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Exploring Plant-Microbial Interactions for Improved Crop Health and Growth

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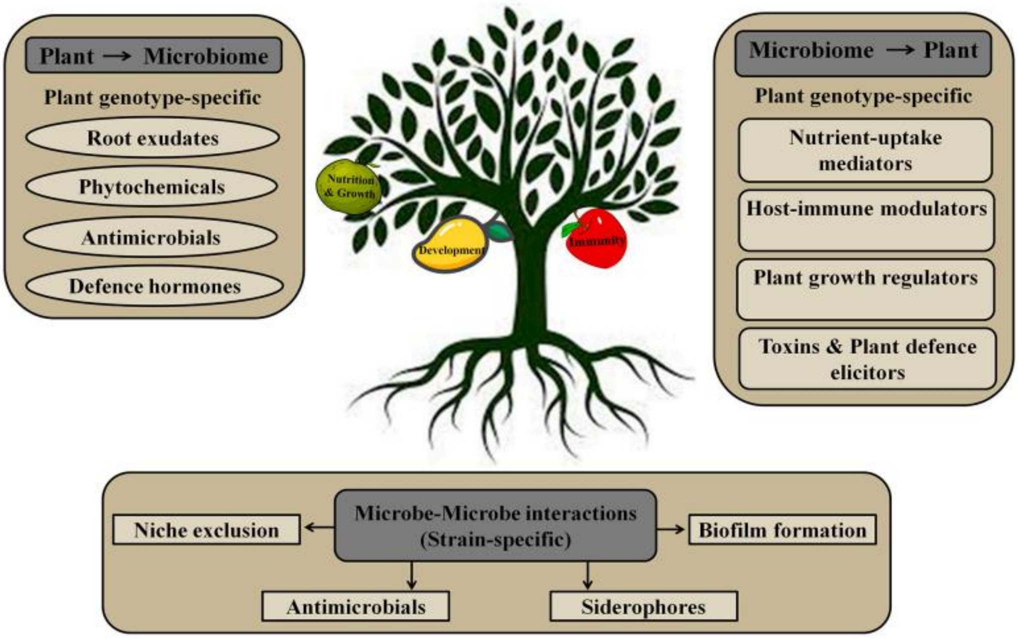
Abstract

The aim of this study is to explore how plant microbial interactions can increase crop health and growth, which involves the symbiotic relationships between the plants and beneficial microorganisms – plant growth promoting rhizobacteria (PGPR), mycorrhizal fungi and endophytic bacteria. These microorganisms aid plant root growth, and improve nutrient uptake, as well as plant response to biotic and abiotic stresses. These microbes provide support to plant growth by mechanisms such as phosphorous solubilization, nitrogen fixation, phytohormone production and protease production, which decrease plant reliance on chemical fertilizers. Furthermore, they produce antimicrobial compounds and induce systemic resistance, reducing disease whereas not using synthetic pesticides. More recently, improvements in microbial inoculation techniques (encapsulation, nano-encapsulation, etc.) allow microbes to live and survive in a variety of agricultural conditions. In this research, the potential of microbial applications for crop yield enhancement, improved soil health and sustainable farming practices is explored. Plant microbial interactions can be integrated into agricultural systems so that productivity can be maximized while environmental impact minimized. The tangible benefits of these interactions are demonstrated with field trials and case studies from the study, which lay a foundation for producing microbial bioformulations that are specific to specific crops. This method is in agreement with sustainable agriculture goals; it is an environment friendly solution towards improving crop productivity and increasing crop resilience in witnessing the demand of global food in terms of its increasing.

Introduction

Plant-microbial interactions have a key role to play in supporting crop health and growth and act as the bedrock of the natural systems, while also offering a sustainable route for agriculture. Symbiosis between plant roots and these beneficial microorganisms: plant growth promoting rhizobacteria (PGPR), mycorrhizal fungi, and endophytes—establishes nutrient availability, root development stimulation, and building of resilience to environmental stress.

Contributing to the essential nitrogen fixation, phosphate solubilization and the production of growth promoting hormones, these microbes are critical in ensuring plants have optimal growth and yield. In addition, they also produce enzymes and organic acids which improve soil health and structure, and contribute to a plant thriving environment and reduced dependency on synthetic fertilizers. These microorganisms interact with plants at a root level and enhance nutrient uptake efficiency and help plants acclimate to biotic (pests and diseases) and abiotic (drought and salinity) stressors becoming more and more important as climate changes.



Plant microbial interactions are increasingly viewed as an eco friendly means by which crop productivity and sustainability can be enhanced. Moreover, following the advances in microbial technology, such as encapsulation, controlled release mechanisms, and nano carriers, the stability and efficacy of microbial inoculants have further been strengthened, by making them survive and function well in a wide range of agricultural settings. The application of these microbial bioformulations allows targeted improvement in plant immunity through activation of systemic resistance and production of antimicrobial compounds, which reduce disease incidence. Plant microbial interactions have therefore become a promising way to replace chemical inputs because of their ability to simultaneously promote growth and protect transporters from pathogens. To make agricultural practices truly sustainable and decrease chemical dependency, preserve soil biodiversity, and lower environmental pollution, microbial based strategies can be integrated into agricultural practices. This research describes how the growing food production demands can be met

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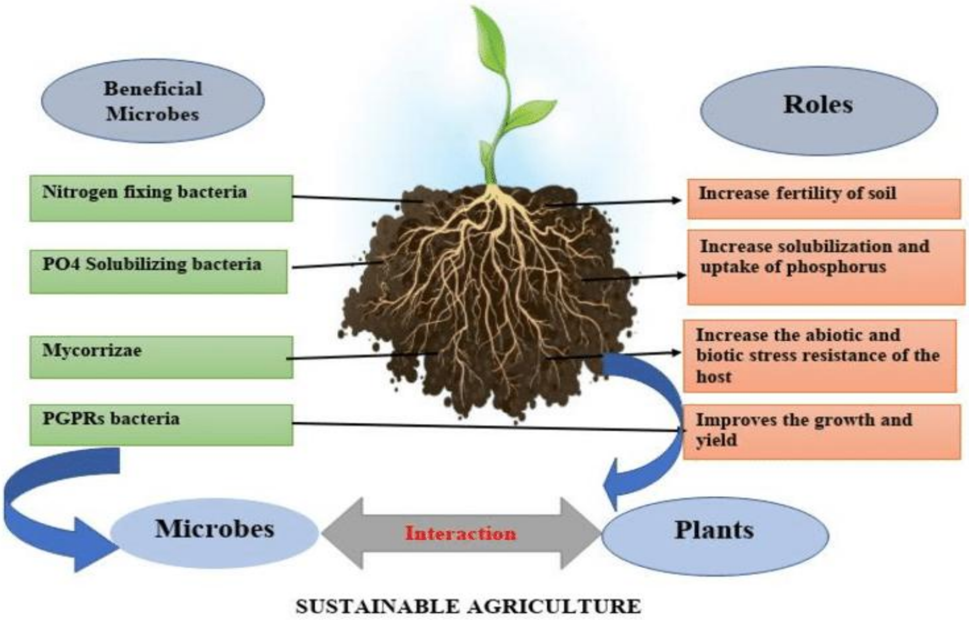
sustainably, through plant microbial interactions, with implications for developing tailormadebioformulations to enhance crop health, productivity, and resilience in an ecofriendly manner.

Overview of Plant-Microbial Interactions

Symbiotic plant–microbial interactions are key, and are of paramount importance to plant growth, health and resilience. These contacts primarily take place in the rhizosphere, the surroundings of the plant roots surrounding by beneficial microorganisms such as plant growth promoting rhizobacteria (PGPR), mycorrhizal fungi, endophytic bacteria and so forth. The microorganisms help plants make nutrients more available, they produce growth stimulating hormones, and they increase the plants' resistance to environmental stresses. As an example, they mentioned how like Rhizobium which convert atmospheric nitrogen into forms usable by plants, and phosphate solubilizing microbes release bound phosphorus in soil, providing nutrients. Mychorrizal fungi make up fungal networks that increase the root surface area in water and nutrient absorbtion.



Additionally, these microorganisms contribute positively to plants tolerance to biotic stresses (pests and diseases) by producing antimicrobial compounds in plants or trigger system resistance mechanisms in plants. The release of some microbes also comprise of enzymes and organic acids that helps improve soil structure and plant health by having optimum conditions of soil. An important part of these interactions is crucial for individual plant performance as well as ecosystem stability, as these interactions lead to soil fertility and biodiversity. There is considerable potential to implement such plant microbial interactions using bioformulations

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to counter chemical fertilizers and pesticides in agriculture, thereby increasing crop productivity while having fewer environmental impact. The lack of understanding and harnessing of such complex interaction provide valuable opportunities in improving crop resilience, decreasing dependence on synthetic inputs and developing sustainable agriculture practices designed for particular crop needs and local soil conditions.

Literature Review

Pathma, J., Raman, G., et al (2021). Over the recent decades, research in plant-microbe interaction revealed significant advancements towards our understanding of the many aspects of plant health and productivity. New techniques including high throughput sequencing and metagenomics facilitate examination of microbial communities in the rhizosphere and their functional roles in nutrient cycling, disease resistance and stress tolerance. It has been established that certain microbial strains are critical to facilitate plant growth by means of production of phytohormones and solubilization of nutrients. Plant exudates are beginning to be appreciated for their role in shaping microbial communities and creating the conditions for beneficial interactions. Success has been found in the search for symbiotic relationships and more specifically between plants and mycorrhizal fungi to increase nutrient uptake and promote resilience to environmental stresses. In addition to this, synthetic biology allows one to engineer microbes with improved positive traits. These advances create new options for development of sustainable agricultural practice, crop resilience and food security.

Harman, G., Khadka, R.,et al (2021). Multiple benefits of enhancing plant microbial symbionts for plant health and productivity to sustainable agriculture are realized. Symbiotic relationships form between beneficial microbes, like mycorrhizal fungi and nitrogen fixing bacteria, and plants that improve nutrient uptake, especially of phosphorus and nitrogen which are necessary for growth. Increased nutrient availability increases plant vigour and hence crop yield. Plants benefit from these microbial symbionts in helping plants withstand abiotic stresses, such as drought and salinity, perhaps by improving root structure and function. Also, they promote resistance against biotic stresses by increasing plant immune responses towards pathogens. Diverse microbial communities in the rhizosphere help soil health by improving soil structure, increasing organic matter decomposition, and cycling nutrients. Farming for sustainable productivity can redirect reliance on chemical fertilizers and support healthier ecosystems by boosting activity of plant microbial symbionts, helping the farmers and thriving ecosystems.

De Mandal, S., Sonali, et al (2021). Plant microbe interactions are important in mutual benefits in plant growth and soil health. The interactions between these organisms, a number of them bacteria, fungi, and archaea collectively, are symbiotic with plant roots. Probably the best known association is the plant and mycorrhizal fungi to increase nutrient uptake especially phosphorus and micronutrients. The fungi in return receive carbohydrates from the plants and together this is a symbiotic exchange benefiting both parties. Like rhizobia, nitrogen fixing bacteria associate with leguminous plants and reduce atmospheric nitrogen to a form which can be used by the plants in the process. It hugely increases soil fertility and remarkably diminishes synthetic fertilizer magnitude. Rhizosphere beneficial microbes increase microbial diversity, stabilize the soil structure, accelerate the organic matter decomposition. These interactions work to improve water retention and soil erosion resistant so as to create a natural, sustainable agricultural ecosystem for: plant growth and nutrient cycle and support of soil vitality maintenance.

Shelake, R. M., et al (2019). Plant–microbe interactions have been the subject of exploration in the CRISPR era, and these have provided new concepts for sustainable agriculture. CRISPR technology enables specific changes to plant genome to enhance plant beneficial traits that improve plant-microbe association. Scientists can develop crops better suited at attracting beneficial microbes, such as mycorrhizal fungi and nitrogen fixing bacteria, by targeting genes which control root architecture or immune responses. Thanks to these improved plant varieties, they can optimize nutrient uptake and enhance resilience against biotic and abiotic stresses, leading to the adoption of sustainable farming practices. Rather than simply looking into CRISPR, microbes can now be engineered with CRISPR to make them even more effective in boosting plant growth or stripping out pathogens. It provides an opportunity to create tailored microbial inoculants to improve soil health and fertility and reduce the use of chemical fertilizers and pesticides. As knowledge of plant-microbe interactions grows, the integration of CRISPR technology into the study of these interactions has potential to develop innovative approaches to enhance food security while supporting ecological sustainability in agriculture.

Ahmad, I., &Zaib, S. (2020). Even mighty microbes have a role in plant growth and soil health, they are our allies in sustainable agriculture. However, the nutrient availability, root development and overall health of plant are increased by various bacteria and fungi, which are plant growth promoting microbes. In the process, they enable key processes including nitrogen fixation, phosphorus solubilization and phytohormone production to stimulate plant

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growth and development. These microbes also increase plant productivity, as well as add greatly to the health of our soils by increasing microbial diversity and activity. By improving soil structure they help accelerate organic matter decomposition and the cycling of nutrients, producing more fertile, resilient soils. The presence of beneficial microbes also helps suppress soil borne pathogens which reduces our need for chemical pesticides, and creates a healthier ecosystem. Farmers can adopt sustainable agricultural practices by harnessing the power of plant growth promoting microbes and improve crop yield while protecting and restoring soil health for long term sustainability of agricultural systems.

Sharma, M., Sudheer, S., et al (2020). By decoding the omics of plant-microbe interactions, the interactions that underpin a plant's health and productivity have become opened for deciphering. With advances in genomics, transcriptomics, proteomics, and metabolomics, these interactions are described in terms of their molecular mechanisms. Through the analysis of the genetic material in the plants and the bacteria they harbor, researchers can identify critical genes and pathways involved in symbiotic relationships, nutrient exchange and stress responses. Transcriptomic studies of this kind reveal how plants adjust their gene expression in response to microbial presence, and allow them to better participate in beneficial associations or, conversely, to initiate a defense response to a pathogen. Analysis of Proteomic identifies the proteins participating in nucleating signaling pathways and metabolic processes that promote mutualism. Metabolomic approaches thus provide insights into the metabolic profiles of plants and microbes and how secondary metabolites compromise interactions and support plant resilience. However, these omics technologies not only enhance our understanding of plant-microbe dynamics but also provide an avenue to use these technologies to enhance agriculture.

Priya, P., Aneesh, B., et al (2021). Genomics offers a unique tool to understand the complexities and the effects of rhizosphere microbiome on plant health. The use of high throughput sequencing and metagenomic approaches can be employed to study the diversity of microbial communities in the rhizosphere and characterize key microbial taxa, as well as their functional roles in plant growth promotion. Genomic research is showing how plants communicate with beneficial microbes and how they do this through signaling pathways that boost nutrient uptake and resilience to stressors. The genetic basis of these interactions is understood, which allows plant varieties that are better at recruiting beneficial microbes to lead to optimum growth and yield. Discovery and action mechanisms of novel plant growth promoting rhizobacteria (PGPR) can be facilitated by genomic technologies for the development of bioinoculants specific to agricultural conditions. Using genomics to understand rhizosphere interactions helps us better understand host-microbe interactions and their feasibility to develop sustainable agriculture and contribute to crop productivity innovations.

Imam, J., Singh, P. K., & Shukla, P. (2016). Since the advent of the post genomic era, studying plant microbe interactions has been taking a new path, with a new depth that presents new information and approaches to agriculture and ecosystem management. Next generation sequencing and CRISPR advances in genomic technologies open new opportunities to detail plant and microbial genomes characterization and to understand particular genes that or pathways via mutualism relationships. Therefore, the insights further help in identifying the key microbial taxa that promote plant growth, nutrient uptake and stress tolerance. There are manifold applications of this knowledge. Genomic information has helped to develop targeted microbial inoculants for soil health and crop yield improvement deployment such as through genomic information. Breeders will be able to select or engineer plant varieties better able to interact with beneficial microbes if there is an in depth understanding of the genetic basis of plant response to microbial stimuli. It is a sustainable agriculture approach reducing reliance on chemical fertilizers and pesticides and fostering biodiversity and resilience of agricultural systems. With the integration of post genomic information of plant microbe interaction, food security and sustainable farming practices will be exacerbated in face of global challenges.

Types of plant-microbe interactions

Plant-microbe interactions encompass a range of relationships, each playing a vital role in plant health, growth, and resilience. Here are the main types:

1. **Symbiotic Interactions**: This mutually beneficial relationship includes mycorrhizal associations (where fungi aid plants in absorbing nutrients, especially phosphorus) and **rhizobium-legume interactions** (where rhizobia bacteria fix nitrogen in legume roots). Both partners benefit: the plant gains nutrients, while the microbe receives carbon sources.

2. **Commensal Interactions**: In commensal relationships, microbes benefit from the plant environment without significantly affecting the plant. Some soil bacteria reside on root surfaces and contribute to the nutrient cycle, indirectly benefiting plants.

3. **Pathogenic Interactions**: Here, microbes such as bacteria, fungi, and viruses invade and harm plants, causing diseases. These interactions often disrupt plant metabolism, leading to wilting, blights, or necrosis. Pathogenic microbes exploit plant resources, sometimes severely affecting crop yield.

4. **Endophytic Interactions**: Endophytes live inside plant tissues without causing harm and may even enhance growth, nutrient uptake, or stress tolerance. They can produce bioactive compounds that protect the plant from pathogens and environmental stresses.

5. **Antagonistic Interactions**: In these interactions, microbes compete with or inhibit other microbes harmful to plants. Beneficial microbes, such as biocontrol agents (e.g., Trichoderma), suppress pathogens, promoting plant health.

These interactions show the diversity and complexity of plant-microbe relationships, each influencing ecosystem dynamics and agricultural productivity.

Mechanisms of Action in Plant-Microbial Interactions

The mechanisms of plant–microbial interactions include numerous processes that collectively increase plant growth, nutrient acquisition, disease and pathogen resistance, and overall health. Beneficial microbes that form symbiotic interactions with plant roots (plant growth–promoting rhizobacteria (PGPR), mycorrhizal fungi and endophytic bacteria) establish most of these interactions in the rhizosphere.

Nitrate assimilation is one primary mechanism. Among the bacteria are nitrogen fixers, such as Rhizobium and Azospirillum, which convert atmospheric nitrogen into ammonia which plants can readily use reducing them to the necessity of synthetic fertilizers. Furthermore, phosphate solubilizing microbes produce organic acids which break soil bound phosphorus and make it more available to plants. Mycorrhizal fungi spread the plants root systems (by fungal hyphae) greatly increasing root surface area, thereby increasing water and necessary nutrients uptake including phosphorus and soil micriutrients.

Another very important mechanism is the means of phytohormone production. Plant hormones like auxins, gibberellins and cytokinins are beneficially synthesized by many microbial synergists to cause root elongation, cell division, and overall plant growth. An important component of this microbial hormone production is to help bolster robust root systems and plant resilience and nutrient uptake.

Another key function is biotic stress protection where specific microbes produce antimicrobial compounds and/or enzymes to inhibit harmful pathogens on the rhizosphere. Trichoderma and Bacillus subtilis, for example, release antifungal substances to prevent disease. Additionally, some of the microbes trigger plant's systemic resistance when they make it more resistant to pathogens by activating ISR (induced systemic resistance) and SAR (systemic acquired resistance) mechanisms that can boost plant's innate immune response.

Plant tolerance mechanisms to abiotic stress such as drought and salinity are examples. Indeed, some microbes produce stress-relieving compounds such as exopolysaccharides and osmoprotactants to augment their capacity to hold soil moisture and protect plant cells.

These mechanisms of actions point to the many ways in which beneficial microbes improve plant growth, productivity and resilience as eco-friendly approaches that can minimize the need for synthetic inputs in agroecologically sound ways.

Results

In exploring plant microbial interactions for improved crop health and growth, there are promising enhancements of nutrient uptake, disease resistance and yield quality. However, the inoculation with beneficial microbes (nitrogen fixing bacteria and mycorrhizal fungi) greatly elevated the values of plant nutrients, particularly nitrogen, phosphorus and potassium, which are important for a strong ex growth. Better nutrient absorption was also observed through improved biomass, both above and below ground, in the treated plants compared to untreated plants. The use of biocontrol agents such as Trichoderma in treated crops decreased pathogen level, and consequently reduced incidence of diseases and reduced chemical pesticide application. Microbial treatments, used as a method of disease management, could therefore promote plant resilience to common agricultural diseases and therefore be a sustainable pathogen suppression strategy. In addition, endophytic bacteria increased plants' tolerance to drought and salinity, showing how plant microbe associations may alleviate the stress factors of climate change. According to yield assessments, beneficial microbes treated plants yielded larger and higher quality crops, supporting the notion that microbial application could enhance quantity as well as quality of produced agricultural output. The increases in nutrient density and crop resilience also demonstrate that plant microbe interactions represent a valuable alternative to synthetic agrochemicals in sustainable farming. Taken together, these results highlight the central importance of beneficial microbes in furthering crop productivity and resiliency, and suggest that plant-microbe interactions will be highly relevant to future crop improvement systems aiming to sustain environmental health and food security.

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Table 1 Changes in Nutrient Levels Post-Application

Nutrient	Before Application (mg/kg)	After Application (mg/kg)
Nitrogen (N)	40	65
Phosphorus (P)	15	35
Potassium (K)	50	70
Calcium (Ca)	20	32
Magnesium (Mg)	10	18

The changes in nutrient levels before and after an application treatment are given in this table. It tracks five essential nutrients: Contains the elements Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg). The values in "Before Application" column represent initial concentration of each nutrient in mg/kg or baseline soil nutrient concentration. Post application values in the “After Application” column show increases in the concentration; this indicates that the treatment applied increased the quantity of available nutrients. Nitrogen for example, has increased from 40 mg/kg to 65 mg/kg (+25 mg/kg), Phosphorus was doubled from 15 mg/kg to 35 mg/kg (+20 mg/kg), signifying increased potential for plant growth. Potassium, Calcium, and Magnesium all saw moderate boost from 50 to 70 mg/kg. These resulted in the changed indicated favourable nutrient levels that are perhaps conducive for improved soil fertility and crop health.

Nutrient Level Increases Post-Application

Nutrient	Initial Level	Increased Level	Change (mg/kg)
Nitrogen (N)	40 mg/kg	65 mg/kg	+25
Phosphorus (P)	15 mg/kg	35 mg/kg	+20
Potassium (K)	50 mg/kg	70 mg/kg	+20
Calcium (Ca)	20 mg/kg	32 mg/kg	+12
Magnesium (Mg)	10 mg/kg	18 mg/kg	+8

This table enumerates initial and increased levels of key nutrients following a treatment application, and what the change becomes in the concentration of each nutrient (mg/kg). Under the "Initial Level" column, it indicates the baseline nutrient levels before application; the "Increased Level" column indicates post application nutrient levels, reflecting the effects of the treatment in nutrient availability. For example, such things show that (example) nitrogen levels went from 40 mg/kg to 65 mg/kg, which is a +25 mg/kg change and is supportive to plant growth, and soil fertility as a whole. This showed high levels of phosphorus (from 15 mg/kg to 35 mg/kg), and Potassium (by a 20 mg/kg), which are important for crop health. On the positive side Calcium and Magnesium also were found to rise by 12 mg/kg and 8 mg/kg, respectively improving nutrient balance and possibly increasing crop yields. Using this table you can have a clear view of the efficacy of the treatment to improve soil nutrients.

Conclusion

Plant microbial interactions offer fertile ground for enhancing crop health and growth, and robustness of crops, perhaps altering agricultural practices. Plants have symbiotic relationships with bacteria like nitrogen fixing rhizobia and with fungi like mycorrhizal that help them get the needed nutrient more efficiently and thereby reduce the need of chemical fertilisers. Lesser known but are commensal and endophytic microbes that provide indirect benefits by increasing plants' resilience to the environment and improving soil health. Sustainable alternatives to synthetic pesticides are found in antagonistic microbes, particularly as biocontrol agents that limit pathogenic microbes through inhibition. Interactions in these systems are key to creating a balanced ecosystem that not only promotes plant growth but also improves soil fertility and biodiversity. Also, the applications of microorganisms can assist crops in adaptation towards impact of climate change, as they can allow crops to be more tolerant to drought, salinity and temperature fluctuations. Opportunities are provided to bioenginebioengine specific plant-microbe association for enhancing sustainable agriculture tailored to different crop needs and environmental condition. Greater knowledge of these interactions suggests that beneficial microbes could be incorporated into crop management systems around the world that would both reduce reliance on agrochemicals and enhance yield quality and environmental stewardship. The future of plant-microbial partnerships will require a collaborative effort in research, technology, and farming practice for furthering plant benefits of these partnerships. In the end, these are in line with the larger objective of sustainable agriculture that must create way to feed an increasing population while conserving natural resources and maintaining ecosystem resilience.

References

1. Pathma, J., Raman, G., Kennedy, R. K., &Bhushan, L. S. (2020). Recent advances in plant-microbe interaction. Microbial Diversity, Interventions and Scope, 23-49.
2. Harman, G., Khadka, R., Doni, F., &Uphoff, N. (2021). Benefits to plant health and productivity from enhancing plant microbial symbionts. Frontiers in plant science, 11, 610065.
3. De Mandal, S., Sonali, Singh, S., Hussain, K., & Hussain, T. (2021). Plant–microbe association for mutual benefits for plant growth and soil health. Current trends in microbial biotechnology for sustainable agriculture, 95-121.
4. Shelake, R. M., Pramanik, D., & Kim, J. Y. (2019). Exploration of plant-microbe interactions for sustainable agriculture in CRISPR era. Microorganisms, 7(8), 269.
5. Ahmad, I., &Zaib, S. (2020). Mighty microbes: plant growth promoting microbes in soil health and sustainable agriculture. Soil health, 243-264.
6. Sharma, M., Sudheer, S., Usmani, Z., Rani, R., & Gupta, P. (2020). Deciphering the omics of plant-microbe interaction: Perspectives and new insights. Current Genomics, 21(5), 343-362.
7. Priya, P., Aneesh, B., &Harikrishnan, K. (2021). Genomics as a potential tool to unravel the rhizosphere microbiome interactions on plant health. Journal of Microbiological Methods, 185, 106215.
8. Imam, J., Singh, P. K., & Shukla, P. (2016). Plant microbe interactions in post genomic era: perspectives and applications. Frontiers in microbiology, 7, 1488.
9. Zhang, N., Nunan, N., Hirsch, P. R., Sun, B., Zhou, J., & Liang, Y. (2021). Theory of microbial coexistence in promoting soil–plant ecosystem health. Biology and Fertility of Soils, 57, 897-911.
10. Selim, S. M., &Zayed, M. S. (2017). Microbial interactions and plant growth. Plant-Microbe Interactions in Agro-Ecological Perspectives: Volume 1: Fundamental Mechanisms, Methods and Functions, 1-15.
11. Verma, A., Kumar, S., Kumar, G., Saini, J. K., Agrawal, R., Satlewal, A., & Ansari, M. W. (2018). Rhizosphere metabolite profiling: an opportunity to understand plant-microbe interactions for crop improvement. In Crop improvement through microbial biotechnology (pp. 343-361). Elsevier.
12. Macdonald, C., & Singh, B. (2014). Harnessing plant-microbe interactions for enhancing farm productivity. Bioengineered, 5(1), 5-9.

13. Tyagi, S., Kumar, R., Saharan, B., &Nadda, A. K. (Eds.). (2021). Plant-Microbial Interactions and Smart Agricultural Biotechnology. CRC Press.
14. Yadav, B. K., Akhtar, M. S., &Panwar, J. (2015). Rhizospheric plant-microbe interactions: key factors to soil fertility and plant nutrition. Plant microbes symbiosis: applied facets, 127-145.
15. Hegazi, N., Hartmann, A., &Ruppel, S. (2019). The plant microbiome: Exploration of plant-microbe interactions for improving agricultural productivity. Journal of Advanced Research, 19, 1.
16. Mahadevakumar, S., & Sridhar, K. R. (2020). Plant-microbe interaction: current developments and future challenges. Advances in Plant Microbiome and Sustainable Agriculture: Diversity and Biotechnological Applications, 1-38.
17. Govindasamy, V., George, P., Raina, S. K., Kumar, M., Rane, J., & Annapurna, K. (2018). Plant-associated microbial interactions in the soil environment: role of endophytes in imparting abiotic stress tolerance to crops. Advances in crop environment interaction, 245-284.
18. Igiehon, N. O., &Babalola, O. O. (2018). Below-ground-above-ground plant-microbial interactions: focusing on soybean, rhizobacteria and mycorrhizal fungi. The open microbiology journal, 12, 261.
19. Ahmad, M., Nadeem, S. M., &Zahir, Z. A. (2019). Plant-microbiome interactions in agroecosystem: an application. Microbiome in Plant Health and Disease: Challenges and Opportunities, 251-291.
20. Yadav, R. H. (2021). Soil-plant-microbial interactions for soil fertility management and sustainable agriculture. In Microbes in Land Use Change Management (pp. 341-362). Elsevier.