Green Reports

Ariviyal Publishing

Review Article

DOI: 10.36686/Ariviyal.GR.2021.02.04.009

Green Rep., 2021, 2(4), 1-8.

Chemistry of Microbial Life in Phyllosphere: A Review

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ISSN: 2582-6239

Publication details
Received: 24th November 2020
Revised: 28th December 2020
Accepted: 28th December 2020
Published: 08th January 2021

Abstract: The phyllosphere is associated with a diverse community of microorganisms. The association of phyllosphere microbes and host plant affects the both health and function of plant. The phyllosphere supports a huge diversity of microbes. Phyllospheric microbes mostly include bacteria and fungi, work as mutualists and promote the plant growth and make them tolerant to various environmental stresses. They use the plant as habitat for their own growth and reproduction. The little informations are known about the colonization of pathogenic and beneficial bacteria in the phyllosphere across the whole plant life-cycle which limits our abilities to understand the role of phyllospheric microbes in plant performance. The phyllosphere is actually the habitat of microbes provided by the aboveground parts of plants. It supports a large and complex microbial community on global scale. This review covers all information about the diversity, source, nature and composition of microbial life in phyllosphere.

Keywords: Phyllosphere; Phyllospheric Microbial Diversity; Endophytes; Epiphytes; Phyllospheric Microbial Composition

1. Introduction

The above-ground part of plants i.e. leaves, stems, buds, flowers and fruits provide a habitat to microbial life. This habitat is called as phyllosphere.[1] Although archaea, filamentous fungi and yeasts are present in phyllosphere but Bacteria are considered as the most dominant and important microbial inhabitants of the phyllosphere.[2] These microbes are epiphytes i.e. found on the plant surface as well as endophytes i.e. found within plant tissues. In case of rhizospheric zone, the microbes play an important role in regulating soil organic matter decomposition and nutrient cycling. The rhizospheric zone is a major gateways for nutrients and water.[3] The rhizospheric microorganisms produce vitamins, plant hormones, antibiotics and other communication molecules that enhance the plant growth and alleviate abiotic stresses over the plant.[4] Moreover, for proper soil management these are very important.[5] Other than Rhizosphere, The phyllosphere also represents a niche with great environmental and agricultural significance. Soil microbes are a dynamic component of soil and performed many beneficial functions in the soil system.[6] There are great evidences for interactions of phyllosphere microbial inhabitants that affect the fitness of natural populations of plant and also improve the quality and productivity of agricultural crops. Phyllospheric bacteria have ability to promote the growth of plant. These bacteria can suppress and stimulate the colonization and infection of tissues by plant pathogens. Similarly, phyllospheric fungal that are endophytes of leaves can deter herbivores, protect the plant against various pathogens and also make the plant tolerant against the abiotic stress i.e. drought.

There are the great evidence for vital roles within the phyllosphere microbial community which have given it the global significance.[7] The best example of significance of phyllospheric microbial communities is nitrogen fixation. The estimated rates of bacterial nitrogen fixation in the phyllosphere can vary. The measured rate of nitrogen fixation in the phyllosphere of trees in some tropical habitats is over 60 kg N ha^{-1}.[8] The amounts of fixed nitrogen is considerably lower in the phyllosphere of temperate trees as compared to the tropical habitat. The process of nitrogen fixation through bacteria has been reported in phyllosphere of many crop plants.[9] Other than nitrogen fixation, Methanol degradation and nitrification are the other environmentally important microbial processes in the phyllosphere. However, the rate of these processes in the phyllosphere remains to be demystified. Mostly culture-dependant methods are used to judge the knowledge of the structure and activities of phyllosphere microbial communities. Information and data obtained from these culture-dependant methods relate only to culturable members of the phyllosphere community.[10] It doesn't provide any information about the unculturabled vast majority of microbes present in samples. The new insights into the complexity of phyllosphere microbial communities are provided by the recent application of culture-independent method based on characterizations of small subunit rRNA gene sequence for microbial community analysis.[11]

Recent use of culture-independent method has changed our understanding of the structure and diversity of phyllosphere microbial communities. A variety of factors including plant, microbial and other environmental factors control the establishment of microbial communities in the phyllosphere.[12] The role of plants genotypes played in selecting phyllosphere microbial communities has been recognized. On the basis of plant genotype, the evidence for the different factors that regulate the structure of phyllosphere communities has been evaluated.[13]

2. Phyllosphere Microbial Life: The Diversity

Microbial communities residing in close contact with plants are found in the rhizosphere and phyllosphere. In case of phyllosphere some microbial communities are residing as epiphytes on the surface and some are inside plants as endophytes.[14] The diverse microbial communities are present in phyllosphere that are supporting numerous genera of bacteria, yeasts, filamentous fungi, algae and in some cases nematodes and protozoans are also present.[15] From phyllosphere microbial communities, Bacteria are the most diversed and numerous microbes present in leaves with culturable counts of rang between 102 to 1012 cells per gram of leaf. The Culture-based studies demonstrated more than 78 bacterial species of 37 known bacterial genera in sugar beet and 88 bacterial species representing 37 known bacterial genera in wheat over the whole of the growing season.[16] Many of recent studies have revealed that the profiling of phyllosphere microbial communities based on culture-dependent methods is likely to be inaccurate and to underestimate diversity. In the case of the phyllosphere, use of culture-independent method has shown that although thinkings regarding to the most dominant inhabitants are mostly correct, the diversity of phyllosphere microbial communities is greater than that of previously recognized.[17] The 16S rDNA is directly cloned from leaf samples and it's analysis has demonstrated that proteobacteria is the most dominant group of microbes found on leaves and confirm the data that is obtained using culture-dependant methods. In a examinations of bacterial communities of phyllosphere in a tropical brazillian forest, about 97% of the bacterial sequences were from previously undescribed species and data was obtained from the phyllosphere of different plant species supporting from 95 to 671 bacterial species.[18] The extent of diversity occurs in other plant species is uncleared. However, 5 of 17 bands cut from 16S rRNA denaturant gradient gel electrophoresis gels have less than 90% similarity to database entries.[19]

It has been explored in in a study of a range of temperate agricultural crop species. It suggests that in some situations phyllospheres of crop plants can support large numbers of novel bacteria.[20] The large number of sequences investigated in the culture-independent studies conducted to date has been limited, so that only dominant members of the community are likely to have been detected, and the true extent of phyllospheric bacterial diversity that's why remains to be determined.[21] Yeasts are the main epiphytic fungal group present in the phyllosphere with filamentous fungi that are present as dormant spores rather than active mycelia. The populations of culturable yeast can range between 10 and 1010 CFU g^{-1} leaf.[22] The diversity of culturable yeasts appears to be mostly limited to three genera i.e. Cryptococcus, Sporobolomyces and Rhodotorula. The total species number can reach over 40, with large number species of each coexisting in the phyllosphere, along with a lot of other genera that occur less frequently.[23] The sizes of population of Filamentous fungus can range between 102 and 108 CFU g^{-1} leaf. Usually, the most abundant considered fungi are Cladosporium and Alternaria and found on leaves.[24]

The several other genera, including Penicillium, Acremonium, Mucor and Aspergillus are also found. Filamentous fungi appear to occur ubiquitously as endophytes. Using culture-dependant method, more than 340 genetically different taxa can be obtained from individuals of two tropical forest.[25] There is the great evidence for host preference within the endophyte community. Culture-independent method is not still used to characterize fungal diversity in the phyllosphere.

Culture-independent analysis represents a powerful way to investigate the dynamics and distribution of specific bacterial groups of interest by using phylogenetic specific primers.[26] In terminal restriction fragment length polymorphism, we can get several phylogentic groups or functional genes that are analysed at the same time. T-RFLP provides an opportunity to improve throughput of samples in a cost-effective manner.[27] However, these methods remain time-consuming and future developments depends upon high throughput methods. Phylogenetic microarrays clearly provide a method and allow the presence and amount of thousands of microorganisms to determine at the same time and can also be used to determine the novel members of the phylogenetic groups.[28] In the same way, arrays of functional gene provide a way to characterize the activity of phyllosphere microbial community and used with phylogenetic microarrays for linking the microbial community structure to function in well manner. In order to determine and understand the structure and diversity of phyllopsheric microbial communities, it is very important to understand the different environmental and biological factors. These factors control the dynamics and establishment of microbial communities of phyllosphere.[29]

3. Phyllosphere Microbial Life: The Source

The microbial sources on the phyllosphere are manifold. The epiphytic yeasts, bacteria and filamentous fungi arrive on the leaf surface through different sources that may be insect-borne, atmosphere-borne, seed-borne or animal-borne. The most important sources for the colonization of new plants are leaves, tree buds, seeds of annual plants and the debris from previous crops. They are a main source of bacteria present in the phyllosphere.[30] The microbes having no or limited multiplication in the phyllosphere are transient epiphytes. Similarly, those microbes that have a capacity for multiplication in the absence of wounds are considered as residual epiphytes.[31] The populations of microbes can change in size among and within plant species over a short time periods. They also have great variations on the bases growing season. Some of the epiphytic bacteria are present on leaves after the bud emergence seeds formation.

They are subsequently increasing in the quantity. On the growing season, bacteria are dominating and there is a general succession of microbial populations on leaves.[32] It followed by yeasts and finally filamentous fungi. The composition and concentration of atmospheric microflora can vary in diurnally and seasonally. It can also change in response to environmental events including rainfall and high wind. It directly influences the immigration of microbes to the phyllosphere.[33] The agricultural practices like harvesting and cultivations also have a great influence on atmospheric microbiology and colonization of nearby plants.[34] The impaction onto the leaf surface, sedimentation or rain splash and contamination with soil can also result in immigration of microbes to leaves from the atmosphere. The microbes present on seeds and roots become endophytic in the roots.[35] When they enter the vascular system, they are transferred internally to the aerial parts of plants. Then they establish as phyllosphere endophytes.[36] Endophytes also arise from ingression into the internal leaf spaces. Then the colonization by epiphytes occurs. It is suggested that epiphytes and endophytes are part of the phyllosphere.[37] Micro-organisms present in phyllosphere then become established and colonize in leaf to become a residual epiphyte.[38]

The distribution pattern of microbes on leaves is not similar at all. The epidermal cell wall junctions are the most common sites of bacterial colonization. It is especially present in protected sites in grooves along the veins, at stomata and at the base of trichomes.[39] Their major sites of occurrence are under the cuticle, in the cuticle depressions and near hydrathodes. They are also present in specific sites that only occur on particular plants like pectate hairs in olive and stomatal pits in oleander. Generally, the greater numbers of bacteria are found on lower leaf surfaces than that of upper leaf surfaces. It is possibly because the lower leaf surfaces have a greater density of trichomes, stomata or a thinner layer of cuticle. The distribution of bacterial populations in the phyllosphere differ in very small scales almost as little as 0.1 mm2.[40] They can be often well-described by a log normal distribution. The distribution of yeasts and filamentous fungi is described by a normal distribution in good manners. Mostly, the microorganisms occur as aggregates or biofilm-like structures of bacteria, yeasts and filamentous fungi. Micro-organisms are also present individually on the leaf surface.[41] All micro-organisms present in the phyllosphere don't have ability to colonize and grow. It reflects the processes of emigration through dispersal mechanisms including rain splash, bounce-off, and wash-off, removal by insects or water movement. The environmental, physicochemical and genetic features of the plant determine the ability microbes to survive and grow. The specific properties exhibited by the phyllosphere microorganisms determine the structure and diversity of the phyllospheric microbial community. There are a number of areas that require more complete understanding are related to the colonization of phyllosphere.[42] There are little researches to explore the transmission of microbes from roots to aerial parts of plants and have been a neglected area of research.

4. Phyllosphere Microbial Life: The Nature and Composition

Phyllosphere microbial communities have a diverse array of microorganisms and are typically dominated by bacteria. Phyllosphere bacterial communities are less species rich than that of rhizosphere.[43] The well represented bacteria on the leaf surface are Alphaproteobacteria. These bacteria play vital ecological roles and are metabolically diverse.[44] The recent surveys of phyllosphere bacterial community composition also explore Gammaproteobacteria.[45] The role of the Phyllosphere microbial communities is determined on the base of various functions that are performed by them. They play vital role in plant health and function phyllosphere bacteria because the carry out methyltrophy, nitrogenfixation, nitrification, or anoxygenic photosynthesis. The next most dominant bacterial lineages in phyllosphere communities are Bacteroidetes and Actinobacteria.[46] These two phyla are also well represented in the rhizosphere. Bacteroidetes that are present in the phyllosphere are from the families of Cytophagaceae or Chitinophagaceae. The members of these families are often aerobic and pigmented. They are well adapted to the leaf surface. Actinobacteria that are present in the phyllosphere includes members that are plant pathogens, nitrogen-fixing symbionts, and fungal antagonists and decomposers. But many of these roles have not been demonstrated in the phyllospheric environment. The Actinobacteria are used as afoliar-applied plant growth promoter.[47] The presence and distribution of archaea in the phyllosphere is less common and they appear to contribute a minor to the microbial community. Fungi community of phyllosphere is an important component of the phyllosphere microbiota.[48] The variety of ecological roles are performed by fungal community. This fungal community is composed of organisms with a wide range of population sizes. It fluctuates in distinct seasonal trends based on the growing season. Moulds of Ascomycota on the leaf surface before senescence are often the dominant fungi in phyllosphere.[49] Yeasts belonging to the Ascomycota and Basidiomycota are other important fungi. The fungal microbiome becomes dominated by filamentous fungi. The vital role and distribution of other microbial eukaryotes including protists on plant leaves is not still well examined.[50]

The next-generation sequencing of community metagenomes throughout phyllosphere microbes show highly redundant functionality.[51] The environmental conditions i.e. changing temperature, low nutrients, humidity high UV etc. select the consistent biological traits. Generally, in phyllosphere the metabolic diversity exists primarily in the context of utilisable carbon compounds.[52] The presence of proteorhodopsin genes related to anoxygenic photosynthesis is an adaptations that seem particularly useful in the phyllosphere. But still more studies are needed to explore this phenomenon. The predominant most important factor that influences the composition of the phyllospheric microbial community is plant species identity. There is a lot variability in microbiome composition within a single plant species.[53] The variation in phyllospheric composition represents a combination of leaf succession and age along with environmental variation and changes in the microbial composition of the atmosphere.[54] Because of these dramatic variations, the phyllospheric microbial communities differ significantly on the bases of seasonal time scales. Whereas it is expected that the evergreen plants may show less influence of leaf age. Spatial differences in the phyllosphere are less studied in well manner in individual plant species. The extent to which environmental gradients or dispersal limitation that determine phyllospheric microbial composition is unclear.[55]

5. Phyllosphere Microbial Life: The Leaf as Habitat

The surface of a leaf works ad home place for diverse bacterial communities. The unique environment is perceived by every individual cell these communities and then they respond accordingly. The single-cell approaches are essential to investigate the behaviour at scales relevant to bacteria.[56] The important lessons are provided by single-cell studies and it also describe how current omics approaches fail to give an accurate description of the behaviour of phyllosphere bacterial populations in heterogeneous environments. Soon the power of single-cell and omics approaches will be combined by upcoming techniques. There are a wide range of microorganisms including fungi, bacteria and oomycetes. The phyllosphere, surface of aboveground organs of plants, is a large microbial habitat.[57] The phyllosphere is dominated by leaves i.e. a heterogeneous topography at the micrometre scale.[58] It mostly consists of elevations including epidermal cells and grooves between epidermal cells. Mostly, stomata, trichomes, hydathodes and glandular trichomes intersperse these two most abundant features. The presence, density and distribution of which depends upon leaf side and plant species. Therefore, many different microhabitats are offered by leave. The dense population of microorganisms is founded on the leaf surfaces.[59]

Bacteria are the most dominant group of microbes in the phyllosphere community. In this habitat, these dense microbial populations are given the microclimatic conditions. As the leaves are light-harvesting organs and covered by a waxy cuticle layer, it provides an environment in which epiphytes constantly need to cope with low water, ultraviolet (UV) radiation exposure and high temperature fluctuations during day time and also variations within a single leaf. Therefore, epiphytes are admired for their ability to cope with these combination of environmental stresses.[60] In the previous decade, a comprehensive catalogues of microbial life of leaves of different plant species was generated by in-depth sequencing approaches. It is demonstrated that a diverse microbiota colonize the phyllosphere which is specific to each plant species.[61] The leaf-associated phyllospheric bacterial communities consist of recurring taxa at higher phylogenetic ranks and the composition can differ at the species level.

6. Phyllosphere Microbial Life: Adaptations to the phyllosphere habitat

On the basis of phenotypic and genetic diversity, it is very difficult to characterize the soil microbial communities.[62] Other than plant and environmental factors, the extent to which microbial colonists explore the properties of phyllospheric microbes adoption is determined by themselves and they also determine the extent to which they are able to establish phyllospheric microbial communities on the leaf surface.[63] Some phyllospheric microbes, have inherent ability to survive in the existing habitat and some are capable of modifying the environment to reduce the levels ofstress they are exposed to and that is why they are able to survive there. It is determined by culture-independent analyses that the tolerance to ultraviolet (UV) radiation is an important selection pressure for growth and survival in a habitat. On the leaf surface, the most isolated phyllospheric microbes are capable to withstand with high UV radiation levels.[64] Dark melanin-type pigments in fungi are play an important role as a protective pigments. Similarly, the UV-B-induced hyphal wall thickening also lowers the levels of the fungal colony.[65] It is demonstrated that the most UV-B-tolerant bacterial strains from the phyllosphere of peanut produce pink or orange pigments. The multiple mechanisms of UV-B protectant are exhibited by phyllosphere microbes. The key limiting factors for microbial growth in the phyllosphere is the low level of water availability and nutrients. These limitations are overcome by variety of mechanisms given by epiphytes. Some surfactants that are released by some epiphytic Pseudomonas app. enhance the wettability of leaf. It makes the surfaces easier for phyllosphere microbes to use water and also increase diffusion and solubilization of nutrients. Therefore, it increases the substrate availability for epiphytic bacteria. It is demonstrated that a number of phyllosphere bacteria show an increase in permeability of the cuticle that enhance the water and nutrient availability in the phyllosphere.[66] The mechanism that enhance nutrient availability also relate to the ability to produce toxins and that affect ion transport across plant cell plasma membranes.

Syringomycin is a toxin that is secreted by plant pathogen i.e. Pseudomonas syringae pv. syringae ans eventually cause the cell lysis.[67] Whereas the nonpathogenic epiphytic strains of P.syringae pv. syringae produce low levels of effect such that necrosis and disease do not occur although release of plant nutrients is still stimulated. Syringomycin that acts as a surfactant and it provides two possible mechanisms to increase the availability nutrient in the phyllospheric zone.[68] Similarly, another important and widespread mechanism is the production and release of plant growth regulators. The indole-3-acetic acid (IAA) is commonly produced among bacterial epiphytes.[69] It is associated with increased nutrient leakage and microbial fitness. It is demonstrated that the functional type-III secretion pathway in Pseudomonas fluorescens and Pseudomonas putida provides the capacity for modification of the local habitat.[70] It may also be needed for growth and survival in the phyllosphere. For the bacterial attachment and colonization ofthe phyllosphere, the production of pili and flagellae are also important. Another important thing for phyllosphere colonization is the range of genes and gene products and that are now being identified by using molecular techniques. These molecular techniques provide further insights into mechanisms involved in epiphytic growth.[71]

As the distribution of bacterial on the leaf surface is not uniformed, the aggregates of cells occur. These aggregates provide the epiphytes having an ability to survive and colonize in the phyllosphere and also modify the local environment.[72] The bacteria produce extracellular polysaccharides (EPS) and these EPS protect the bacteria from water stress.[73] They are also helpful in anchorage of the cells to the leaf surface. These aggregates also protect from predation, bacteriocides and UVR. They also moderate pH and gas exchange and also enhance genetic exchange mainly via plasmid transfer. Therefore, they show cell density-dependent behaviour. It is mediated by accumulation of diffusible molecules like N-acyl homoserine lactones via quorum sensing.[74] It also have a lot of effects on microbial behaviour like EPS, antibiotic production, pathogenicity traits. It is noted that if signalling controls the functioning of aggregates, it might be possible in nearby future that microbiologists can manipulate the microbial populations on the phyllosphere if the molecular signals and receptors that are essential for aggregate behaviour are identified.[75]

7. Phyllosphere Microbial Life and Plant Genotype

The phyllospheric microbial populations have great variations in size and composition. These variations are both spatially and temporally on the same plant and differ between different plants as well as parts of plants in the same place.[76] Even they can differ on the same plant species in different places. These variations reflect from the environmental conditions prevailing at a particular time and at a particular place of sampling. Therefore, they influence the processes of microbial emigration, immigration, growth and death. However, the microbial population of phyllosphere also have a relevance to a large extent with the phenotypic characteristics exhibited by the plants that are ultimately controlled by their genetic make-up.[77]

It is demonstrated that there are there are some important factors that work as hot-spots of microbial growth on the leaf and which is associated with specific sites. The genotype has an important role in determining establishment and colonization of microbial communities within plant species in the phyllosphere.[78] It is also demonstrated that the relationship between genetic control of plant phenotypic characteristics and their concomitant has great effects on phyllospheric microbial populations other than its potential importance.[79] Mostly the culture dependent approaches is used to investigate the effects of plant genotype on phyllosphere microbial communities. In Different nine cotton cultivars, the bacterial population sizes and structure differ. Similarly, pea 5 cultivars contain endophytic bacteria with one showing a higher level of colonization than the others.[80]

In one cultivar tomato out of four, in a gnotobiotic system, supports some of the Pseudomonas sp. on the shoot exterior and followed by bacterial application on the seed.[81] In different cultivars of snap bean, the differences in ability to support populations of Pseudomonas syringae pv. syringae is also found.[82] However, there is no differences in occurrence of native, epiphytic mycoparasites of three main coffee cultivars or clones of the same group.[83] Similarly, there is also no differences between epiphytes on three cultivars of apple[84] as well as in endophytes in three cultivars of wheat.[85] The particularly valuable and important approach for elucidating interactions between plant genotype and phyllosphere microbial community structure is Culture-independent community profiling approach.[86] It is indicated by several studies that various different cultivars of the same species of plant have different phyllosphere microbial populations. It is founded that the phyllospheric microbial populations of bacteria is different in various cultivars of sweet pepper and tomato.[87] As well as both epiphytes and endophytes also differ in various varieties of potato.[88,89]

Some of the microbial communities are more affected by plant genotype than others. It is demonstrated that there are the great variations in phyllosphere bacterial community structure of wheat cultivars. Although there are no any specific differences in archaeal communities.[90] Similar studies has been made on lettuce cultivar which demonstrates the colonization of leaves by *Salmonella enterica*,[91] with significant serovar–cultivar interactions demonstrated. Furthermore, diversity of endophyte bacterial populations varies between the three cultivars lettuce. It is suggested from data that the degree to which *S. enterica* is able for endophytic colonization of plants part which is determined by competitive interactions with the natural community of endophyte bacteria. It is shown from the culture-dependent analysis that genetic modification of plant with an antibacterial peptide failed to have influence on number or structure of phyllospheric bacterial or fungal populations. Although magainin in case of potato tubers doesn't exhibit lower total numbers of bacteria than then that of unmodified plants.[92]

The modification of potato has been made with a gene that produces antibacterial T4-lysozyme or attacin ⁄ cecropin. In contrast, it is shown that it induces greater difference in phyllosphere microbial community structure and which is relative to variations between three cultivars. The difference in field site and different plant growth stage has greater influence on phyllosphere bacterial community structure than that of cultivar or genetic modification. The microbial communities having different genotypes have different responses to environmental variables. It is demonstrated by the various experiments that there are various alterations in endophyte bacterial community structure chilling sweet pepper plants related extent of the effect difference between various cultivars. It also depends upon cultivar chilling tolerance.

It is shown in wheat cultivars that the response of phyllosphere bacterial communities to UV-B radiation depended upon host genotype. But it is not cleared that these variations reflect the direct effects on phyllosphere bacterial community and indirect effects associated with variations in the plant responses to UV-B. Furthermore, the colonization and survival of microbial inoculants are greatly influenced by plant genotype in the phyllosphere.[93] The plant growth promoting *Azospirillum* inoculant's survival differs in the phyllosphere of tomato genotypes. The response of the phyllospheric bacterial community to inoculation changes between different genotypes. There is limited data on plant genotypic diversity relationships in case of fungi. Although, it has been demonstrated by various studies that differences in the nature of endophytes are associated with contrasting host genotypes. The distinct phyllospheric communities of endophytes are associated with various Populus hybrids.[94]

Although for the determination of structure of phyllosphere microbial communities, the plant genotype works an important factor and the mechanisms for controlling these interactions remain to be explained. The potential for examining plant genotype–phyllosphere microbiology interactions is shown by various plant science resources. The mapping populations[95] have a great potential to identify plant genes that is controlling leaf microbiology in particular recombinant inbred.

8. Phyllosphere Microbial Life: The Future Directions

The culture-independent molecular analysis of phyllosphere microbial populations is still in progress. The recent studies has made it cleared that the actual phyllosphere microbiology is more complex than that of previously understood. Although a lot of studies and progress based on these studies has been made in order to explain the structure and distribution of phyllospheric microbial communities. There is very little knowing about the functional consequences of the phyllospheric microbial communities and their compositions that are vital for favouring the individual plants. Its knowing is also very important for the quality and microbiological safety of fresh produce and various environmental processes. Microbial communities get access to phyllosphere by atmospheric deposition from plant and soil sources. They can also colonize plants via roots and then become transported to aerial plant parts. The vital relative importance of these mechanisms remains to be determined.

9. Conclusions

The phyllospheric microbial colonization and establishment has been recognized and to be the result of interplay between plant, environmental variations and the physiological characteristics of microbial communities. The contrasting genotypes can support different microbial communities within plant species. These understanding provide an opportunity to understand the molecular mechanisms. Through these mechanisms the plants control microbial populations in the phyllosphere. Various methods are provided by these studies to manipulate phyllosphere microbial communities through plant genotype. It provides the exciting opportunities in order to manage applied aspects of phyllosphere microbiology.

Conflicts of Interest

The authors declare no conflict of interest.

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