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"Plant Growth Promoting Bacteria in Rhizomicrobial Environments"

Dr Ashok Kr. Singh

SRTC PG College Utraula Balrampur 271604 UP India

ABSTRACT

Microbes are associated with every plant tissue and in combination with the plant form the halobiont. Plants regulate the composition and activity of their associated bacterial community carefully. These microbes provide a wide range of services and benefits to the plant in return the plant provides the microbial community with reduced carbon and other metabolites. Soils are generally a moist environment rich in reduced carbon which supports extensive soil microbial communities. The rhizomicrobiome is of great importance to agriculture growing to the rich diversity of root exudates and plant cell debris that attract diverse and unique patterns of microbial colonization. Microbes play key roles in nutrient acquisition and assimilation improved soil texture secreting and modulating extracellular molecules such as hormones secondary metabolites antibiotics and various signal compounds leading to enhancement of plant growth. The microbes and compounds they secrete constitute valuable bio stimulants and play vital roles in modulating plant stress responses. The research has demonstrated that inoculating plants with plant-growth promoting rhizobacteria that can be an effective strategy to stimulate crop growth. These strategies can improve crop tolerance for the abiotic stresses such as drought heat and salinity likely to become more frequent as climate change conditions continue to develop. This discovery has resulted in multifunctional PGPB based formulations for commercial agriculture to minimize the use of synthetic fertilizers and agrochemicals. This review introduces the concept and role of the phytomicrobiome and the agricultural context underlying food security and mechanisms of plant growth promotion by PGPB including signal exchange between plant roots.

Key Words: phytomicrobiome, halobiont, rhizosphere, PGPB, sustainable agriculture, secondary metabolites, plant growth.

INTRODUCTION

A plant growing under field conditions is not an individual it is a complex community with suitable and relatively constant partner relationships. A well-structured and regulated community of microorganisms is always associated with the plant. This community is the phyto microbiome exist with all multicellular organisms and probably all eukaryotes. This microbial community has been associated with terrestrial plants since their earliest evolution to assist early land plants faced with challenges such as access to nutrients novel and often stressful conditions and pathogens. These microorganism including bacteria of the phyto microbiome associated will all major plant structures such as flowers, fruits, stems, leaves and roots. The microbial community associated with the roots the rhizomicrobiome is the most populous and elaborate of all those associated with higher plants (1). The genetically modified bacteria from natural and managed habitats will impact on managements of agriculture and environmental settings. The potential application of these bacteria includes crop production and protection. The safely deploy these bacteria should be able to provide significant benefits managements of crop production (14). Many members of the phytomicrobiome cannot be cultured and it has only been since the advent of metagenomics and related methods that we are able to assess how membership is changed by conditions plant genotype and plant development. The plant exerts considerable control over the composition of the rhizomicrobiome. It produces root exudates of various compositions which can be more suitable as a source of reduced carbon to some microbes than others. The plant also produces signal compounds that and regulate their genetic and biochemical activities (7). The soil microbial community undertakes various aspects of self-regulation. The microbes can produce quorum sensing compounds to communicate when conditions warrant a collective physiological shift. Plants have evolved to respond to microbial quorum sensing compounds and to produce analogues providing plants with another level of regulation over the rhizomicrobiome. Finally, it is now becoming apparent that there is some degree of hierarchy within the phyto microbiome whose activities are regulated by plants and hub species in turn regulate broader activities within the phyto microbiome.

Plants Community

The global food production was comprised of two main advances, chemical inputs as pesticides, herbicides, and chemical fertilizers and root improved crop plants through targeted breeding and advanced genetic manipulations. This new revolution in agricultural innovation will be needed to sustain the food, fibre, and fuel needs of a growing global population and a changing climate. The revolution could be based on biological inputs through utilization of the phyto microbiome with inoculants, microbially produced compounds and improved crops by manipulation of the phyto microbiome community structure. The use of microbial based agricultural inputs has beginning with broad-scale rhizobia inoculation of legumes (4). The use of bacterial taxa in plant production has been describes for *Bacillus* sp *Pseudomonas sp, Actinobacteria sp* and *Lactobacillus* sp (16). The other taxa *Acetobacter sp*, *Azospirillum sp, Paenibacillus sp, Serratia sp, Burkholderia sp, Herbaspirillum sp*, and *Rhodococcus sp* have also been shown to enhance crop production. The effects of climate change are expected to impose more environmental stresses on crops world-wide. Moreover, as climate change progresses significant areas of high-quality agricultural lands will likely be lost to rising seas, erosion, salinization and desertification. This means that crop yields will need to be maintained in spite of production on a smaller area of land under more stressful conditions. The phyto microbiome plays a critical role in the survival of the halobiont, particularly for plants growing in extreme environments. The plants that live in hypersaline coastal environments or geothermal soils rely on endophytic fungi to survive (11).

Microbial Activity

The soils with dynamic microbial ecologies and high organic matter typically have lower fertilizer requirements than conventionally managed soils. The bulk microbial activity in soils is often considered when managing the application of organic nutrient sources. Phyto microbiome reveal specific plant-microbe interactions that directly aid in plant nutrition (2). Microbes that assist in plant nutrient biofertilizers act through a variety of mechanisms including augmenting surface area accessed by plant roots, nitrogen fixation, phosphorous solubilization, siderophore, hydrogen, carbon and nitrogen production. The manipulating of microbial activity has great potential to provide crops with nutritional requirements. The most extensively studied and exploited beneficial plant bacteria relationship is the nitrogen fixing symbiosis between rhizobia and legumes. The legumes provide rhizobia with reduced carbon and a protected anaerobic environment required for nitrogenase activity while rhizobia provide the legumes with biologically available nitrogen. The legume forms a new organ the nodule to the house of rhizobia and the rhizobia in turn changes from its free-living rod-shaped cell type to a branched nitrogen fixing bacteroid (8). The rhizobia nitrogen fixation contributes significant amounts of nitrogen to global agricultural systems. Rhizobia inoculants of leguminous crops are the example of commercial microbial products in agriculture and still represent the most widely used agricultural inoculants. The genetic improvements in efficiency of the nitrogen fixing symbiosis of rhizobia and crop plants have been elusive. The fixation of atmospheric nitrogen and conversion to ammonia is an energy demanding process which means oxidative phosphorylation of carbon sources to generate ATP must be favoured over glycogen synthesis within the bacterial cell to increase nitrogen fixation. The interest began to mount around the development of commercial inoculants of free-living nitrogen fixing bacteria such as *Azoarcus sp, Burkholderia sp, Gluconacetobacter sp, Diazotrophicus sp, Herbaspirillum sp, Azotobacter sp, Bacillus sp* and *Azospirillum sp*. (17). These free-living diazotrophs provide nitrogen to a much wider range of crop plants than rhizobia. The commercial inoculants of *Azospirillum* sp have been effective in increasing the yield of various cereal crops and other bacteria that do not fix nitrogen have been shown to increase nitrogen uptake in plants, thus increasing nitrogen use efficiency likely due to increased root growth which allows plants to access more soil (2). The most agricultural soils contain ample quantities of phosphorous much of it is in non-soluble forms. To supplement indigenous soil phosphorous crops are typically fertilized with rock phosphate mined from one of a few large deposits. The phosphorus solubilizing microorganisms can help plants access the reservoir of non-labile phosphorus by releasing it from its recalcitrant forms. The inorganic phosphorous complexed with calcium, iron and aluminium can be solubilized by organic acids excreted by PSMs. Production of hydrogen, carbon and nitrogen by PGPB was originally thought to promote plant growth by suppressing pathogens who argued that hydrogen, carbon and nitrogen indirectly increases phosphorous availability by metal chelation and sequestration of these geochemical entities (9).

PlantHormones

Phytohormones are key players in regulating plant growth and development. They function as molecular signals in response to environmental factors that regulate plant growth. Many rhizosphere bacteria are excrete hormones for root uptake or manipulate hormone balance in the plants to boost growth and stress response, Many PGPB can produce auxins to exert particularly strong effects on root growth and architecture. Indole-3-acetic acid is the most widely auxin produced by PGPB. The PGPB that produce auxins have been shown to elicit transcriptional changes in hormone, defence-related, and cell wall related genes, induce longer roots, increase root biomass and decrease stomata size and density and activate auxin response genes that enhance plant growth (12). Many PGPB produce gibberellins which enhanced plant shoot growth. Production of cytokinin's by PGPB can also lead to enhanced root exudate production by the plant potentially increasing the presence of PGPB associated with the plant. Ethylene is a gaseous hormone, active at extremely low concentrations and is a stress hormone as illustrated by its concentration spiking during various abiotic and biotic stresses. Accumulation of ethylene in response to stress may increase plant tolerance or exacerbate stress-response symptoms and senescence (6). PGPB function has been studied under both stressed and unstressed conditions and often provides greater growth stimulation under stressful conditions for instance under drought stress. Ethylene plays an important role for improving plant stress tolerance for some PGPB secrete I-amino cyclopropane-l-carboxylase

(ACC) deaminase which reduces ethylene production in plants.

MicrobesSignals

A wide range of secondary metabolites and volatile organic compounds produced by bacteria can improve stress tolerance and stimulate growth in plants. The *Bacillus megaterium* secretes a polyamine and spermidine resulting in an increase in biomass, altered root architecture and elevated photosynthetic capacity. The inoculated plants exhibited higher drought tolerance and abscisic acid content under PEG induced water-deficit stress. A range of PGPB produce hydrogen, carbon and nitrogen which can control the level of deleterious microbes in the rhizosphere. The volatile organic compounds produced by PGPB stimulate plant growth, resulting in increased shoot biomass and improve plant stress resistance. The lumchrome and riboflavin can act as microbe-to-plant signal compounds able to stimulate plant growth. These compounds can cause meaningful alterations in plant development and accelerate appearance of leaves more rapid development and leaf expansion enhanced growth. It can increase plant height and overall leaf area resulting in improved production of biomass. Microbe-to-plant signal compounds lipochitin oligosaccharides and thuricine have been shown to increase plant growth for diverse species particularly when plants are growing under stressful conditions.

Root Signals

The seed is imbibing and germinating, then roots are growing and finally senescing, molecules are released from roots into the surrounding soil. These molecules support microbial growth and activity in the rhizosphere. The variation in root exudation timing, amount, and constituents provides a mechanism by which plants can manipulate composition and abundances of their root-associated microbiota. The exudates are consisting mainly of sugars, amino acids and organic acids that are present at high concentrations in the cytoplasm of the plant, but also include smaller amounts of complex secondary metabolites such as flavonoids, terpenes, and phenolic compounds that can attract specific microbes in the rhizosphere. The exudation of the signal molecules salicylic acid into the rhizosphere can be involved in the interplay between roots and microbes during the initial events of colonization (3).

Rhizosphere Biofilms

The plant rhizosphere is colonized by microorganisms from the soil and the seed. The determinants of soil microorganisms are based on properties such as carbon and nitrogen availability, organic matter content, water availability and pH as well as biogeographic patterns including soil type and seasonality (5)This is necessary to develop strategies for effective inoculation methods so that bacteria of interest gain advantage in colonization efficiency over others. Plant-associated biofilms have established on various parts of plants such as leaves, roots, seeds and internal vasculature. The ability to form biofilms not only enhances bacterial survival but also enhances plant growth through the various PGPB-associated mechanisms to a greater extent than their planktonic cell counterparts. The advantage of biofilms over planktonic cells is their higher resistance to antibiotics, leading to improved chance of survival in a competitive soil environment. This is an important consideration when applying microbial inoculants to soils where microbes face intense competition and adapted to challenging conditions as indigenous soil microbes. The biofilms produced from *Pseudomonas sp*, *Trichoderma sp*, *Bradyrhizobium sp* and *Penicillium sp* showed greater ammonia production, IAA production, phosphate solubilization, siderophore production and nitrogenase activity than the planktonic inoculate.

Beneficial Inoculate

The development of new PGPB inoculate mechanisms, namely nitrogen fixation, ACC deaminase activity, auxin synthesis and calcium phosphate solubilization is a specific achievement. The developing inoculates containing highly effective microbes with a long shelf-life and high rhizosphere colonization rate poses a major challenge for commercialization. PGPB are often used to inoculate plant material without an appropriate carrier or in quantities that do not allow for efficient rhizosphere colonization under field conditions, due to competition with resident soil micro- and macro-fauna (15). The soils growing high value crops are often fumigated with broad spectrum biocidal fumigants that alter the bio-community structure of the soil. Long-term fumigation affects soil microbes and their interactions that help plants with nutrient acquisition and mobilization, thereby affecting soil health. The bio-inoculants has been done to integrate microbiome-based plant breeding to achieve a heritable PGPB community that enhances crop productivity. The combination of bioremediation with plant growth promotion would be a beneficial approach in addressing this global agriculture problem. The designing microbial consortia to address various aspects of bioremediation and plant growth potential is an essential aspect to this approach. The synthesis of bio-inoculants for specific soil conditions, to overcome environmental constraints, and training farmers and associated staff to efficiently apply them to crop plants is very important element in the development and deployment of more beneficial inoculate. The beneficial rhizobacteria may secrete antibiotics and other compounds antagonistic to plant pathogens. This is achieved by extensive sampling of plants from a range of habitats agricultural, dry, wet, cold, hot and saline. The cultivable strains can be screened for ability to enhance germination of crop plants. The isolates can be screened for ability to accelerate emergence and early plant growth, under controlled environment conditions. Germination and early plant growth experimentation should be conducted under both optimal and stressful plant-growth conditions. The easiest stress to apply uniformly is salt stress; salt stress responses are generally representative of responses expected for other stresses (13). The most promising

PGPR can then be evaluated under the more complex and demanding conditions of the field to select the top-performing strains for commercialization.

Crop Productivity

The utilization of bacterial consortia has inconsistent effects on crop yield. The mixing of a bacterium *Bacillus amyloliquefaciens* with a fungus *Trichoderma virens* improves yields of corn, tomato and other crops. The combination of*Trichoderma sp* with *Bradyrhizobium sp* for improved growth of soybean while applications of arbuscular mycorrhizal fungi and *Trichoderma sp* for improved growth and treatment of pathogens present in the soil. The inoculation with nitrogen fixing bacteria *Azospirillum sp* and *Azobacter sp* allowed half-rate nitrogen fertilizer application and increased sesame seed yield and oil quality. A consortium of bacteria *Bacillus sp* and *Serrati* sp reduced the incidence of root knot nematode in tomato, increased fruit yield and quality. The biofuels are derived from non-food biomass often lignocellulosic material, to minimize competition with food production along with high value bioproducts, to reduce the atmospheric carbon dioxide emissions associated with fossil fuels (10). The growth and productivity of purpose grown biofuel crops can be improved through inoculation with PGPB as has been demonstrated for switchgrass. Marginal and contaminated lands can be used to grow biofuel crops in order to avoid conflicts around food versus energy crops. The use of PGPB that contain natural potential to cope with soil contaminants, the biofuel crops could be used efficiently for phytoremediation and also to reduce high levels of agrochemicals residues in agriculture lands.

CONCLUSION

The relationships between plants and the phyto microbes are ancient and represent the result of a very long coevolution. The members of the phyto microbiome offer huge potential in terms of new and more sustainable crop management practices however it is also clear that we understand only a tiny amount of this potential and a very great deal remains to be done. These could be focused on stimulation of plant growth, particularly under adverse conditions, such heat and drought stress, which are becoming increasingly prevalent as climate change progresses. We have examined the steps necessary to develop these technologies into products and have them approved for sale through the regulatory process. The public concern around the use of chemicals and biologicals are seen as a positive alternative in the form of plant probiotics. It is our duty to try to anticipate any problems with phyto microbiome technologies and to forestall their development, while projecting the benefits to the public. The phyto microbiome offers enormous potential for agricultural benefit in terms of global food security, crop production sustainability and making agricultural systems climate change resilient. We need to ensure that this is approached in a systematic, thorough and broadly considered manner.

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