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A Multi-Trait Mechanisms of PGPR in Plant Disease Management

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Abstract

In today, science has developed in all the sectors around global wide, but the starvation, nutrient deficiencies, new emerging diseases and mortality were increased due to population growth rate, land degradation, soil nutrient loss and insufficient level of food sources and highest demand. Under these situations, global level scientific visions and approaches were highly focused on the usage of microorganisms in the agriculture and related sectors as a green way or "organic agriculture". This approach was applied in the strategies such as biocontrol, biofertilizers and biopesticides (PGPR and fungi). These microorganisms were used on the basis of biological and metabolic pathways. Using beneficial microbes (PGPR) is a tremendous nature oriented because it needs highly knowledgeable about microorganisms. When we assumed it, all living organisms and nature become the safest one achieved with harmless-green way of food security on the earth.

Introduction

In rhizosphere, some free-living bacterial species were presented in the root region around crop root portion and colonized around it (rhizoplane) or root itself (within radicular tissues). This bacterial community was called as "plant growth promoting rhizobacteria" (PGPR). Naturally, 1 to 2% of bacteria promote plant growth in rhizosphere with highly diversified population nature (*Pseudomonas* spp., fluorescent *Pseudomonads*, *Bacillus* spp., *Rhizobium* spp., *Azospirillum*, *Azotobacter*, *Klebsiella* (rhizobacteria), *Streptomyces* spp., *Nocardia* spp., *Microbispora, Amycolaptosis, Actinomadura* and *Saccharothrix* (actinomycetes) pigmented *Saccharomyces* spp., *Cystobasidium, Rhodotorula, Rhodosporidiobolus, Sporobolomyces* and *Vishniacozyma* spp., non-pigmented *Bannozyma, Colacogloea, Curvibasidium, Serretia* spp., *Hamamotoa* and *Oberwinklerozyma* (yeasts) from 10^8 to 10^9 cfu/gram of soil. They have different by their biological mechanisms, bioactive compounds, survival nature and type of approaches during applications. Their multi-trait mechanisms were highly specialized and fruitful to plant disease management (Reis *et al.*, 2020). These mechanisms are discussed under below.

Nitrogen Fixation

Nitrogen is a base component for all living organisms in the form of proteins and amino acids. So, all essential biological activities based on N_2 in the earth. In soil, free living bacterial species (diazotropic) are able to fix the nitrogen and provide to plants for its growth. This process called as "biological nitrogen fixation (BNF)". Its two types like, symbiotic and asymbiotic. In symbiotic, several species of *Rhizobium* and *Azospirillum* (Cereals) were made the beneficial relationship between plant roots and provide

nodules during N_2 fixation (*Rhizobium* vs. legumes). Some other asymbiotic species were act as nitrogen fixers without any relationship (*e.g*., *Cyanobacteria, Anabaena*, *Nostoc*, *Azotobacter*, *Beijernckia* and *Clostridium*). This bacterial species had specialized nitrogenase (*nif*) genes for fixation and further fixed the N_2 in soil (El-sayed *et al*., 2020).

Phosphate Solubilization

Phosphorus (P) is the second most important nutrient for plant growth and participating in major role *viz*., metabolism, protein and nucleic acid synthesis, and kinase regulation. It presents in the soil/ plant volume as (0.2%/ 0.05%) with two forms of inorganic (P_i) and organic (P_0). Only 0.1% of phosphorus can be utilized by plants from soil and noted as limited one (Maharajan *et al*., 2018). Phosphate anions (PO_4^{3-}) in chemical fertilizers where extremely reactive and become fixed through interactions with Ca^{2+}, Fe^{3+}, and Al^{3+} ions in the soil to form insoluble phosphate complexes and accumulation in the soil, during that period plant utilization efficiency of P at 5-25%. It is causing loss of soil fertility and P enrichment in soil conditions. Under these situations, and optimizing the P content in soil is essential it done by microorganisms called as "phosphate solubilizing bacteria (PSB)". These bacterial communities convert the unavailable form of P (both P_0 and P_i) into available P to satisfy the requirements of plants through dissolution and absorption. According to the different phosphorus-dissolving patterns, PSBs can be classified into two classes: (1) P_i-solubilizing microorganisms that secrete organic acid to dissolve P_i compounds, and (2) P_0-mineralizing microorganisms that secrete phosphatase to enzymatically mineralize P_0 compounds.

Sequestering Iron

Iron is an important fourth most abundant element in soil and rarely found in free form. It plays a vital role in microorganisms, plants and animals, exists in two states like ferric (Fe^{3+}) and ferrous (Fe^{2+}). It's involved in the biological activities on cell morphology, DNA / RNA synthesis, sporulation, TCA cycle, N_2 fixation, nucleic acid synthesis, photosynthesis, chlorophyll and vitamins formation, cofactor for enzymes *viz*., PO, SOD, DAHP synthetase, ferredoxin and flavoproteins. The optimum range of iron required at 12 to 24 ppm. During, growing period 5-10 kg/ha of iron was has required under standard pH of 7. In this situation, iron available in the form of $Fe(OH)_3$, the time utilizing that iron form is essential for dissoluble in form iron oxides and hydroxides by plants. So, plants evolved a diverse mechanism were followed in iron uptake. Under this stress or starvation period plants (dicot and monocot) and microorganisms produced a specialized iron chelating structures called as "siderophores". It is two types like, phytosiderophores and microbe siderophores. The siderophores are produced by plants in two types *viz*., nicotianamine (NA) and 2'-deoxymugenic acids (*Oryza sativa*).

Production of Signal Molecules

Communication is a big tool for migrate, survival, colonization and increase the population in localized regions, this thumb rule is applicable for all living organisms. In plant growth promoting rhizobacteria are specialized and diversified between them. Under root region, they can be surviving, colonization and increased the density of population due to their production of signal molecules. These signal molecules are acting as messengers between the bacterial community and host. It also specific and defending upon the bacterial species and host plants that communication is called as "quorum sensing". This messenger molecule is chemically as N-acyl-homoserine-lactones (AHLs). It was conveyed the signal molecules for the survive (forming nutritional competition), secretion of secondary metabolites (HCN and siderophores), PO_4 and heavy metal solubilization (*Bacillus* spp. and *Pantoea agglomerans*) N_2 fixation (*Rhizobium* spp.), triggering phytohormones stimulation (IAA, cytokinin, gibberellins, ethylene and ACC-deaminase), microbial antibiotics (synthesis-phenazines, pyrolnitrins, surfactin, iturin, fengycin and DABG), induction of ISR (by ET and jasmonic acid). Above these funcitions are regulated by biological and metabolically through AHLs against soilborne pathogens.

Ammonia Production

The soil consists with all residues of living organisms and most abundant N containing molecules in the form of different protein residues. Mostly, 60% of N in the plants and microbial cells as a form like, chitin and peptidoglycan. Soil organic nitrogen residues were converted as ammonia nitrifiers by *Pseudomonas* spp. and *Bacillus* spp., the amino acids were digested to produce ammonia called as "ammonification". After the ammonical form is converted into nitrite by soil bacteria like, *Nitrobacter* and *Nitrosomonas* sp.

Modulating Phytohormones Level

Plant hormones play a key role in growth regulator to plant, from sowing to maturation it balanced the concentration level and maintained the physiological (cell development, cell division, osmoprotectants, biomass) and bio-metabolism (germination, photosynthesis, organelle development, stress-release-factors) against towards abiotic and biotic stress during crop period. Several hormones like, cytokinins (CK), gibberellins (GA), indoleacetic acid (IAA/ auxin), absicic acid and ethylene (ET). A wide group of microorganisms belonged in the phytohormonal modification where relationship with environment; the species like, *Arthrobacter, Bacillus* spp., *Enterobacter, Pantoea, Pseudomonas* spp., *Rhizobium* spp., *Cellulosimicrobium, Mycobacterium, Orchrobactrum, Paenibacillus, Azospirillum,*

Stenotrophomonas, Mycoplana, Rahnella, Klebisiella, Leifsonia, Achromobacter xylosoxidans, Streptomyces spp., *Nocardia, Nocardiopsis, Spirillospora, Microbispora* and *Micromonospora*.

Drought and Salt Tolerance

During cropping season, the crop was met with several abiotic factors such as high temperature, poor water holding capacity of soil, acid/ alkalinity of soil, heavy metalized soil and poor soil nutritional status. It implicated in the reduction of plant metabolic and physiological activities on biomass and yield reduction, growth retard, imposing nutritional deficiency in plants, poor root and shoot growth associated with unfavoured atmospheric conditions Above these conditions, phytohormones stimulation by PGPR regulates the growth and elongation of roots (MR and LR), water absorption, nutrient uptake, osmotic regulation by polysaccharide – trehalose and fructose, strengthening the plant cell wall by "K" deposition and stomatal opening were regulated by IAA and ethylene. Under salt conditions, the ability of plant withstand has increased by ACC-deaminase, its stimulated by diverse group of PGPR *viz*., *Acinetobacter, Achromobacter, A. tumefaciens, Alcaligenes, Azospirillum, Bacillus* spp., *Burkholderia, Enterobacter, Ralstonia, Pseudomonas* spp. *Serratia marcescens*, *Ensifer melioti*, *Halomonas maura*, *Orchrobactrum intermedium* and *Rhizobium* spp.

Competition

In earth, everyone living organisms are dependent or independent with other species for survival, colonization and reproduction. This rule is most suited between beneficial and harmful organisms in agriculture. This principle is applicable during utilized by PGPR. In crop rhizosphere, these PGPR were made a big nutritional competition between plant pathogens. It's an initial destruction progress for plant pathogens invasion into plants. This nutritional competition drived through "parasitim or hyperparasitism". They draw the nutrition from plants or pathogens by specialized form of pegs and absorbing the sources. The different spp. of *Pseudomonas*, *B. subtilis*, *Streptomyces* were used in rice, chickpea, tomato against for sheath blight, root rot and wilt.

Antibiotics Production

It is one of the major roles to elevate the induction of pathogens to plants. Antibiotics are a low molecular weight compound that inhibit the biological activities, interpreted the metabolism of pathogens, retarded their survival and colanization and destruction. A diverse group of microbes produced huge numbers of antibiotics *viz*., actinomycetes (8700), bacteria (2900) and fungi (4900). Less than 1% of bacteria can be cultured remaining identified as rRNA genes. Mostly, well known species of *Agrobacterium, Pantoea*, *Serratia* and *Stentrophomonas* produced. Especially antibiotics such as tas A, subtilin, bacilysin, sublancin, chlorotetain, subtilosin, bacilllaene, bacillomycin, basalin, Iturin, surfactin, fengycin, polymyxin, circulin, colistin, mupirocin and zwittermycin A (*Bacillus* spp.); 2,4-diaacetyl phloroglucinol (DAPG), pyocyanin, pyoluterin, pyrolnitrin, phenazine-1-carboxylic acid (PCA) and oomycin A, rhamnolipids, cepacimide A, azomycin A, cepafungins, karalicin, aerugine, kanosamine, viscosinamide, butyrolactones and pseudomonic acid (*Pseudomonas* spp.); chloramphenicol, streptomycin, tetracycline, oxytetracycline (*Streptomyces* spp.); oligomycin and xanthobaccin (*Stenotrophomonas*). In fungal, *Trichoderma* spp. produced 6-PAP, gliovirin, gliotoxin, viridin were used as antimicrobial by their lethal activities.

Bacteriocins

It is a micromolar weighted proteaceous toxins produced by bacteria for lives in competitive microbial environment. They destroy the neighbouring bacterial species through bacterio-cyanogenic cells. It inhibited the pathogens survival, colonization and infection at initial stage with narrow spectrum. The bacteriocins like colicins (*E. coli*), megacins (*B. megaterium*), marcescins (*S. marcescens*), cloacins (*Enterobacter cloacae*) and pyocins from *P. pyogenes*. Sometimes, these compounds given harmful to human and animals also.

Production of Lytic Enzymes

During plant disease management several types of PGPR are used against pathogens by their antagonistic abilities. Among them, the PGPR blocked the invasion of pathogen by broad spectrum of activity is production of hydrolytic enzymes during hyper parasitism. In this process, the PGPR produced several lytic enzymes against plant pathogens and their survival by lytic enzymes (CWDEs) for the cell wall degradation *viz*., chitinases, cellulases, proteases, lipases and β-1,3-glucanases by wide group of PGPR and antagonistic fungi such as *Pseudomonas fluorescens* LRB3W1, *P. fluorescens* Pf1, *P. aeuroginosa, P. chlororaphis, P. putida, B. subtilis, B. coagulans, B. cereus, B. megaterium, B. thuringiensis, B. cepacia*, *Paenibacillus* sp., *Streptomyces* spp. *S. marcescens* and *Cellulomonas* sp. ASN2 were effectively against soil borne pathogens *viz*., *R. solani, M. phaseolina, Fusarium* spp., *Pythium ultimum, S. rolfsii and B. cinerea*.

Induced Systemic Resistance

The induced systemic resistance (ISR) is an artificial application for the enhance of immune system in plants against diseases and pests. Naturally, resistance was divided in to two categories based on them functionally during induction of pests or diseases and associated with

expression of their resistance *viz*., (1) systemic resistance (during pathogens or herbivorous insect's incidence, then plant express the resistance against to that by the stimulation of hormone salicylic acid (SA) and its immediately responded); (2) When the soil microbiome enrichment with beneficial microbes (PGPR or PGPB), it enhances the immunity against to biotic stresses through triggering the response of signals *viz*., MAMP (microbe associated molecular pattern) elicitors (flagellin, chitin and lipopolysaccharides (LPS), phytohormones stimulation JA/ET, volatile organic compounds (VOCs), acetoin, 2,3-butanediol, siderophores, hydrogen cyanates (alkanes, alcohols, esters, terpenoids, sesquiterpenes ketones and sulfides). These signals were perceived from plant through patter recognition receptors (PRRs). Both resistance (SAR/ ISR) variated by the principles *viz*., SAR is characterized by increased the levels of the salicylic acid which, through redox-regulated protein non expressor of PR 1 genes (NPR1), activates the expression of large set of pathogenesis related (PR) genes (PR-1a, PR-1b, PR-1c, β-1,3-glucanase, chitinase, thaumatin like and lipid transfer proteins) were involved in defence response from nucleus to outer membrane. At ISR, mediated through JA (jasmonic acid) and ET (ethylene) which, expressed the NPR 1 genes without PR gene activation and activated from cytoplasmic signals (Cytosolic) to outer membrane. A vast group of PGPR used in the ISR mechanisms through different initial approaches *viz*., soil application, seed treatment, foliar application and seed fortification by species such as *Pseudomonas, Bacillus, Streptomyces,* and *Trichoderma* (fungi) also.

Conclusion

From green revolution, our farmers only considered a high yield and production in all crops through hybrid seeds, farming mechanization and high usage of chemical fertilizers and plant protection chemicals. These implementations were highly influenced the yield but it given opposite reactions in the changing of soil nature and nutritional status, infertility, overcome resistance against fungicides and new emerging diseases and production loss. So, our farmers need alternate strategies for protect the land usage and increase the production by green way (using as biocontrol agents and organic farming). Above mentioned mechanisms are in shadow pages behind PGPR but results in brightening the plant disease management always.

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