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PGPR: present role, mechanism of action and future prospects along bottlenecks in commercialization

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Abstract
Throughout the plant developmental phases, there exist a strong relationship among soil, plant and rhizosphere microorganisms. The development of strong relationship links with the release of root exudates from plants. Diverse community of soil microorganisms depends on these exudations, establishing a strong interaction from growth promotion to parasitism. PGPR may compete for nutrients against pathogens, produces systematic resistance and antibiotics. They may promote plant growth through phytohormones and solubilizing minerals that affects the plant growth. The biological control of plant diseases through microbial-inoculants have enough potential for a large market share throughout the world, with annual growth-rate of almost 15-20%. The application of microbial based products is an eco-friendly approach and are the most suitable option for reducing the application of chemical fertilizers. The problem with microbial approach comes under field conditions where these microbes have to compete with various biotic and abiotic stresses. Marketing and commercialization are other important factors. However, success of marketing and commercialization is heavily dependent on advancement and improvements in interdisciplinary research, formulation methods, large-scale production, awareness and education of farming community. There is dire need to introduce an integrated approach of microbial based inoculation along with chemical one.

Keywords
PGPR, Plant growth promotion, commercialization, sustainable food production

Introduction

Food is one of the basic necessities of human being, which plays a major part in the development of societies. The rapid increase in human population and massive increase in environmental pollution have severe affect on universal food production. According to a survey, the current world's population which is around 7 billion, is expected to increase up to 10 billion in coming years (Glick, 2014). The ever-increasing population has drastic pressure on agricultural soils, leading to agricultural land degradation, the cultivation shifts to more soil types and increase demand of production per unit area. The application of higher nutrients can lead towards sustainable yield. The increase demand for fertilizers have increased the initial cost for farmers. The major restriction to agricultural production is the excessive use of chemical fertilizers in the prevailing environment (Jewell et al., 2010). Climatic conditions are also aggravating the severity of existing stresses, mainly drought, humidity, salinity and high temperature, which showed notable reduction in wheat, rice and maize yield (Jewell et al., 2010; Bianco and Defez, 2011; Shrivastava and Kumar, 2015). Soil salinity is one of the major agricultural issues that turns around 1-2% of productive agricultural lands into unproductive ones. The growth, development and yield

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of plants has been severely affected by salinity.
Moreover, salinity affects the plant metabolic, morphological, biochemical and physiological processes (Khan et al., 2017). Drought stress is expecting to affect more than 50% of arable land by 2050. The plant growth and development are influenced by drought stress through changing water relations, disturbing the nutrient uptake and photosynthetic processes (Heffernan, 2013; Naveed et al., 2014). In present time, heavy metal pollution is severely increasing the environmental pollution. The toxicity of heavy metal is of great concern and strictly needs to be eliminated (Etesami, 2018). Some of the heavy-metals are no doubt necessary at low concentrations, but at higher concentrations affect the growth, development and yield of crop (Saleem et al., 2018). Heavy metals mainly present in soil, taken up and transported through the plant body into the food chain (DalCorso et al., 2019). Heavy metals interfere the absorption of essential minerals that disturb the nutritional balance of plant body (Dal Corso et al., 2019). The major reasons of the nutritional imbalance are salinization, transport of important plant ions along with heavy metals and the competitive ions uptake. The nutritional imbalance affects the normal plant growth and development through its effect on water absorption, plant cell and plant nutrition.
The global climatic conditions are expecting to enhance the non-biological stresses in near future. The overcoming costs associated with these stresses are hypothetically higher. Due to their nasty effects, non-biological stresses results in reduction of crop yield up to 70%. For that reason, the dwindling of such environmental stresses using environmental approaches is of utmost importance (Sattar et al., 2019).
The use of beneficial soil microorganisms is one of the environmentally friendly approach for achieving sustainable agriculture. Microbial inoculants help farming community with better choice to meet the demand of sustainable agriculture. The application of microbial solutions and strong interaction of plant root soil microorganisms are of unique importance to improve soil health and productivity (Lugtenberg et al., 2002). The microorganisms associated with rhizosphere have major role in development of plant-resistance biotic and abiotic stresses (Sing et al., 2019; Shrivastava and Kumar, 2015). The induced systemic tolerance through microbially induced physic-o-chemical changes in plant body results in enhanced plant resistance (Yang et al., 2009).
Plant growth promoting rhizobacteria (PGPR) associated with rhizosphere can increase the plant growth, yield and development of plant through direct and indirect mechanism. The important known mechanism of rhizobacteria includes bioremediation of heavy metal contaminated soil through sequestering metals and degrading xenobiotic compounds (Glick, 2010), decreasing ethylene induced stress through ACC deaminase (Glick, 2004), provision of nitrogen through biological nitrogen fixation, siderophore production (iron chelation), the phytohormone production (IAA, ABA, GA, CK), acts as a biocontrol agent, mineral solubilization and most importantly increased resistance against non-biological resistance (Compant et al., 2005, Glick, 2014). Microorganisms were being used to improve plant growth and development, however, now a days their major role is the management of abiotic stresses in a defined way. Several researches are developing a hypothesis that PGPR authorizing agricultural crop plants to improve productivity under various abiotic and biotic stresses by diversified ways (Etesami, 2018). Rhizobacterial microorganisms have been known as an effective candidate in plants under saline conditions (Qin et al., 2016).
Several genera of PGPRs including Bacillus, Azospiriliium, Pseudomonas, Brady rhizobium, Aeromonas and Acetobacter have been pronounced for improving crop yield in salt affected soils. These bacterial isolates maintain their original traits at higher salt concentration. Various PGPRs are reported to produce resistance against drought tolerance (Kaushal and Wani, 2016). Drought resistance mechanism induced by PGPRs against various stresses is linked with physiological and chemical changes (Kaushal and Wani, 2016).

PGPRs potential for sustainable agriculture

Rhizosphere is the nutrient enrich part where millions of soil microorganisms lives and thrives on root exudates, referred to as rhizodeposits, comprising of various lubricant compounds that help in the nutrient acquisition (García-Salamanca et al., 2013, Jackson et al., 2019). Rhizodeposists behave like a chemo-attractant that welcome diverse group of microbial communities (Huang et al., 2014). A group of beneficial soil microorganisms that are involved in the plant growth and development through plant-microbe interaction are referred to as PGPR (Ma et al., 2019). PGPR improve the growth and development of crops through direct

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and indirect mechanism through assuring the uptake of macro and micronutrient by several mechanism (Khan and Bano, 2016). At the same time, PGPR act as biocontrol agent protecting the plants against various pathogens including insects, viruses and fungi (Mishra et al., 2015). These microbes can act diseases, improve stress tolerance, improve the fertilizer and nutrient use efficiency and helps in bioremediation process (Pieterse and Wees, 2015, Lecomte et al., 2016, Zameer et al., 2016).

There are number of experiments supporting the role of PGPR to improve the growth, yield and development of plants under stress conditions. Plant growth promoting rhizobacteria produces several compounds including ACC-deaminase, siderophore, phytohormones, organic acids and plays a major part in biological nitrogen fixation. The said compounds either affects the plant metabolic process directly to improve its development or increase the nutrient absorption of plants through improving its adaptive capacity (Grobelak et al., 2015). Microbial produced hormones including cytokinin's, auxin, abscisic acid and ethylene helps the crop-plants in growth and development such as cell division, root extension and cell enlargement (Kudoyarova etal.,2015). comprehensively, the soil microorganisms are the major leading force for improving the soil health and fertility status and recovering the soil nutrients (Ahemad and Kibret, 2014). Streptomyces, Burkholderia, Pseduomonas, Bacillus and Serratia are important bacterial genera and Trichoderma, and Coniothyrium are important fungal genera, that are well-characterized for plant growth promotion through suppressing the plant pathogens (Chen et al., 2016).

No doubt, the processes involving the success of microorganisms in stress and disease control are quite complex, these beneficial microorganisms improves the plant growth through inhibiting the negative effect of plant pathogens. Numerous plant growth promoting, and biocontrol products are easily available in market for farming community and several such products are in the way of development. Integration of soil microorganisms for plant-growth-promotion and eliminating or reducing the application of chemical fertilizers is highly dependent on effective screening, selection, and safety analysis of potentially microbial strains. Moreover, enough knowledge of marketing, current scenario, target diseases, registration process and most importantly initial cost of production need to be revised on consistent basis. The future era is of microbiology, if they are used and handled in a sustainable way. Although, fungi and bacteria are of extreme importance against plant pathogens in developing potential resistance, however our main focus in current review is only on the bacterial communities involved in plant growth and development.

PGPRs: as a biocontrol agent and plant growth promoters

Each year, agriculture sector faces a severe problem of plant pathogens which results in clumsy loss of food stuff and cash crops. Due to ever increasing population, these losses need to be addressed in an effective way to make sure the quality and quantity of agricultural products (Ekundayo et al., 2011). Farming community heavily rely on pesticides, insecticides and fertilizers for improving plant growth, yield and for biocontrol of pathogens. With the passage of time, the development of insect-weed-resistance verities and concerns over human health have brought about remarkable consideration for PGPR (Ekundayo et al., 2011). Meanwhile, the excessive use of chemical pesticides has not only increased the environmental problem but also reduced the diversity and activity of indigenous microbial communities (Babalola and Glick, 2012). Keeping in view the current scenario, the use of beneficial soil microorganisms in place of chemical fertilizers is a better option for sustainable agriculture and an eco-friendly approach as well (Zahir et al., 2019). The microbial approach has multiple advantages over other existing chemical techniques, such as

(i) Environmentally friendly approach
(ii) Balance approach for sustainable agriculture
(iii) Long term consistent benefit of microbial approach
(iv) Cost effective

Marketing and commercialization of PGPR

The major and the foremost task of success of PGPR heavily rely on its marketing and commercialization. The production of appropriate microbial inoculation from laboratory to farmers field requires careful management practices, proper study, market analysis and survey, before approaching to the farming field. The selection of appropriate microbial isolate depends on the specific crop and climatic conditions for commercial availability. Like was, if a specific crop is at risk to fungi, the selection might be based on specific antagonistic activity of microbes for fungus. The climatic conditions of an environment have major impact on microorganism's

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performance (Compant et al., 2010). Keeping in view the climatic scenario, microbes in the laboratory are subjected to different biotic and abiotic stresses to make them fight against natural environmental conditions. The ecological zone of a country is an integration of climatic, temperature and soil properties of a specific region. It is a quiet complex and difficult process to develop novel microbial consortium for different ecological zones according to different crops. Climatic conditions like increased temperature might result in severe drought that not only affect the crop growth and development but also the performance of PGPR (Heidari and Golpayegani, 2012). The performance of indigenous microbes has not discovered yet, because of this commercial inoculation may not be successful as they are natively not derived from locally rhizospheric soils. Climatic conditions are subjected to induce changes in plant growth and development through changing its physiology and disturbing root exudation. L-tryptophan is precursor to IAA and that amino acid is present in root exudates, as climatic conditions severely affects the L-Trp concentration, means that PGPR will produce minute quantity of IAA that will ultimately affect the root proliferation and vegetative growth. The higher concentration of tryptophan in the root exudates boost up the microbial activity (Kravchenko et al., 2004).

PGPR might be known for their beneficial effects on plant growth and development in terms of their desired characteristics and colonization properties under certain stress environment (Compant et al., 2010). The success of microbial inoculants in various climatic conditions can be predicted through understanding the disease control mechanism, growth promotion traits and resistance against biotic and abiotic factors. To achieve maximum microbial effectiveness, the identification and isolation of region-specific microbes with better microbial traits are necessary. For marketing of microbial inoculation, the crop requirements are considered at top priority. Hence, there is no specific single microbial strain that can perform well in different climatic conditions and for different crops. The major and foremost steps of commercialization include;

1. Field survey of farmers field
2. Isolation of specific microbial strains with specific characters
3. Selection of suitable carrier material
4. Method of inoculation

Moreover, the commercial companies prefer the microbes with zero impact on environment and human being. Government should regulate the laws for selection and screening purpose for commercial marketing purpose. Another major issue might be the neglected non-targeted effects such as;

1. Replacement of native species
2. Hypo virulent strains may lead towards pathogenicity
3. Toxicity or allergenicity

The abovementioned safety concerns need to be clarified before the largescale acceptance, registration and adoption of PGPR for pest and disease management.

Limitations to advertise PGPRs

According to an estimation, agricultural crops are attacked by around 67, 000 various pest species including weeds, phytopathogens, vertebrates and invertebrates, causing almost 45-50% of yield loss throughout the World (Chandler et al., 2011). The success rate of PGPR has increased substantially over chemical fertilizers and supplementation and they are the best replacement of chemical fertilizers (Droby et al., 2009). In comparison with chemical pesticides, a few biocontrol agents are however registered for commercially available. The formulation of a productive microbial strains requires that the specific strains should have higher saprophytic ability, broad spectrum of action, compatibility with other microbial strains, growth promotion capability, environmental safety and most importantly should bear biotic and abiotic stresses (Nakkeeran et al., 2005). The carrier selection is the most important step for efficiency and survival ability of microbes. The value-addition of multiple compounds as an active agent to improve the sustainability, stability, efficiency of application, persistency and safety features. Most of the time, the microbial products are formed as oil-based liquids, granular form, dusts and dry powder. The microbial formulations are mostly in two forms liquid suspensions and solid powder form. Various carrier-materials being used in formulation are peat, turf, lignite, alginate, press mud, vermiculate and zeolite. These carriers are actually source of nutrition for the microbial community and protects them from harsh environment and desiccation to increase their shelf life.

The marketing and commercialization of microbial based products rely on market demand, consistency, broad spectrum action, environmental safety, low capital cost, eco-friendly behavior and strong association between industries and research wing (Bhattacharyya and Jha, 2012). Some of the most important factors that limit the marketing of PGPR includes;

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1. Specificity of microbial products
2. Microbial-selection for product formation
3. Farmers psychology
4. Stability issue
5. Climatic conditions
6. Lack of skilled labor
7. Regulatory authorities

Limitations in PGPRs application

The application of microbial inoculations in phytoremediation, bioremediation, as a biofertilizer and biocontrol heavily rely on their persistent ability to compete with native microbial communities and environmental stresses. The major issue with the microbial survival comes under field conditions. The colonization of crop-plants by selected microbial inoculation is influenced by number of factors including physical and chemical properties of soil, biological activity of indigenous microbes and agricultural management practices like crop rotation. The success of most of the inoculants mostly follow the first come first served principle.

Conclusion and Way forward

The current review acknowledges that microbial; formulations not only improve the plant growth and development but also trigger more resistance against biotic and abiotic stresses. Most of the bacterial isolates significantly improves plant-growth characteristics like plant height, germination rate, shoot and root parameters and most importantly nutrient contents in economically important crops like peas, potato, rice and tomato. The replacement of a chemical fertilizers requires a strong biopesticide to compete with existing problems. Prior to commercialization, the molecular analysis leads to stabilization of PGPRs effect in biological control and risk assessment. Successful and effective application of microbes for crop-protection and disease control in near future will strongly demand a choice of specific organism and technical improvements in formulations and upscaling techniques. Therefore, it is the need of hour to isolate a single microbial consortium with multiple plant growth and plant protecting parameters to benefit the farming community. PGPR make use of several mechanism to promote plant growth. However, carefully controlled field trials of crop plants inoculated with PGPR inoculants is necessary for improved commercial exploitation of PGPR.

In conclusion and for future prospects, the success and development of microbial inoculant producing research organization and industries involving in commercialization will depend on extensive measures including product-marketing, business management techniques, research and education. Moreover, the optimization of bacterial isolates for proper fermentation and formulation processes is still required to get success in agricultural fields.

Disclosure of potential conflicts of interests

There are no conflicts of interest of this study

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