Editorial

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Beneficial plant-microbe interactions for agricultural sustainability

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The plant microbiomes have been sorted from the plants growing in the natural habitats as well as harsh environmental habitats. Extreme habitats represent unique ecosystems for novel microbial diversity. The plant microbial communities from harsh conditions (pH, salinity, water stress/deficiency, and extremes of temperature) give resources to know how the microbes and plant survive under the extreme habitats. The beneficial microbes-interaction help to plant for growth, crop production and soil fertility. Today, it is a widely accepted fact that certain novel and efficient microbial strains of plant microbiomes, referred to as plant growth promoting (PGP) microorganism, enhance plant growth, fitness, protect from pathogenic organism as well as help to maintain the soil health under the any environmental conditions [1]. Microbial biotechnology approaches provides the best understanding about the microbial diversity, plant microbes-interaction and potential biotechnological applications of plant microbiomes for plant growth productivity and crop protection [2, 3]. Plant microbial diversity is considered important for maintaining soil fertility and enhances crop production for agricultural sustainability.

The beneficial microbial communities associated with plant ecosystems have been grouped into three categories, e.g. phyllospheric, endophytic and rhizospheric (Fig.1). The phyllosphere (stems-caulosphere, leaves-phylloplane, flowers-anthosphere and fruits-carposphere) is common niche for interaction between beneficial microbes and plant [4]. Phyllospheric microbiomes are most adapted plant microbes on surface of plant and such microbes have ability tolerate more abiotic stress of UV radiation and high temperature (35–50°C) as compare to endophytic and rhizospheric microbiomes. There is huge number of research on phyllospheric microbiomes and their applications for PGP and crop protection via different plant growth promoting mechanism. The phyllospheric microbes belongs to different species of diverse genera such as *Achromobacter*, *Acinetobacter*, *Agrobacterium*, *Arthrobacter*, *Bacillus, Delftia, Methylobacterium, Pantoea, Pseudomonas,* and *Xanthomonas* [5-7]. The another plant microbes interction as endophytic microbiomes. The endophytic microbiomes are beneficial plant growth microbes that enter into the internal tissue of plant (root, stem flower, fruits or seeds) either vertically or horizontally. A huge number of endophytic microbiomes belonging to different species of genera including *Azoarcus, Achromobacter, Burkholderia, Nocardioides, Herbaspirillum, Pantoea, Klebsiella, Gluconoacetobacter, Enterobacter, Microbiospora, Micromomospora, Planomonospora, Pseudomonas,* S*treptomyces* have been identified as PGP endophytic microbes [8-12]. The most important association between plant and microbes is interaction of soil microbes with plant root ecosystems as rhizospheric microbiomes. The microbes present in soil ecosystems attracted towards the rhizospheric zone due release of roots exudates. A huge number of species of diverse genera as rhizospheric microbes such as *Methylobacterium, Pseudomonas, Serratia, Rhizobium, Paenibacillus, Erwinia, Enterobacter, Flavobacterium, Bacillus, Azospirillum, Burkholderia, Arthrobacter, Alcaligenes,* and *Acinetobacter* have characterized for plant growth promotion [13-16]. Microbial biotechnology and related fields has opened up new potential concerning the applications of beneficial microbiomes for the promotion of plant growth as biofertilizers and as biocontrol agents or biopesticides for soil-borne pathogens. The microbial inoculation as biofertilizers and biopesticides has stimulatory effect on plant.

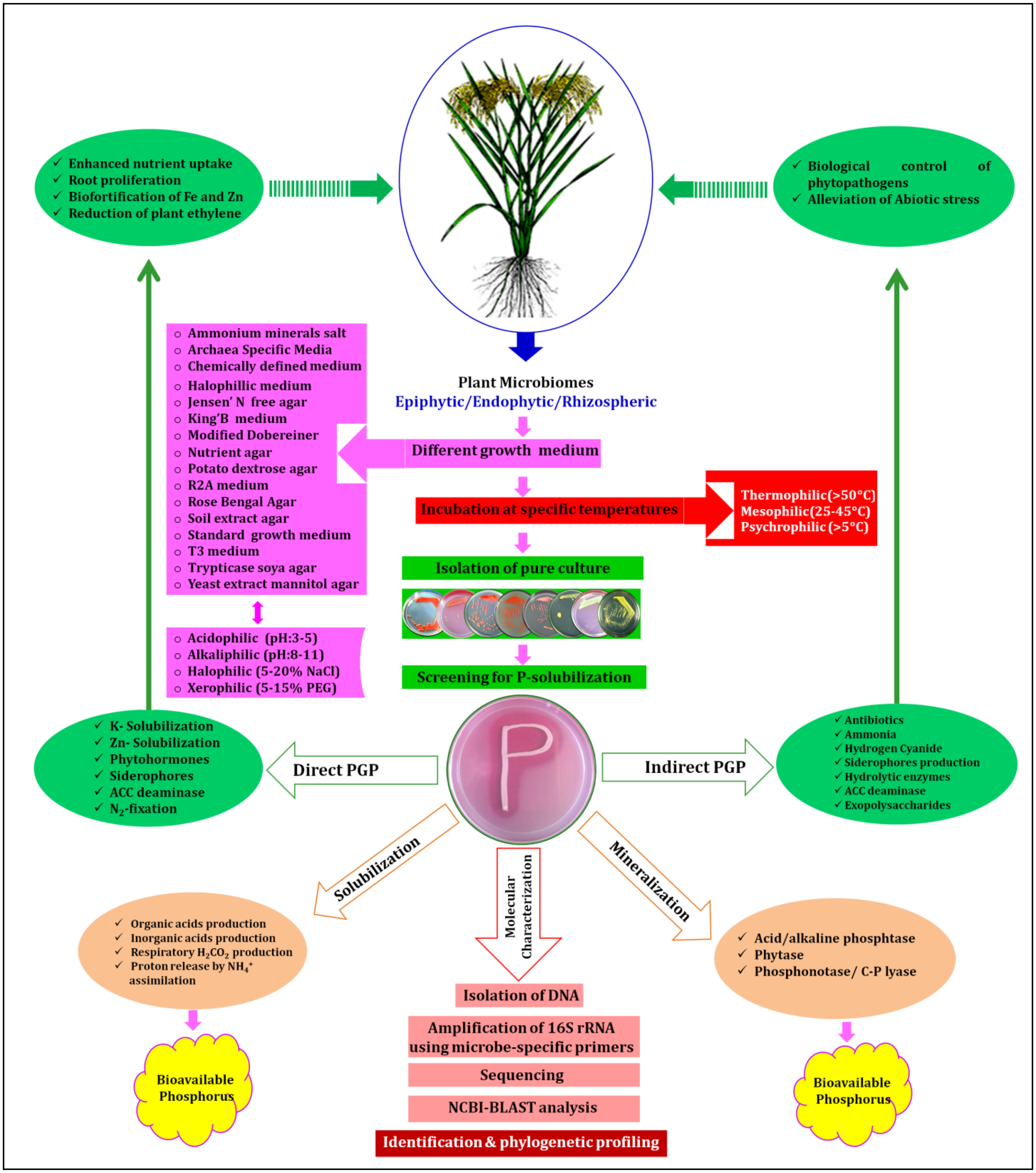

Figure 1: A systemic representation of plant-microbe interactions (Epiphytic, endophytic, and rhizospheric) and their role in plant growth promotion. Adapted with permission from Kour, et al. [3]

The extremophilic microbes such as psychrotrophic, thermotolerant, halotolerant, acidotolerant, alkalitolerant and drought tolerant are associated with crop growing in harsh agro-ecosystems such as acidic/alkalinity, salinity, drought and high/low temperatures. The microbes from plant growing in alkaline/acidic environments have been reported including *Azotobacter*, *Flavobacterium, Bacillus, Burkholderia*, *Methylobacterium*, *Pseudomonas,* and *Serratia* [17, 18]. Soil salinity is one of important limiting factor among different abiotic stress for agricultural crops worldwide. Halophilic bacteria and haloarchaea associated the plant growing in hypersaline habitats with saturated salt concentration [19]. These halophilic/halotolerant microbiomes help the PGP and adaptation under the abiotic stress of hypersalinity. Drought stress limits the plant growth and crops productivity [20, 21]. Plant responses to water deficient stresses include an increase in abscisic acid (ABA) levels that cause closure of stomata; reduces the availability of carbon dioxide for photosynthesis, which can lead to the formation of reactive oxygen species (ROS). Inoculation of drought-tolerant microbes such as *Azotobacter*, *Flavobacterium, Bacillus, Burkholderia*, *Methylobacterium*, *Pseudomonas,* and *Serratia* mitigates the drought stress in plants, increasing plant growth and enhanced the crop yield. Plant microbiomes have a high potential bioresources as biofertilizers, biostimulators, and biopesticides for agriculture because they could be used for plant growth promotion under the low/high temperature conditions.

The plant microbe-interaction is due to release of root exudates and microbial activities. Microbes utilize the root exudates for their growth, reproduction and development. The microbes associated with plant can enhance plant growth; improve plant nutrition through diverse PGP attributes. Plant microbiomes naturally produce different hormones (phytohormones) such as auxins (IAA) and gibberellins (GA). The GA production is most distinctive for the rhizosphere microbiomes whereas production of indole acetic acids is common to all soil and plant microbiomes i.e. endophytic, epiphytic and rhizospheric. The plant microbes have capability to produced 1-Aminocyclopropane-1-carboxylic acid. The 1-Aminocyclopropane-1-carboxylic acid is precursor of plant hormones ethylene i.e. stress-induced phytohormones which is responsible for inhibition of plant growth and development. Soil and plant microbiomes with plant growth promoting attributes which possess the enzyme, 1-Aminocyclopropane-1-carboxylic acid, help plant growth and development by decreasing ethylene levels. Microbes with ACC deaminase activities help the plants for growth and mitigation of different abiotic stresses i.e. salinity, low temperature and drought. Microbial strains such as *Rhizobium, Burkholderia, Bacillus, Alcaligenes, Acinetobacter,* and *Achromobacter* exhibiting 1-Aminocyclopropane-1-carboxylic acid production activity. Nitrogen is one of the major limiting factors for plant growth. There are well known microbial communities which are associated with plant ecosystems or free-living in nature have ability to convert the atmospheric nitrogen available for plants. The applications of nitrogen-fixing microbes as biofertilizers have emerged as eco-friendly technology for increasing the growth and crop yield. A huge number of nitrogen-fixing microbes like *Rhizobium*, *Herbaspirillum*, Frankia, *Gluconoacetobacter*, *Azospirillum*, and *Azoarcus* have been reported as associated with plants [22-27]. Phosphorus is one of the major vital macronutrients for proper growth, reproduction and development of plant. Plant microbiomes specifically rhizospheric microbiomes offer a biological rescue system for conversion of insoluble inorganic phosphorus into soluble and available form to plant ecosystem (Fig.1).

A huge number of plant microbiomes with P-solubilizing property have been reported which include members belonging to *Pseudomonas*, *Pantoea*, *Halolamina*, *Enterobacter*, *Citrobacter*, *Burkholderia*, *Bacillus* and *Azotobacter* [3, 28, 29]. The indirect mechanism of PGP occurs when beneficial plant microbiomes prevent the detrimental effects of phytopathogens. Different species of microbial genera such as *Pseudomonas*, *Microbacterium*, *Kluyvera*, *Flavobacterium*, *Curtobacterium*, *Clavibacter*, *Bacillus*, and *Alcaligenes* have been reported as biocontrol agents for different plant pathogens [30, 31]

In conclusion, the need of today's world is high crop productivity as well as soil fertility and health *via* eco-friendly manners. Future research in plant microbiomes and soil microbiomes will rely on the development of microbial biotechnological approaches to increase our knowledge of soil as well as plant microbiomes and to achieve an integrated management of soil and plant pathogenic microbiomes. The soil or plant microbiome as single or in consortium with antagonistic substance producing, mineral solubilizing, phytohormones producing and nitrogen-fixing attributes could be effectively used as biopesticides and biofertilizers to reduce the chemical fertilizers for agricultural sustainability.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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