



Microbiomes: A Key for Sustainable Agriculture

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Solar radiation, water, and healthy soil are essential for agricultural productivity, yet industrial agriculture's reliance on chemical pesticides and fertilizers damages these resources. To meet increasing global food demands sustainably, it is vital to adopt practices that reduce fertilizer and water use. The microbiome, composed of millions of microorganisms in plants and soil, plays a crucial role in promoting plant growth, enhancing nutrient efficiency, and managing pests and pathogens. Isolating key microorganisms to develop biofertilizers presents a sustainable alternative to chemical inputs. Innovations involving microbiomes, including the use of probiotic microbes like *Lactobacillus* and *Methanospaera*, represent the future of agriculture. By effectively utilizing the microbiome, we can achieve sustainable farming practices that benefit both the environment and human health.

Microbiome

The term "microbiome" comes from the ancient Greek words "mikros," meaning small, and "bios," meaning life. It was first coined by Nobel Laureate and microbiologist Joshua Lederberg in 2001. World Microbiome Day is celebrated annually on June 27, an initiative launched by the APC Microbiome Institute in Ireland in 2019. The theme for World Microbiome Day 2023 is "microbes and food." The microbiome encompasses the entire habitat, including various microorganisms (such as bacteria, archaea, eukaryotes, and viruses), their genomes, and the surrounding environmental conditions. In contrast, "microbiota" specifically refers to the collection of microorganisms found in a particular environment. Plants serve as complex ecological systems that host diverse microorganisms in their rhizosphere, surface tissues (rhizoplane and phylloplane), and inner tissues (endosphere). These microorganisms establish a range of interactions with plants, which can be beneficial, neutral, or harmful. The long-standing relationship between plants and their surrounding environment has been a significant focus of research in the scientific community.

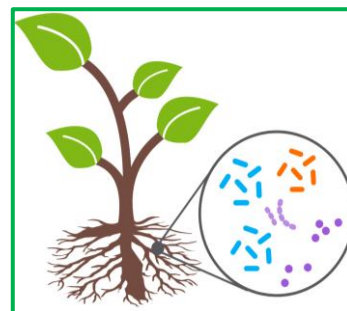
What is Microbiome?

A microbiome is the community of microorganisms that can usually be found living together in any given habitat. In 1988, Whipps and colleagues described, "microbiome" as a combination of the words "micro" and "biome", naming a characteristic microbial community in a reasonably well-defined habitat which has distinct physio-chemical properties as their theatre of activity.

Types of Microbiome

- 1. Human Microbiome:** The human microbiome refers to the microorganisms that inhabit the human body. It includes the microbiomes of different body sites, such as the skin, mouth, gut, urogenital tract and respiratory system.

2. **Soil Microbiome:** The soil is teeming up with microorganisms that play vital role in nutrient cycling, decomposition of organic matter and overall soil health.
3. **Marine microbiome:** These microorganisms play essential role in marine ecosystems, including carbon cycling, nutrient availability and the production of oxygen.
4. **Built-environment microbiome:** The built environment, such as homes, offices, hospitals, and public spaces, also has its own microbiome.
5. **Other Microbiomes:** In addition to the mentioned types, there are microbiomes associated with specific environments, such as freshwater ecosystems, hot springs, deserts and even extreme environments like Antarctica. Each of these microbiomes has unique microbial communities adapted to their specific conditions.
6. **Plant microbiomes:** Plant microbiomes are characteristic microbial communities in habitats that are well-defined by distinct physio-chemical properties *e. g.*, rhizoplane (the surface of the root), rhizosphere (the soil influenced by the root), phyllosphere (stem and leaves) and endosphere (inner plant parts).



A diverse number of important microbes are found in various parts of the plant, *i.e.* root, shoot, leaf, seed and flower, which play significant roles in plant health, development and productivity and could contribute directly to improving the quality and quantity of food production.

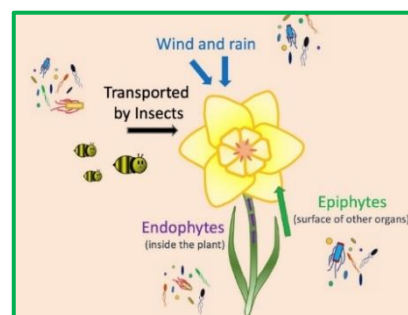
Types of Plant Microbiome: Plant microbiomes are diverse, containing both beneficial and harmful microorganisms, and can be categorized into three types based on their interactions with plants:

1. **Rhizospheric Plant Microbiome:** Microbes in the soil around the roots.
2. **Phyllospheric Plant Microbiome:** Microbes on plant surfaces, such as leaves and stems.
3. **Endophytic Plant Microbiome:** Microbes residing within plant tissues.

Microorganisms associated with plants are classified as **epiphytes** (*e.g.*, *Paenibacillus macerans* and *Bacillus pumilus*, which live on plant surfaces) and **endophytes** (*e.g.*, *Rhizobia*, *Microbacterium trichothecenolyticum*, and *Brevibacillus choshinensis*, which inhabit plant tissues). Research increasingly recognizes the essential role of endophytes in plant health, suggesting that targeting them could yield more effective microbial inoculants for boosting crop productivity compared to general soil inoculants. Their close association with plant tissues minimizes competition from indigenous soil microbiomes, enhancing their support for plant growth.

1. **Seed microbiomes:** The seed microbiome concept was introduced by Mitter *et al.* (2017). While it is believed that components can be vertically transmitted, the assembly process is not well understood. Seeds host diverse microbes that can form beneficial, neutral, or harmful associations, impacting plant health. Different crop varieties may have unique microbiomes on their seeds, serving as reservoirs for the endophytic microbiome in future generations. Seed fungal endophytes are primarily classified within the phylum Ascomycota.

2. **Floral (anthosphere) microbiome:** Flower (anthosphere) microbiomes are essential for ecosystem services, including plant reproductive success and interactions with beneficial insects like pollinators. The dominant genera in flower microbiomes, such as **Proteobacteria**, **Firmicutes**, and **Bacteroidetes**, differ from those in leaf and root microbiomes due to their unique ecological functions. This variation is influenced



by the nutrient-rich, high-osmotic environments in nectar and the open nature of flowers, which attract various insects and animals that can transmit both pathogens and beneficial probiotics.

3. **Leaf Microbiome:** The leaf microbiome is crucial for plant growth and development, playing significant roles in photosynthesis and transpiration. The phylum **Proteobacteria** is commonly found in leaf microbiomes, consisting of gram-negative bacteria categorized into alpha, beta, gamma, and delta based on nucleotide sequence homology. In maize, the dominant genera are **Sphingomonas** and **Methylobacterium**, while **Pseudomonas**, **Burkholderia**, **Mycoplasma**, and **Xanthomonas** are among the most abundant in the leaf microbiome of rice plants.
4. **Shoot Microbiome:** Endophytic bacteria in the shoot and other plant parts are similar to those found in the rhizosphere, indicating that soil is a primary source of endophytes. Culturable endophytes in shoot tissue belong to diverse genera across the phyla **Actinobacteria**, **Firmicutes**, **Proteobacteria**, and **Bacteroidetes**. These endophytes can multiply in the shoot meristem of newly forming tissue and can be passed vertically through seeds.
5. **Rhizosphere Microbiome:** The rhizosphere microbiome is critical for nutrient acquisition and plant defense against pests and diseases. It is influenced by soil properties, plant growth stages, and agricultural management practices. Plants release significant amounts of root exudates, including sugars and amino acids, which provide nutrients for microorganisms in the rhizosphere. The active emission of volatile organic compounds (VOCs) from root exudates also recruits specific microbes. Current knowledge of root exudation is based largely on hydroponic conditions, which may not accurately reflect soil environments and likely varies between soil types. Root microbiomes are proposed to function similarly to gut microbiomes in human health, offering nutrient provision, protection against pests and pathogens, and resilience to environmental stresses.

Recent studies show that the root microbiome is primarily dominated by **Actinobacteria**, **Proteobacteria**, **Planctomycetes**, **Verrucomicrobia**, **Firmicutes**, **Acidobacteria**, **Bacteroidetes**, and **Gemmatimonadetes**. Below-ground microbiomes vary by region, with a small fraction of rhizosphere bacteria entering root tissues to form the endophytic microbiome. Microbial diversity decreases from soil to rhizosphere to endosphere, indicating a key role of host filtration. Dominant taxa include **Proteobacteria**, **Actinobacteria**, **Firmicutes**, and **Bacteroidetes**, alongside fungal taxa like **Ascomycota** and **Basidiomycota**.

Factors Influencing Plant-Microbe Interactions

1. Plant-microbe interactions are influenced by intrinsic factors (genotype, developmental stage) and external factors (agricultural management, abiotic and biotic stress). Environmental conditions, such as temperature and rainfall, significantly impact microbiome structure.
2. Abiotic stresses (drought, salinity, heat) also regulate associations. Anthropogenic factors, including land tillage and fertilizer application, alter microbial communities by reducing competition and enhancing food availability. Host factors, such as species and genotype, lead to diverse root microbiomes, even among similar plants.
3. Root tips and hairs change soil structure, affecting microbial communities. Root exudates, consisting of sugars, acids, and antimicrobial compounds, regulate microbial assemblages, while compounds like nitriles enhance nitrogen uptake. Edaphic factors, including soil pH, carbon content, and nutrient status, also influence microbiome composition. Overall, the indigenous soil microbial population significantly affects plant-microbe interactions.







Prospects of Microbiomes for Sustainable Agriculture

- Conventional farming heavily relies on synthetic agrochemicals and improved plant varieties, boosting productivity and food availability.
- However, excessive use of agrochemicals leads to food contamination, environmental damage, and health issues, including cancer, infertility, and neurological disorders.
- Leveraging the phytomicrobiome offers a promising solution to enhance sustainable agricultural productivity while mitigating these challenges.
- Advances in microbiome engineering may replace toxic chemicals and fertilizers, promoting sustainable resource use and improving food processing.
- Utilizing beneficial phytomicrobiomes can address food security and environmental sustainability.
- The scientific community is increasingly focused on plant-microbe interactions and bio-stimulants to improve sustainable agricultural practices.

Role of The Microbiome in Agriculture

The plant microbiome is crucial for plant health and productivity, garnering significant attention in recent years. Microbes in the rhizosphere can form beneficial, neutral, or detrimental relationships with host plants. Key benefits include:

- **Symbiotic Relationships:** Nitrogen-fixing bacteria (e.g., rhizobia), arbuscular mycorrhizal fungi, and phosphate-solubilizing bacteria help plants obtain essential nutrients like nitrogen and phosphorus.
- **Saprophytic Microbes:** These microbes are vital for decomposing organic matter and remediating residual pesticides and hydrocarbons, thereby maintaining plant health.

	Bioremediation
	N - Fixing
	P - Solubilization
	Bio pesticide/ Bio herbicide
	Organic matter decomposition
	Suppress biotic and abiotic stress

Constraints on the Use of Microbial Products

- **Improper Use:** Effective Plant Growth-Promoting Rhizobacteria (PGPR) are often not utilized according to recommended protocols by farmers, impacting their effectiveness.
- **Non-local Strains:** Many microbial formulations come from different agro-climatic zones, leading to ineffective results when used in local conditions. Farmers may find little to no impact on plant growth when using these products.
- **Phytomicrobiome Solutions:** Microbial inoculants derived from the core microbiome can address these issues, as they have co-evolved with specific plant species, allowing for better colonization and influence on plant phenotypes.
- **Endophytic Microbes:** Utilizing endophytic members of the core microbiome can minimize competition with soil microbes since these microbes can colonize internal plant tissues, providing protection and enhancing plant health.

Conclusion

The microbiome plays a vital role in promoting plant growth by enhancing nutrient acquisition and serving as an eco-friendly alternative to chemical fertilizers. It acts as a second immune system, protecting plants against biotic stresses (such as pests, diseases, and weeds) and abiotic stresses (including drought, heat, salinity, and heavy metal toxicity), ultimately improving plant health and productivity. Consequently, there is a pressing need to focus on microbiome studies to develop and implement beneficial microbial solutions for plant protection and to promote sustainable agricultural practices.