https://doi.org/10.56946/jspae.v1i2.73

ISSN: 2957-9082
Journal of Soil, Plant and Environment

Review

Comprehensive analysis of the mechanism underlying plastic microbiome and plants interaction, with future perspectives

Qaisar khan[1]*, Muhammad Kashif[2], Syed Jalil Shah[3]

[1]College of Agriculture, Guangxi Key Laboratory of Sugarcane, Guangxi University, Nanning, 530004, China
[2]National Engineering Research Center for Non-Food Biorefinery, State Key Laboratory of Non-Food Biomass and Enzyme Technology, Guangxi Key Laboratory of Bio-refinery, Guangxi Research Center for Biological Science and Technology, Guangxi Academy of Sciences, Nanning, 530007, China
[3]School of Chemistry and Chemical Engineering, Guangxi University, Nanning 530004, China
Corresponding Author: qaisar.khan@yahoo.com

Received: 01 Oct 2022
Revised: 07 Nov 2022
Accepted: 14 Nov 2022

ABSTRACT: Agriculture has a vital role in the life cycle of an economy. Phytopathogenic microorganisms negatively influence many crops, the economy, and the Environment worldwide. Beneficial plant microbiomes have the immense potential to provide cost-effective and maintainable solutions to existing agricultural challenges. The yield improvement can partly be credited to advanced plant pest and disease management, including better knowledge of phytopathogens and diverse control methods. Well-organized and balanced crop protection is of vast economic and ecological importance for food and feed production. A varied variety of goods made of plastics are utilized in farming which consists of poly-tunnels, plastic reservoirs, mulches, ropes, agrochemical cans, various nets, irrigation systems, packaging bags, nursery pots, anti-bird nets, greenhouses, and their components, wear and tear of these products are hosts of diverse microorganisms in agriculture. However, little investigation has been done to explore plastic microbes' diversity, survival strategies, and interaction mechanisms with plants. Several advanced approaches, including metagenomics, metabolomics, metatranscriptomics, metaproteomics, and culturomics, are currently available to scrutinize the multiplicity, composition, and functions of the microbiomes in soil and plant habitats such as rhizosphere, phyllosphere, and endosphere. This review highlights the increasing use of plastic, plastic microbiomes, subsequent challenges, and future perspectives in agriculture. It emphasizes using advanced molecular tools and techniques to explore the microbiome diversity and the mechanism of plant-microbe interaction. The analyzed knowledge gaps in the host-pathogen relationship research area will help to redraft better research approaches based on economic thresholds.

KEYWORDS: Agricultural plastic, plant microbiome interaction, agrotechnical control, omics application, competence and persistence

1. Introduction

As sessile organisms, plants are under endless attack by microbes entering them for nutrients, shelter, and survival. Mutualistic and parasitic microorganisms colonize the above and below-ground parts of the plant. These microbes could be divided into two groups according to colonization areas, those which inhabit the exterior parts of the plant, generally called epiphytes, and those that live inside the plants are endophytes. Phyllosphere microorganisms colonize the leaf surface, and those which populate regions closest to the root system are the most abundant microorganisms, known as rhizosphere inhabitants (Dong et al., 2019; Sivakumar et al., 2020). The rhizosphere microbes are attracted to the root system because of root exudates (Lakshmanan et al., 2014). The exudates differ according to the plant's developmental stages and physiological conditions (Choudhary et al., 2016). The conscription of microbes to the root regions results from plant exudation and has a diverse role in the growth, development, and inhibition of host pathogens (Philippot et al., 2013). This association suggests an interdependency between the host plants and microbes in the above and below-ground environments.

Sustainability is the capability of the ecosphere and human society to live together. Three main factors compose sustainability: society, Environment, and economy (Naamala et al., 2016). So, it is significant to scheme economically affordable mechanisms to implement approaches to protect resources, be Environment friendly, and have social acceptance. Knowing enough about the tools and pathways of critical values necessary for conniving strategies to face increasing global food demand without destroying the ecosystem is essential. Diverse microorganisms in contact with plants consist of organisms living on surfaces, within cells, and in the soil near the root interfaces of the plant (Cepeda, 2012).

Various microbial groups impact plant health, growth, development, and yield positively or negatively. Indirectly, microbes could become a source of negativity, such as the initiation of diseases in plants, the manufacture of phytotoxic elements, the encouragement of soil-borne microorganisms, and the reticence of seed germination (Daisley et al., 2022). The existence of particular pathogens in agriculture can bring complete crop failure. If the situation is so, the farmers need blanket approaches to extinguish harmful microbes' threats (Watson et al., 2002).

Beneficial microorganisms have numerous roles and actions within the agricultural sector that are significant for plant sustainable growth and development (Sundh et al., 2021). Plant growth-promoting bacteria have been reported to play an essential role in maintaining the soil's physical, chemical, and biological properties by accelerating nutrient and water uptake, particularly in abiotic stress situations, one of the main hurdles in agricultural development and yield improvement (Abdelaal et al., 2021). Unearthing novel microorganisms and assessing their efficiency would be significant for high-yield sustainability in agriculture (Herman et al., 2019).

2. Plants microbe interaction

During their life, plants continuously interact with diverse microorganisms, such as pathogens, symbionts, and commensal. These microbes' interactions could significantly impact plants' vital traits, including their growth and resilience against biotic and abiotic stress and shelf life. Pathological microbes severely threaten the growth and yield of essential crop plants worldwide. However, the interaction between plants and microbes may have positive or negative effects according to the types and nature of plants and microbes and their circumstances (Compant et al., 2019). The genes of microbes in the microbiome that interact with plants have their genetic repertoire and can improve the host plant's adaptation to an environmental perturbation or prevent it from performing (Douglas and Werren, 2016; López-Mondéjar et al., 2017). So, it needs a meticulous investigation to isolate the beneficial microbes from microbiomes and use them for crop growth improvement, yield enhancement, and cost reduction.

3. Sources of microbial contamination

3.1 Plastic as microorganisms host

Food, fruits and vegetables have significant nutritional values and health impacts established for a long time. Plants, mainly comestible vegetables, and other crops host various microorganisms on their surfaces. Some recognized bacterial contamination sources include contaminated manure, irrigation water, soil, livestock, wildlife, and several other factors, mainly plastics, that cause the occurrence, destiny, transportation, survival, and proliferation of pathogens in the vast diversity of bases where they are active. When pathogenic bacteria are introduced into the growing Environment, they colonize the plants and remain attached to fresh produce through several mechanisms.

3.2 Contamination prevention

To guarantee production protection on a sustainable scale, it is imperative to properly recognize the paths of pathogen's entry, fortune, carriage, establishment, and survival in the agricultural Environment like soil, irrigation water, manure, seeds, and other tools and sources. Rhizosphere microbiota has been widely and deeply studied for decades; however, leaf microbiota and biofilms in irrigation systems are still ineffectively explored. The sources of microbiota on plant leaves have not been fully known until today. Phyllosphere is diverse in structure, and microorganisms can enter via air, soil, plants, animals, insects, birds, water, and other circumstantial materials (Vorholt, 2012)

4. Plastic use and challenges

4.1 Plastic a need of everyday life

Plastic use is inevitable in daily life and can be noticed on beaches, streets, gutters, storm drains, wedged in trees, behind bushes, and stomachs of dead animals in massive quantities (Pacific, 2019; Rodrigues et al., 2019). Plastics are ubiquitous, and investigators are just beginning to know how to handle the adverse effects of rising plastic pollutants on the ecosystem (Forrest et al., 2019). The range of plastic contamination and its impacts on the biosphere is alarming and needs massive strategies to deal with the challenges (Almroth and Eggert, 2019; Gross and Enck, 2021). The contributors to plastic pollution are significant in numbers and unavoidable. Plastics can potentially interfere with the life activities of humans, animals, forests, oceans, and agriculture, highlighting the emergency for developing vital tools and approaches to solve the problem of plastic pollution (Chae and An, 2018; Vriend et al., 2021).

4.2 Plastic production

Plastic products are a matter of routine use worldwide, and their kinds and amounts of utilization differ by area and region, which depends on mechanization and supply chain. In 2021, 390.7 million tonnes (Mt) of plastic were produced globally. 90.2% of the 390.7 million tonnes of plastic is fossil-based, 8.3% post-consumer recycled, and 1.5% bio-based/bio-attributed (Fig. 1). In North America (18%), EU27+3 (15%), China (32%), Japan (3%), Latin America (4%), Middle East Africa (8%), the rest of Asia (17%) and CIS[2] (3%) of 390.7 million tonnes plastic were produced (Fig. 2). 4% of this global plastic was used in farming, gardening, and agriculture in 2021.

5. Plastic application in agricultural

The plastic product application broadly involves protecting, distributing, retailing, and maintaining quality in agriculture, livestock, aquaculture, and fisheries. The main types of agricultural plastic include surface mulching films, tunnels, greenhouses, nets, irrigation tubes, fleece, driplines, sacks, bottles, silage films, coatings on fertilizers, pesticides, seeds, fruit protectors, plant protectors, ropes, lines, traps, enclosures, bale wrap, plastic bags, ear tags, tree shelters, fishing gear, pesticide containers, polymer-coated controlled release fertilizers, nets used for aquacultural and fisheries operations (Fig. 3) (FAO, 2021). These ubiquitous plastics carry possible microorganisms which induce health risks to plants and produce consequences. Plastics carry pathogenic microbes and support the genetic element's horizontal exchange in the niche, which can initiate pathogen evolution in a virgin habitat (Maraveas, 2020; Serna-Abascal et al., 2022). The specific interaction mechanisms and impacts of plastic-associated microbiomes on crops remain unknown.

6. Plant-microbe interaction investigation

Understanding plant-microbe interaction includes genetic, molecular, and biochemical approaches; however, the recent past has witnessed important technical innovations in super-resolution microscopy and cryo-electron microscopy techniques to view microbes at the nanoscopic level. Moreover, new tools and algorithms for live imaging and data processing have been established, and evolving subfields in cell biology extend researchers valued viewpoints for more mechanistic studies. Overall, current advances in cell biology provide extraordinary chances to study plant-microbe interaction at the cellular, molecular and nanoscopic levels (Dal Cortivo et al., 2017). Advanced RNA., DNA., genome, proteome certification, and analysis techniques are used to discover plant-microbe interaction mechanisms for crop improvement (Douglas and Werren, 2016). If the features of microbial communities in the rhizosphere, phyllosphere, and on the surfaces of the irrigation system are beneficial and influential could be used as a sustainable alternative for crop improvement and productivity in long-term schemes (Vishwakarma et al., 2020).

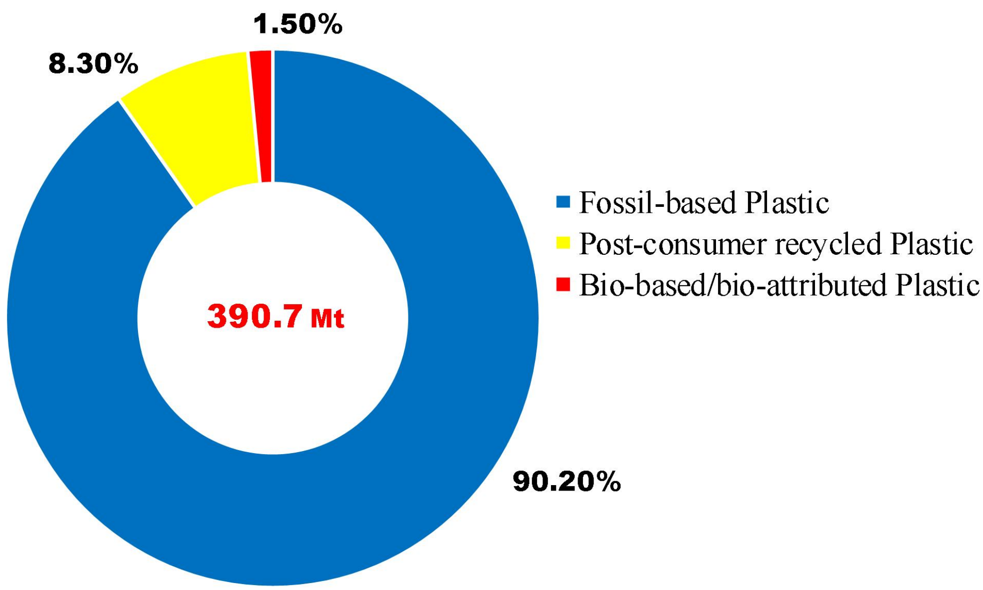

Figure 1. Global plastics production in 2021 (Data source: Plastics Europe e.V., 2021)

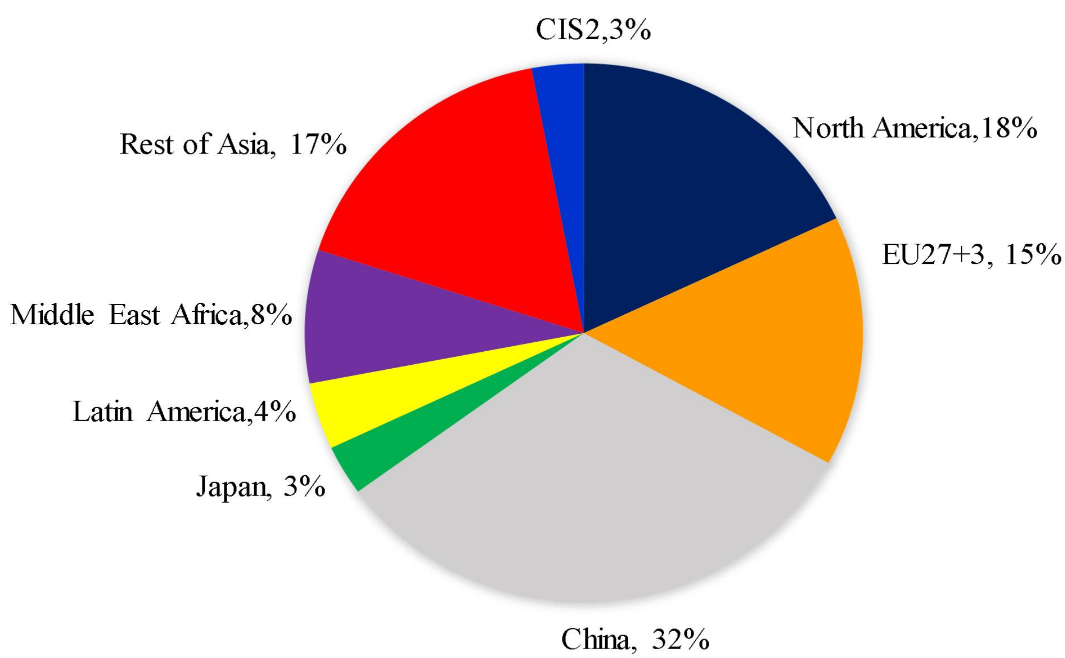

Figure 2. Worldwide distribution of plastics production in 2021 (Data source: Plastics Europe e.V., 2021).

Figure 3. Use of plastic in agriculture for different purposes. A: Mulching films, B: Bunker covers, C: Bale nets and twines, D: Ropes, E: Fishing nets, F: Hydroponic irrigation pipes, G: Plastic cane as pots (ISBN 978-92-5-135402-5. ©FAO, 2021)

7. Plant microbiomes

Plants are exposed to various communities of microorganisms, and microbiota colonizes all accessible tissues. The microbiome resides in the endosphere, phyllosphere, rhizosphere nutrient solutions, and irrigation system, creating host-plant interaction (Fig.4). Environment induces interactions and increases plant resilience to subsequent stresses (Naylor and Coleman-Derr, 2018; Trivedi et al., 2020). Promising advancements have been made in recognizing the impact of the microbiome on plant growth and development, but the traits responsible for plant resilience to environmental conditions need to be identified. The advanced research on plant-microbiome interaction is essential for forecasting and evaluating the effects of climate alteration on key competence and diversity.

7.1 Phyllosphere microorganisms

The phyllosphere is an ecosystem, unlike the rhizosphere and endosphere (Enespa and Chandra, 2022). The phyllosphere contains prokaryotes, eukaryotes, viruses interacting mutually, and their host plants (Lindow and Brandl, 2003). Limited nutrient availability and changing climatic circumstances make the phyllosphere an active and stressful environment for its microbiomes (Couée et al., 2006; Trouvelot et al., 2014). Future investigation into phyllosphere microbiomes and stimulants may clarify the mechanisms and operations that regulate the connection between plants and microbiomes in the atmosphere.

7.2 Endosphere microorganisms

Microorganisms called endophytes which penetrate and inhabit the internal tissues of plants, create the endosphere microbiome. The scientific community was with opinion for a long time; plants with no indications of illnesses have no microorganisms, generally bacteria (Compant et al., 2021). Endophyte is a habitat containing all those microorganisms that spend entire or part of their life in internal tissues (Hardoim et al., 2015). Endophytic microbes have drawn much attention because of their mysterious interaction with plants. Having enough knowledge about endophytic microbial life the endosphere is still taken as a habitat with no fit conditions for microbial diversity (Theis et al., 2016). So, it is critical to investigate endophytic microbial groups, existing environmental factors, and their roles in improving plant growth and development with their impacts on yield.

7.3 Rhizosphere microorganisms

A thin area of soil around the roots of a plant which is influenced by numerous factors, such as root exudates and related soil microorganisms, is termed a rhizosphere (Chesworth, 2008). The rhizosphere is a significant portion of soil that is accountable for several metabolic processes, like the cycling of nutrients and carbon uptake (Ng and Ng, 2014; Singh, 2013). The roots of plants generate an interface between the soil environment and the plant, which hosts a massive pool of microbial communities (Hakim et al., 2021). The rhizosphere contains diverse microorganisms such as bacteria, algae, parasites, fungi, and viruses (Kumar and Dubey, 2020). Rhizosphere microbiota shield plants against phytopathogens and promotes plant growth and development by producing plant growth hormones. It also helps plants resistance against environmental unrests like irregular variations in temperature, salinity, drought, and all other harshnesses (Burghardt, 2020; Lu et al., 2018). However, discovering the mechanism present under the interaction of plants and rhizosphere microorganisms still needs further investigation.

8. Advanced probing tools and techniques

Currently many microbial investigating tools and techniques are available including microbial cultivation by plating methods, electron microscopy-SEM-TEM (Goldsmith and Miller, 2009; Wisse et al., 2010) , nucleic acid extraction, DNA sequencing, PCR/qPCR (Del Mar Lleò et al., 2000; Garibyan and Avashia, 2013; Khan et al., 2016; Overbergh et al., 2003; Pagano et al., 2011; v. Wintzingerode et al., 1997), clone genomic libraries, stable isotope probing, microarrays, next generation technique (NGS) metagenomics (Marchev et al., 2021), transcriptomic (Handelsman, 2004; Khan et al., 2021), proteomics (Khan et al., 2022), molecular finger printings techniques, denaturing gradient gel electrophoresis (DGGE) (Al‐Mailem et al., 2017), terminal-restriction length polymorphism (T-RFLP) (Portillo et al., 2011), temperature gradient gel electrophoresis (TGGE) (Ritchie et al., 2000), single-strand conformational polymorphisms (SSCP) (Johnston‐Monje and Lopez Mejia, 2020), ribosomal internal spacer analysis (RISA) (Osborn et al., 2000) , length heterogeneity-PCR (LH-PCR) (DeAngelis et al., 2011), random amplified polymorphic DNA (RAPD) (Bardakci, 2001; Broadway, 2012) and biosensors (Gavrilaș et al., 2022) etc. However, the methods, tools, and techniques are selected according to the need of the research goals and directions.

9. Conclusion

The rising global population at an alarming

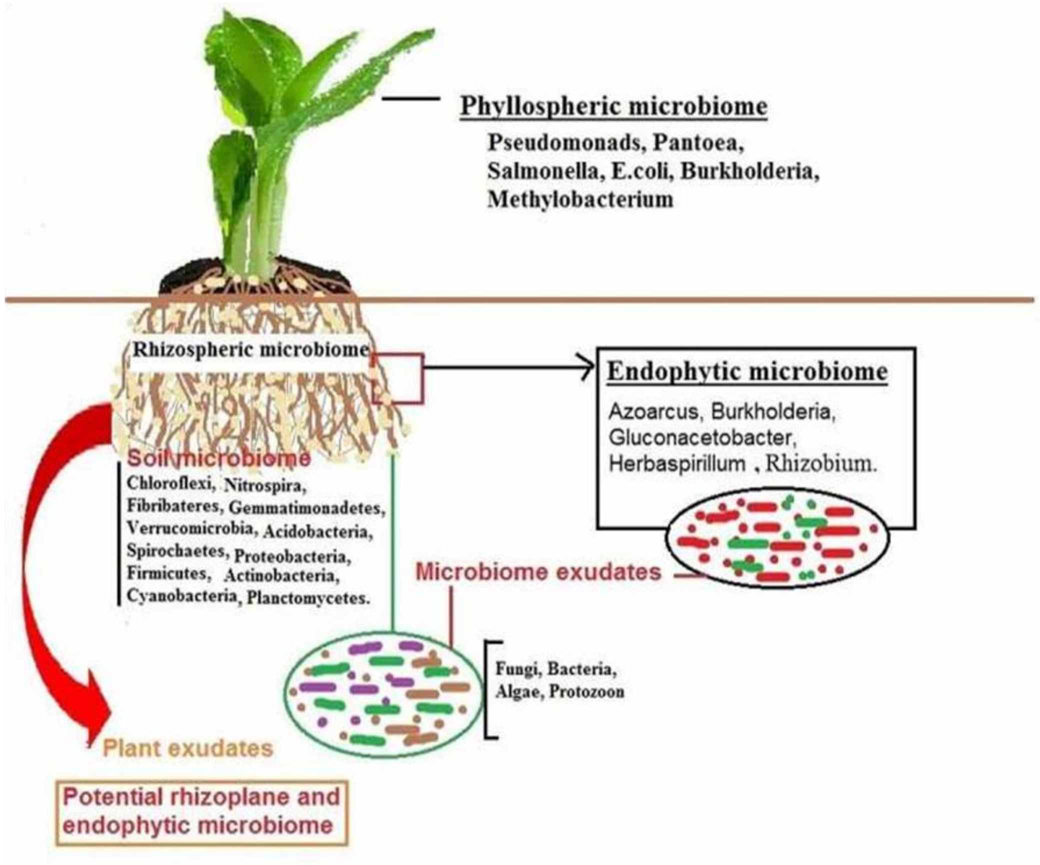

Figure. 4. Plant microbiomes classification (Enespa and Prem Chandra, 2022)

rate requires enhanced crop production to sustain the world's food needs supply and ensure agricultural sustainability. Missing feasible replacements for plastic use in agricultural activities made it impractical to avoid their utilization, and there are no silver bullets to eradicate the challenges due to plastic application. Plastic use in agricultural activities may have worthy advantages in the short term; however, long-term negative impacts cannot be overlooked, particularly as microbes host. Detection of microbiomes in rhizospheric, phyllospheric, and endophytic zones of plants and the mechanism of their interactions are highly important. A wide range of advanced tools and techniques is available which could be applied to achieve comprehensive knowledge about microbes' diversity, interaction mechanism, and positive or negative impacts on plants, especially crops. Understanding the microbe's diversity, lethality, and positive roles in a particular habitat will enable scientists to design precautionary measures against contamination and subsequent losses. The isolation and identification of beneficial microbial strains could be used in crops to achieve commercial targets. A comprehensive understanding of the underlying mechanism in plant microbes' interaction is necessary, which could be reached via novel methodologies and protocol optimization. The development of precautions and principles applied in sampling, packing, preservation, storage, transportation, and disposal to minimize the risk of contamination is also a substantial need.

10. Future perspectives

From the commercial point of view, it would be valuable to recognize the strains and their roles in a crop cultivated in a particular environment rather than detecting whole microbiota. The investigations should focus on the microbes in nutrient solutions, irrigation systems, all agricultural use plastics, and plant parts above and below ground. Knowledge of molecular mechanisms underlying plant-microbe interaction will be useful for manipulating and developing strategies in the future. Disclosing microbial effects on resource use efficiency in the crop will facilitate precise cost-effective analysis. Identifying novel plant growth-promoting microbes will reduce agricultural costs and environmental pollution. Genetic and chemical analysis of exudates is essential to understand microbe's recruitment in the rhizosphere. Comprehensive elucidation of plastic microbiomes' nature and their interaction with plants is crucial to better manage the damaging risks in the agricultural economy. Identified beneficial microbes could be used to improve plant growth and production. It will provide the foundation for the enhanced governing system with broad plastic application in agricultural practices locally and globally.

Authors Contributions

Q.K designed the research, wrote the manuscript, and contributed to all aspects of the paper. M.K contributed to the microbial section. S.J.S added to the plastic section. The Author (s) read and approved the final manuscript.

Availability of Data and Materials

Not Applicable.

Acknowledgments:

I wish to thank Muhammad Kashif and Syed Jalil Shah for their help writing this review article.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Abdelaal, K., AlKahtani, M., Attia, K., Hafez, Y., Király, L. and Künstler, A. The role of plant growth-promoting bacteria in alleviating the adverse effects of drought on plants. Biology, (2021). 10 (6), 520.

Al-Mailem, D.M., Kansour, M.K. and Radwan, S.S. Capabilities and limitations of DGGE for the analysis of hydrocarbonoclastic prokaryotic communities directly in environmental samples. Microbiologyopen, (2017). 6 (5), e00495.

Almroth, B.C. and Eggert, H. Marine plastic pollution: sources, impacts, and policy issues. Review of environmental economics and policy, (2019).

Bardakci, F. Random amplified polymorphic DNA (RAPD) markers. Turkish Journal of Biology, (2001). 25 (2), 185-196.

Broadway, D.C. How to test for a relative afferent pupillary defect (RAPD). Community Eye Health, (2012). 25 (79-80), 58.

Burghardt, L.T. Evolving together, evolving apart: measuring the fitness of rhizobial bacteria in and out of symbiosis with leguminous plants. New Phytologist, (2020). 228 (1), 28-34.

Cepeda, M.V. (2012): Effects of microbial inoculants on biocontrol and plant growth promotion. PhD thesis, The Ohio State University, USA.

Chae, Y. and An, Y.J. Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. Environmental pollution, (2018). 240, 387-395.

Chesworth, W. (2008): Encyclopedia of soil science. edited by Ward Chesworth, University of Guelph Canada.

Choudhary, D.K., Varma, A. and Tuteja, N. (2016): Plant-microbe interaction: an approach to sustainable agriculture. Springer, 1st ed. edition.

Compant, S., Cambon, M.C., Vacher, C., Mitter, B., Samad, A. and Sessitsch, A. The plant endosphere world–bacterial life within plants. Environmental Microbiology, (2021). 23 (4), 1812-1829.

Compant, S., Samad, A., Faist, H. and Sessitsch, A. A review on the plant microbiome: ecology, functions, and emerging trends in microbial application. Journal of advanced research, (2019). 19, 29-37.

Couée, I., Sulmon, C., Gouesbet, G. and El Amrani, A. Involvement of soluble sugars in reactive oxygen species balance and responses to oxidative stress in plants. Journal of experimental botany, (2006). 57(3), 449-459.

Daisley, B.A., Chernyshova, A.M., Thompson, G.J. and Allen-Vercoe, E. Deteriorating microbiomes in agriculture-the unintended effects of pesticides on microbial life. Microbiome Research Reports, (2022). 1(1), 6.

Dal Cortivo, C., Barion, G., Visioli, G., Mattarozzi, M., Mosca, G. and Vamerali, T. Increased root growth and nitrogen accumulation in common wheat following PGPR inoculation: Assessment of plant-microbe interactions by ESEM. Agriculture, Ecosystems & Environment, (2017). 247, 396-408.

DeAngelis, K.M., Wu, C.H., Beller, H.R., Brodie, E.L., Chakraborty, R., DeSantis, T.Z., Fortney, J.L., Hazen, T.C., Osman, S.R. and Singer, M.E. PCR amplification-independent methods for detection of microbial communities by the high-density microarray PhyloChip. Applied and environmental microbiology, (2011).77(18), 6313-6322.

Del Mar Lleò, M., Pierobon, S., Tafi, M.C., Signoretto, C. and Canepari, P. mRNA detection by reverse transcription-PCR for monitoring viability over time in an Enterococcus faecalis viable but nonculturable population maintained in a laboratory microcosm. Applied and Environmental Microbiology, (2000). 66(10), 4564-4567.

Dong, C.J., Wang, L.L., Li, Q. and Shang, Q.M. Bacterial communities in the rhizosphere, phyllosphere and endosphere of tomato plants. PloS one, (2019).14 (11), e0223847.

Douglas, A.E. and Werren, J.H. Holes in the hologenome: why host-microbe symbioses are not holobionts. Mbio, (2016). 7 (2), e02099-02015.

Enespa and Chandra, P. Tool and techniques study to plant microbiome current understanding and future needs: an overview. Communicative & Integrative Biology, (2022). 15 (1), 209-225.

FAO. Assessment of Agricultural Plastics and Their SustainabilityA Call for Action, (2021). Rome.

Forrest, A., Giacovazzi, L., Dunlop, S., Reisser, J., Tickler, D., Jamieson, A. and Meeuwig, J.J. Eliminating plastic pollution: How a voluntary contribution from industry will drive the circular plastics economy. Frontiers in Marine Science, (2019). 6, 627.

Garibyan, L. and Avashia, N. Research techniques made simple: polymerase chain reaction (PCR). The Journal of investigative dermatology, (2013). 133 (3), e6.

Gavrilaș, S., Ursachi, C.Ș., Perța-Crișan, S. and Munteanu, F.D. Recent Trends in Biosensors for Environmental Quality Monitoring. Sensors, (2022). 22(4), 1513.

Goldsmith, C.S. and Miller, S.E. Modern uses of electron microscopy for detection of viruses. Clinical microbiology reviews, (2009). 22(4), 552-563.

Gross, L. and Enck, J. Confronting plastic pollution to protect environmental and public health. Public Library of Science San Francisco, (2021). p. e3001131 CA USA.

Hakim, S., Naqqash, T., Nawaz, M.S., Laraib, I., Siddique, M.J., Zia, R., Mirza, M.S. and Imran, A. Rhizosphere engineering with plant growth-promoting microorganisms for agriculture and ecological sustainability. Frontiers in Sustainable Food Systems, (2021). 5, 617157.

Handelsman, J. Metagenomics: application of genomics to uncultured microorganisms. Microbiology and molecular biology reviews, (2004). 68 (4), 669-685.

Hardoim, P.R., Van Overbeek, L.S., Berg, G., Pirttilä, A.M., Compant, S., Campisano, A., Döring, M. and Sessitsch, A. The hidden world within plants: ecological and evolutionary considerations for defining functioning of microbial endophytes. Microbiology and molecular biology reviews, (2015).79 (3), 293-320.

Herman, L., Chemaly, M., Cocconcelli, P.S., Fernandez, P., Klein, G., Peixe, L., Prieto, M., Querol, A., Suarez, J.E. and Sundh, I. The qualified presumption of safety assessment and its role in EFSA risk evaluations: 15 years past. FEMS microbiology letters, (2019). 366 (1), fny260.

Johnston-Monje, D. and Lopez Mejia, J. Botanical microbiomes on the cheap: Inexpensive molecular fingerprinting methods to study plant-associated communities of bacteria and fungi. Applications in Plant Sciences, (2020). 8 (4), e11334.

Khan, Q., Chen, J.Y., Zeng, X.P., Qin, Y., Guo, D.J., Mahmood, A., Yang, L.T., Liang, Q., Song, X.P. and Xing, Y.X. Transcriptomic exploration of a high sucrose mutant in comparison with the low sucrose mother genotype in sugarcane during sugar accumulating stage. GCB Bioenergy, (2021). 13(9), 1448-1465.

Khan, Q., Qin, Y., Guo, D.J., Lu, Z., Xie, X.-Q., Yang, L.T., Liang, Q., Song, X.P., Xing, Y.X. and Li, Y.R. Proteome Based Comparative Investigation of a High Sucrose Sugarcane Mutant in Contrast to the Low Sucrose Mother Variety by Using TMT Quantitative Proteomics. Sugar Tech, (2022).1-14.

Khan, S., Ullah, M.W., Siddique, R., Nabi, G., Manan, S., Yousaf, M. and Hou, H. Role of recombinant DNA technology to improve life. International journal of genomics, (2016).

Kumar, A. and Dubey, A. Rhizosphere microbiome: Engineering bacterial competitiveness for enhancing crop production. Journal of Advanced Research, (2020). 24, 337-352.

Lakshmanan, V., Selvaraj, G. and Bais, H.P. Functional soil microbiome: below-ground solutions to an aboveground problem. Plant physiology, (2014). 166 (2), 689-700.

Lindow, S.E. and Brandl, M.T. Microbiology of the phyllosphere. Applied and environmental microbiology, (2003). 69 (4), 1875-1883.

López-Mondéjar, R., Kostovčík, M., Lladó, S., Carro, L. and García-Fraile, P. (2017) Probiotics in agroecosystem. pp. 233-268, Springer.

Lu, T., Ke, M., Lavoie, M., Jin, Y., Fan, X., Zhang, Z., Fu, Z., Sun, L., Gillings, M. and Peñuelas, J. Rhizosphere microorganisms can influence the timing of plant flowering. Microbiome, (2018). 6 (1), 1-12.

Maraveas, C. Environmental sustainability of plastic in agriculture. Agriculture, (2020). 10 (8), 310.

Marchev, A.S., Vasileva, L.V., Amirova, K.M., Savova, M.S., Balcheva-Sivenova, Z.P. and Georgiev, M.I. Metabolomics and health: From nutritional crops and plant-based pharmaceuticals to profiling of human biofluids. Cellular and Molecular Life Sciences, (2021).78 (19), 6487-6503.

Naamala, J., Jaiswal, S.K. and Dakora, F.D. Microsymbiont diversity and phylogeny of native bradyrhizobia associated with soybean (Glycine max L. Merr.) nodulation in South African soils. Systematic and applied microbiology, (2016). 39 (5), 336-344.

Naylor, D. and Coleman-Derr, D. Drought stress and root-associated bacterial communities. Frontiers in plant science, (2018). 8, 2223.

Ng, T. and Ng, C. Functions of mycorrhizae. Mycorrhizas: Structure, Development and Functions, (2014).125-138.

Osborn, A.M., Moore, E.R. and Timmis, K.N. An evaluation of terminal-restriction fragment length polymorphism (T-RFLP) analysis for the study of microbial community structure and dynamics. Environmental microbiology, (2000). 2 (1), 39-50.

Overbergh, L., Giulietti, A., Valckx, D., Decallonne, B., Bouillon, R. and Mathieu, C. The use of real-time reverse transcriptase PCR for the quantification of cytokine gene expression. Journal of biomolecular techniques, (2003).14 (1), 33.

Pacific, N. (2019). Plastic in Everyday Life-Let's Reduce the Use. Natura Pacific.

Pagano, J.M., Clingman, C.C. and Ryder, S.P. Quantitative approaches to monitor protein–nucleic acid interactions using fluorescent probes. RNA, (2011). 17(1), 14-20.

Philippot, L., Raaijmakers, J.M., Lemanceau, P. and Van Der Putten, W.H. Going back to the roots: the microbial ecology of the rhizosphere. Nature Reviews Microbiology, (2013). 11(11), 789-799.

Portillo, M., Villahermosa, D., Corzo, A. and Gonzalez, J. Microbial community fingerprinting by differential display-denaturing gradient gel electrophoresis. Applied and Environmental Microbiology, (2011). 77(1), 351-354.

Ritchie, N.J., Schutter, M.E., Dick, R.P. and Myrold, D.D. Use of length heterogeneity PCR and fatty acid methyl ester profiles to characterize microbial communities in soil. Applied and environmental microbiology, (2000). 66 (4), 1668-1675.

Rodrigues, M., Abrantes, N., Gonçalves, F., Nogueira, H., Marques, J. and Gonçalves, A. Impacts of plastic products used in daily life on the Environment and human health: What is known? Environmental toxicology and pharmacology, (2019). 72, 103239.

Serna-Abascal, C., Pérez-López, A., Villaseñor-Perea, C. and Mancera-Rico, A. Plastics alternative materials used in agriculture: A systematic review and bibliometric analysis. Journal of Agricultural Sciences-Sri Lanka, (2022). 17(1).

Singh, J. Potential Microbes for Sustainable Agriculture. Resonance, (2013). 275-276.

Sivakumar, N., Sathishkumar, R., Selvakumar, G., Shyamkumar, R., and Arjunekumar, K. (2020). Phyllospheric microbiomes: diversity, ecological significance, and biotechnological applications. In Plant microbiomes for sustainable agriculture. pp. 113-172. Springer, Cham

Sundh, I., Del Giudice, T. and Cembalo, L. Reaping the Benefits of Microorganisms in Cropping Systems: Is the Regulatory Policy Adequate? Microorganisms, (2021). 9 (7), 1437.

Theis, K.R., Dheilly, N.M., Klassen, J.L., Brucker, R.M., Baines, J.F., Bosch, T.C., Cryan, J.F., Gilbert, S.F., Goodnight, C.J. and Lloyd, E.A. Getting the hologenome concept right: an eco-evolutionary framework for hosts and their microbiomes. Msystems, (2016).1 (2), e00028-00016.

Trivedi, P., Leach, J.E., Tringe, S.G., Sa, T. and Singh, B.K. Plant–microbiome interactions: from community assembly to plant health. Nature reviews microbiology, (2020). 18 (11), 607-621.

Trouvelot, S., Héloir, M.-C., Poinssot, B., Gauthier, A., Paris, F., Guillier, C., Combier, M., Trdá, L., Daire, X. and Adrian, M. Carbohydrates in plant immunity and plant protection: roles and potential application as foliar sprays. Frontiers in plant science, (2014). 592.

V. Wintzingerode, F., Göbel, U.B. and Stackebrandt, E. Determination of microbial diversity in environmental samples: pitfalls of PCR-based rRNA analysis. FEMS microbiology reviews, (1997). 21 (3), 213-229.

Vishwakarma, K., Kumar, N., Shandilya, C., Mohapatra, S., Bhayana, S. and Varma, A. Revisiting plant-microbe interactions and microbial consortia application for enhancing sustainable agriculture: A review. Frontiers in Microbiology, (2020).11, 560406.

Vorholt, J.A. Microbial life in the phyllosphere. Nature Reviews Microbiology, (2012).10 (12), 828-840.

Vriend, P., Hidayat, H., van Leeuwen, J., Cordova, M., Purba, N., Löhr, A., Faizal, I., Ningsih, N., Agustina, K. and Husrin, S. Plastic pollution research in Indonesia: state of science and future research directions to reduce impacts. Frontiers in Environmental Science, (2021). 187.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R. and Rayns, F. Managing soil fertility in organic farming systems. Soil use and management, (2002). 18, 239-247.

Wisse, E., Braet, F., Duimel, H., Vreuls, C., Koek, G., Damink, S.W.O., van den Broek, M.A., De Geest, B., Dejong, C.H. and Tateno, C. Fixation methods for electron microscopy of human and other liver. World journal of gastroenterology, (2010).16 (23), 2851.

How to cite this article:

Khan, Q., Kashif, M., Shah, S.J. Comprehensive analysis of the mechanism underlying plastic microbiome and plants interaction, with future perspectives. Journal of Soil, Plant and Environment (2022); 1(2)-pp; 31-43. https://doi.org/10.56946/jspae.v1i2.73