Chapter 16
Plant Microbiomes for Sustainable Agriculture: Current Research and Future Challenges

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Abstract The plant microbiomes play important role in plant growth promotion and soil fertility for sustainable agriculture. Plant and soil are valuable natural resource harbouring hotspots of microbes. The soil microbiomes play critical roles in the maintenance of global nutrient balance and ecosystem function. The microbes associated with plant as rhizospheric, endophytic and epiphytic with plant growth-promoting (PGP) attributes have emerged as an important and promising tool for sustainable agriculture. PGP microbes promote plant growth directly or indirectly, either by releasing plant growth regulators; solubilization of phosphorus, potassium and zinc; biological nitrogen fixation or by producing siderophore, ammonia, HCN and other secondary metabolites which are antagonistic against pathogenic microbes. The PGP microbes belonged to genera such as *Achromobacter, Arthrobacter, Aspergillus, Azospirillum, Azotobacter, Bacillus, Burkholderia, Gluconoacetobacter, Methylobacterium, Paenibacillus, Pantoea, Penicillium, Piriformospora, Planomonospora, Pseudomonas, Rhizobium, Serratia* and *Streptomyces*. These PGP microbes could be used as biofertilizers/bio-inoculants at place of chemical fertilizers for sustainable agriculture. This chapter exclusively concluded the horizon covered book content of plant microbiomes for sustainable agriculture. The concluding remark envisioned the future beneficial role of plant microbiomes in plant growth promotion and soil fertility.

Keywords Endophytic · Epiphytic · Microbial diversity · Plant microbiomes · Rhizospheric · Sustainable agriculture

This book contains current knowledge about plant microbiomes. The diverse groups of microbes are the key components of soil–plant systems, where they are engaged in an intense network of rhizosphere/endophytic/phyllosphere interactions. The rhizospheric, endophytic and epiphytic microbes with plant growth-promoting (PGP) attributes have emerged as an important and promising tool for sustainable agriculture. PGP microbes promote plant growth directly or indirectly, by releasing

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plant growth regulators; solubilization of phosphorus, potassium and zinc; biological nitrogen fixation or by producing siderophores, ammonia, HCN and other secondary metabolites which are antagonistic against pathogenic microbes. These PGP microbes could be used as biofertilizers/bio-inoculants in place of chemical fertilizers for sustainable agriculture. The aim of the present book is to collect and compile the current developments in the understanding of the rhizospheric, endophytic and epiphytic microbial diversity associated with plants. The book encompasses current knowledge of plant microbiomes and their potential biotechnological applications for plant growth, crop yield and soil health for sustainable agriculture. The book will be highly useful to the faculty, researchers and students associated with microbiology, biotechnology, agriculture, molecular biology, environmental biology and related subjects.

Rhizosphere harbours potential microbiomes which play a pivotal role in nutrient cycling, enhancing soil fertility, maintaining plant health and productivity. Specific microbiomes that are assembled near roots are considered to be some of the most complex ecosystems on the Earth. Heterogeneous microbial communities of rhizospheric microbiomes considerably vary by soil type, land use pattern, plant species and host genotype. It is demonstrated that root exudates act as substrates and signalling molecules which are required for establishing plant–rhizobacterial interactions (Kour et al. 2019b; Mendes et al. 2013). These research priorities may enable us to manipulate agricultural microbiomes and thereby to develop management strategies for increased production and productivity of global agriculture in a sustainable manner. One of the challenges for future research work includes protection and conservation of rhizosphere biodiversity and their potential application in agricultural soils. Figure 16.1 represents the isolation, characterization and application of plant microbiomes for sustainable agriculture.

Endophytes are the microorganisms that live in the internal tissues of plants. Endophytic microbes hold great importance for the roles that they play in association with the host plants. Endophytes are known to promote the growth of the host plants by various activities such as detoxification of toxic compounds, protection against pathogens and production of plant growth-promoting hormones (Rana et al. 2019b; Suman et al. 2016). Many biotechnologically important metabolites are also produced by the endophytes such as anticancer and antimicrobial compounds. There is a rich diversity of endophytes that needs to be explored for biotechnological purposes. Such endophytes play an important role in plant growth promotion as these provide resistance to plant against different environmental stresses and toxic compounds, protect host plants against several pathogens, and produce many plant growth-promoting hormones. Endophytic microbes are also significantly important as biotransformers of different chemicals and help in recycling of nutrients. The endophytes also find many industrial usages as they are known for the production of many important enzymes and metabolites (Yadav et al. 2019a, b, c).

Endophytes constitute an important component of microbial diversity since 20 years, remarkable progress in the field revealed the significance of endophytic microorganisms. Endophytic microbes are unexplored group of organisms that has

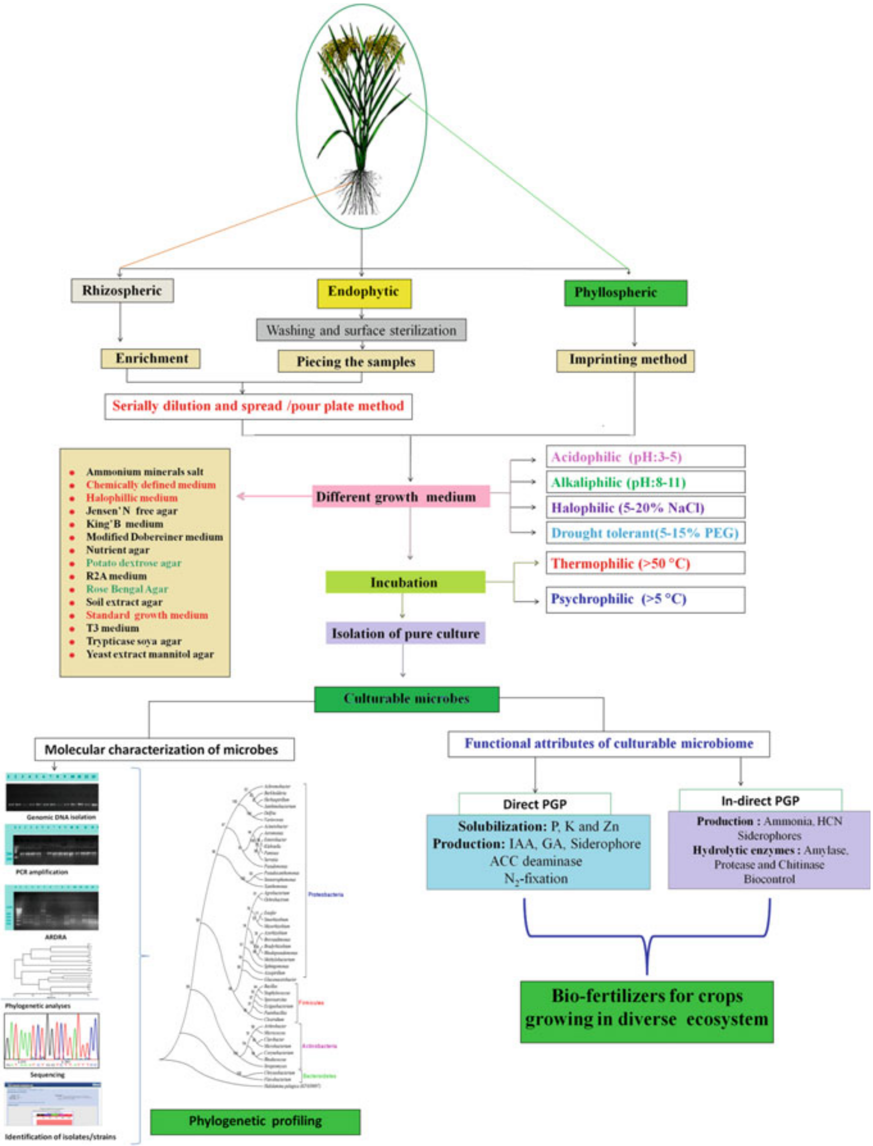

Fig. 16.1 A schematic representation of the isolation, characterization, identification and potential application of culturable and un-culturable microbiomes of crops. Adapted with permission from Verma et al. (2017)

huge potential for innovative pharmaceutical substances; they are established as anti-cancer, antioxidants, antifungal and antiinflammatory. Likewise in recent years, an incredible progress was made in developing them as therapeutic molecules against diverse ailments. In recent years more studies are warranted in bioprospecting new endophytic microorganisms and their applications. Bacterial and fungal endophytes are ubiquitous reside in the internal tissue of living plants. Endophytic fungi distributed out from tropical region to arctic region possess vast potential in terms of secondary metabolite production. It is pertinent to know that the various bioactive indispensable compounds evaluated by these endophytic fungi are host-specific. They are very significant to augmenting the adaptability of the endophyte and its host plants, for instance, biotic and abiotic stress tolerance (Rana et al. 2019a; Yadav 2018).

The phyllosphere referred to the total aerial plant surfaces (above-ground portions), as habitat for microorganisms. Microorganisms establish compositionally complex communities on the leaf surface. The microbiome of phyllosphere is rich in diversity of bacteria, fungi, actinomycetes, cyanobacteria and viruses (Kumar et al. 2019; Müller et al. 2016). Microbes commonly established either epiphytic or endophytic mode of life cycle on phyllosphere environment, which helps the host plant and functional communication with the surrounding environment. The phyllosphere is a unique environment colonized by a wide variety of microorganisms including epiphytes, beneficial and pathogenic, bacteria, fungi and viruses (Bargabus et al. 2002). Understanding the phyllosphere community structure, networking and physiology is a great challenge. However, extensive research on phyllosphere microbiota gives great potential for the applications in economic plant productivity specifically, agriculture and forestry, ecosystem cleaning and health.

Climate variability has been and continues to be, the principal source of fluctuations in global food production in developing countries Oseni and Masarirambi (2011). The important risks of increasing warming of globe are variable and untimely rainfall events, unstable winter seasons, more disease occurrences and crop failures (Adger et al. 2005). Extreme environments represent unique ecosystems which harbour novel biodiversity. Microbial communities associated with plant growing in most diverse conditions, including extremes of temperature, salinity, water deficiency and pH. In order to survive under such extreme conditions, these organisms referred to as extremophiles, have developed adaptive features, which permits them to grow optimally under one or more environmental extremes, while polyextremophiles grow optimally under multiple conditions. These extremophiles can grow optimally in some of the earth's most hostile environments of temperature (−2°–20 °C—psychrophiles; 60°–115 °C—thermophiles), salinity (2–5M NaCl—halophiles) and pH (<4 acidophiles and >9—alkaliphiles) (Yadav et al. 2015c). Microbes associated with crops are able to promote the plant growth. Several microbes have been reported that they can promote plant growth either directly or indirectly. Microbes have been shown to promote plant growth directly, e.g. by fixation of atmospheric nitrogen, solubilization of minerals such as phosphorus, potassium and zinc; production of siderophores and plant growth hormones such cytokinin, auxin and gibberellins.

Several bacteria support plant growth indirectly, via production of antagonistic substances by inducing resistance against plant pathogens (Glick et al. 1999; Tilak et al. 2005).

Salinity of the agriculture soil is the serious issue all over the world and it is also an important environmental factor for reduction of growth and yield of agricultural crops. The density of more salt available in soil may alter the physiological and metabolic activities in the agricultural crops and reduces the growth and production of crops both qualitative and quantitative ways. For combating against soil salinity, many transgenic salt-tolerant crops have been developed but far too little is a success. For solution, In the soils, the use of plant growth-promoting rhizobacteria (PGPR) can be reduced soil salinity, load of chemical fertilizers and pesticide in the agricultural field and improve soil health, seed germination, crop growth and productivity under saline condition PGPR accepted as potential microbes that can tolerant various atmospheric circumstances like more temperature, pH, and saline soils (Yadav and Saxena 2018). Halophilic microbes are isolated from saline soils or rhizosphere of halophytic plants and show plant growth-promoting characters directly like the production of IAA, solubilization of phosphate, production of siderophore, fixation of N_2, deaminase ACC activity or indirectly ways by controlling of phytopathogens under saline condition (Verma et al. 2017). Knowledge of plant–microbe interactions facilitates policies for the protection of crops and saline soil remediation and this type of interaction also observed in the area for ecological appreciative of microbes and which promotes halophyte to adaptability in salinity rich environment.

Drought is a conspicuous stress causing deleterious effect on plant growth and productivity. In order to compensate the yield loss due to drought, efficient and sustainable strategies are required for its management. Drought stress tolerance is a complex trait involving clusters of genes; hence, genetic engineering to generate drought-resistant varieties is a challenging task. In this context, the application of plant growth-promoting microbes (PGPM) to mitigate drought stress is gaining attention as an attractive and cost-effective alternative strategy (Kour et al. 2019a, b, c).

Microorganisms capable of coping with low temperatures are widespread in these natural environments where they often represent the dominant flora and they should, therefore, be regarded as the most successful colonizers of our planet. Psychrophilic microorganisms are adapted to thrive well at low temperatures close to the freezing point of water (Yadav et al. 2015a, b, 2016). Microbial activity of psychrophiles has even been reported at subzero temperatures. In general, psychrophilic microorganisms exhibit higher growth yield and microbial activity at low temperatures compared to temperatures close to the maximum temperature of growth and have more often been put forth as an explanation to successful microbial adaptation to the natural cold environment. Prospecting the cold habitats has led to the isolation of a great diversity of psychrotrophic microorganisms. The cold-adapted microbes have potential biotechnological applications in agriculture, medicine and industry. The bacterial diversity from the cold environment could serve as a database for selection of bioinoculants with PGP ability and could be used for improving the growth and yield of crops grown at high altitudes with prevailing low temperatures (Yadav et al. 2018; 2019d).

Biofertilizers are typically microbial formulations in organic carrier materials that improve soil health and crop growth and development. Of late the use of biofertilizers has gained much acceptance and research interest especially in the developed countries due to ecological impacts associated with the use of synthetic inorganic fertilizers in farming. Microbial formulations could be organism-specific or a consortium of organisms. Many soil microorganisms are endowed with an array of capabilities ranging from production of growth-enhancing substances to the release of substances which ameliorate the effects of various abiotic stress conditions such as drought, salinity, pH stress, heat stress, pollutants and nutrient deficiency.

There has been a sharp increase in the world's population over the past few decades which can be threatening in terms of the food security of the people. Thus, to cater to the huge demand of food, agricultural production should be increased within a short span of time and with limited worldwide agricultural land resources. This situation has driven the farmers all over the world to rely heavily on the commercially available chemical fertilizers for enhanced agricultural productivity. Though there has been a significant rise in the production of crops, these fertilizers have proved to be detrimental for our ecosystem as well as animal and human health. The deteriorative effects of the large chemical inputs in the agricultural systems have not only challenged the sustainability of crop production but also the maintenance of the environment quality. Using biofertilizers is a natural, low-cost, environment-friendly way out to this problem. Biofertilizers comprise living microorganisms capable of supplying sufficient nutrients to the plants, while maintaining high yield. With the ever-growing population, there seems no end to the demand of food but with the availability of the chemical fertilizers, it was thought that the problem could be tackled.

This book will be useful not only to the researchers, but also to each and every stakeholder that contributes toward evergreen agriculture. The enriched efforts of contributors and editorial team have resulted in a volume, which systematically describes to different issues, and applications of plant microbiomes in sustainable agriculture and environments. Needless to mention, that maybe, such volumes will be needed to place the biofertilizers and biopesticides technology in the field to its potential, but this particular book stands on its merit for the information and contents, which will be useful to all.

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