via reducing the destructive effects of growth-inhibiting pathogens (Ahemad and Kibret, 2014). Today, direct effective mechanisms of PGPR such as phytohormones, ionophores, increased phosphorus availability for the plant through enzymatic and non-enzymatic dissolution of mineral and organic insoluble phosphates, expansion of plant root systems, enzymatic activities such as ACC-deaminase, production of rhizobiotoxine to reduce the adverse effects of stress-induced ethylene, enhancement of nodulation and ultimately, bio-fixation of molecular nitrogen have been proved (Klopper and Schroth, 1978). On the other hand, earlier PGPR studies were only conducted on root crops such as potato, radish and sugar beet. However, later studies included a wider range of crops such as cereals and leguminous plants as well (Ligero et al., 1986). Some of the well-known PGPR types include those belonging to *Azotobacter*, *Azospirillum*, *Bacillus*, *Pseudomonas*, *Arthrobacter* and *Enterobacter* genera. What is interesting about PGPR types is the new look at rhizobium bacteria (Ahemad and Kibret, 2014).

Beyond Rhizobium-legume Symbioses (Beyond N_2 Fixation)

Besides their cardinal role in the nitrogen balance of the biosphere, rhizobium bacteria can help increase plant growth and crop yield in some other ways as well.

The Ability to Dissolve Insoluble Mineral Phosphates

There are several reports that indicate the ability of different bacterial strains to bio-solubilize mineral insoluble phosphate compounds (Glick et al., 1998). The main mechanism of solubilizing mineral phosphate has been known to be the result of organic acids produced by soil bacteria. Producing these acids acidifies the area surrounding bacterial cells as a result of which, due to the replacement of H^+ with calcium ions in the soil, phosphor is released (Abd-Alla, 1993). Of organic acids, it seems that Gluconic acid is the most frequent factor in the dissolution of inorganic phosphates (Chabot et al., 1996). Abd-Alla (1993) showed that organic acids detached from the culture medium of *Rhizobium leguminosarum* biovar *phaseoli* cause the said phosphates to dissolve. Moreover, due to the effect of these acids on solutions lacking bacterial cells, the level of dissolved phosphates is almost similar to that of dissolved phosphates in media containing *Rhizobium leguminosarum* (Guerinot, 1991). Research results have indicated that the dissolution of mineral phosphates is not an enzymatic process.

The Ability to Dissolve Insoluble Organic Phosphates

Soil contains a broad spectrum of organic substances which can be used by the plant as a source of phosphorus. For the organic phosphorous to change into an absorbable form for a plant, it should be transformed into its mineral form through the hydrolysis of organic substances (Ligero et al., 1986). Mineralization of phosphorus organic compounds is often done by phosphatase enzymes being also called phosphoric diester hydrolase (or phosphomonoesterase) (Illmer and Schinner, 1995). The ability of rhizobacteria of different genera such as *rhizobium*, *pseudomonas* and *bacillus* has been proved by the production of significant amounts of phosphatases. Chabot et al. (1996) proved that rhizobium bacteria's ability to dissolve phosphate is a major plant growth-promoting mechanism in soils with medium to high fertility levels.

The Ability to Produce Siderophores

Siderophores are organic compounds with low molecular weights, whose ligands have a high-affinity for iron III (Fe^{3+}) binding (Goldstein, 1986). The role of bacteria responsible for the production of microbial siderophores can be indirectly played through the bio-control of phytopathogenic agents or the direct stimulation of plant growth by increasing Fe absorption (Klopper and Schroth, 1978). In the past few years, the ability to synthesize siderophores by several strains of different rhizobium bacteria species has been proved (Goldstein, 1986). The specific importance of siderophores among types of microbial metabolites released in rhizosphere could be to some extent due to the key role that Fe plays in vital metabolic processes in plants, on one hand and to specific features of Fe in the soil, on the other. The role of capable strains in the synthesis of siderophores for controlling phytopathogens has also been proved.

Synthesis of Phytohormones

Some PGPR strains can interfere with the concentration of identified phytohormones and increase plant growth and development (Dalal, 1977). These phytohormones affect the root growth pattern and lead to developing larger roots with more branching and a larger effective area (Rodriguez and Fraga, 1999). In some cases, it has been observed that even with sufficient amounts of nitrogenous fertilizers, plant inoculation with PGPR has caused plant growth and development to increase, which in that case, the presence of other mechanisms such as the synthesis of plant regulating substances (such as IAA) by PGPR has been a growth enhancing factor (Antoun and Kloepper, 2001). Many of the rhizobium species show ability to synthesize IAA and some studies have indicated that auxin plays a key role in the nodulation of legume crops and as a whole, in rhizobium-legume symbiosis. Also, it has been proved that flavonoids (as inducers of nodulation genes) intensify IAA synthesis through rhizobiums. Moreover, it has been shown that compared with roots that don't have nodes, nodular roots contain higher levels of IAA hormone and it plays a role in the development of the root system and its maintenance. Different studies approve that production of higher IAA levels in root nodules must have a rhizobial origin (Arshad and Frankenberger, 1991). Recently, synthesis of Cytokinins (CK) and Gibberellins (GAs) by PGPR has been proved as well (Rodriguez and Fraga, 1999; Ahemad and Kibret, 2014).

Reduced Synthesis of Ethylene in Plants

It's been more than a decade that the inhibitory effect of ethylene on nodule formation in legume crops has been known. Ligero et al. (1986) stated that high levels of ethylene produced in alfalfa (*Medicago sativa L.*) right after being inoculated by *Sinorhizobium meliloti* (a gram negative nitrogen-fixing bacterium or rhizobium) should be a sign of the defensive response of the legume crop to bacterial attack to its root cells. It seems that rhizobial infection in legumes just like other environmental stressors stimulates the plant to synthesize and accumulate additional ethylene known as stress-induced ethylene (Ahemad and Kibret,2014). Studies show that rhizobial bacteria can prevent ethylene concentration from increasing in legume and non-legume crops and cause the negative effects of this hormone on the growth and development of plant organs to decrease (Glick, 1995). This function is performed through at least two known ways: production of ACC-deaminase and rhizobitoxine biosynthesis.

Synthesis of ACC-deaminase

The ACC (1-aminocyclopropane-1-carboxylic acid) deaminase enzyme catalyzes the hydrolysis of the ACC substance and transforms it into ammonium and α-ketobutyric acid(Glick,1995). Since ACC is the precursor of ethylene synthesis in higher plants, its exclusion would reduce ethylene content in the plant (Yasuta et al., 1999). It is noteworthy that the enzyme has only been identified (so far) in soil-inhabiting microorganisms, and those rhizobial strains which contain it, have been able to successfully overcome ethylene’s negative effects on nodulation and elongation of roots in legume and non-legume plant species. To sum up, plant growth promoting rhizobacteria containing the ACC-deaminase enzyme, facilitate the plant growth and development thereby decreasing ethylene level, increasing salt tolerance, and reducing drought stress (Zahir et al., 2008).

Biosynthesis of Rhizobiotoxine

Chemically, rhizobiotoxine [L-2-amino-4-(2-amino-3-hydroxypropoxy)-trans-but-3-enoic acid] is a phytotoxin synthesized by some strains of the legume symbiont genus *Bradyrhizobium elkanii* and the plant pathogen, *Pseudomonas andropogonis*, which are capable of its biosynthesis. Rhizobiotoxine affects ACC-synthase and limits ACC biosynthesis, which will ultimately inhibit extra ethylene production (Vessey, 2003).

Cyanide Biosynthesis

The indirect function of PGPR is the bio-control of phytopathogenic agents. Among the inhibitory mechanisms of these bacteria, secondary metabolites such as hydrogen cyanide (HCN) can be mentioned. Synthesized HCN interrupts the respiratory system of pathogenic fungi and thus, inhibits their growth and activities (Badenoch-Jones et al., 1983). Recently, Antoun and Kloepper (2001) introduced some rhizobium strains as cyanide-producing bacteria. Bagnasco et al. (1998) believed that HCN-producing bacteria can be used as a safe way for the bio-control of rhizopathogens because they have no adverse effects on soil microbial communities or on plant growth. Kremer and Souissi (2001) suggested that the ability to produce HCN in PGPR is a potential and suitable mechanism for the biological control of weeds, which should be taken into more consideration as a new aspect of promoting and stimulating plant growth and increasing crop yield.

Conclusion

Today, fertilizers are vastly used as a means of increasing yield quantity, especially in the developing countries. Therefore, the quality of agricultural crops should be also taken into account so that besides preventing environmental pollution and the destruction of valuable soil and water resources, excessive accumulation of nutrients and other pollutants in plant tissues could be prevented as well. It goes without saying that using biological fertilizers instead of chemical fertilizers can ensure a healthy environment and the sustainability of production resources and by improving the quality of food products, it can have a remarkable effect on improving health in the society. If we add reduced production costs of biological fertilizers and their high efficiency to the advantages mentioned above, preferring to use them instead of chemical fertilizers is a right decision. As a whole, it could be said applying bio-fertilizers of the PGPR type with a positive effect on different growth and development aspects can accelerate plant growth and development through a synergistic effect on growth and development-improving factors and an antagonistic effect on growth and development-decreasing factors and would ultimately increase the crop yield.

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