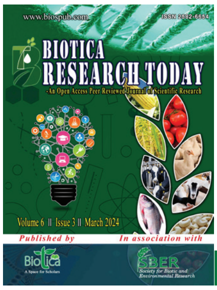

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Microbe-Assisted Plant Breeding: A Paradigm Shift for Sustainable Agriculture

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Abstract

Microbe-assisted plant breeding (MAPB) revolutionizes agriculture by leveraging microbes for enhanced growth and sustainability. MAPB accelerates breeding, optimizes yields and reduces synthetic input dependence by recognizing bacteria, fungi, and viruses as pivotal contributors to plant development. The core microbiome, integral to plant holobiont, provides crucial functional genes. MAPB introduces genetic variability, supports resistance breeding and follows a systematic workflow for success. The study of soil-borne pathogen resistance in common beans unveils intricate rhizosphere dynamics. Overall, MAPB reshapes agriculture, promotes precision breeding and sustainability and reduces reliance on synthetic inputs concisely and impactfully.

Keywords: Genetic variability, Holobiont, Microbe assisted plant breeding, Synthetic input

Introduction

Microbe-assisted plant breeding (MAPB) stands as a prominence of agricultural innovation, showing a paradigm shift that capitalizes on the intricate relationships between plants and microorganisms to revolutionize growth, productivity and sustainability in agriculture. This cutting-edge approach recognizes microbes, including bacteria, fungi and viruses, as pivotal contributors to plant development and health, unlocking a rich source of potential enhancements for agricultural practices. The core of this transformative strategy lies in the strategic application of microbial products such as biofertilizers, biopesticides and biostimulants, derived from naturally occurring microbes or their metabolites. These products are tailored to provide an array of benefits, ranging from accelerated growth and improved health to heightened productivity. MAPB aims to optimize agricultural yields while simultaneously reducing dependence on synthetic inputs. It introduces microbial assistance into traditional breeding programs, expediting the identification of desirable traits through the facilitation of molecular markers and enabling the selection of superior plant varieties. At the heart of this approach is an understanding of concepts like microbiota, microbiome and holobiont, emphasizing the interconnectedness of plants and microorganisms in diverse environments. The concept of a core microbiome, intricately linked with the plant holobiont, becomes central, offering a repository of functional genes crucial for plant fitness.

This work delves into the multifaceted realm of microbe-assisted plant breeding, exploring its potential to unlock novel avenues for sustainable and efficient agriculture. From the concept of holobiont and the genetic variability offered by the microbiome to microbiome-supported resistance breeding and the requirements for effective microbial breeding, this article provides a comprehensive overview of the diverse facets shaping the landscape of microbial-mediated breeding strategies. Through detailed examinations of soil-borne pathogen resistance in common beans and the holistic workflow of microbe-assisted plant breeding, this review elucidates the complexities and promises inherent in harnessing microbial interactions for the advancement of modern agriculture. In essence, this script strives to unravel the transformative potential of microbe-assisted plant breeding and its implications for the future of agricultural practices.

Article History

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Microbe-Assisted Plant Breeding

MAPB represents a cutting-edge paradigm in agriculture, leveraging the intricate relationships between plants and microorganisms to enhance growth, productivity and sustainability. Microbes, encompassing bacteria, fungi and viruses, emerge as key players in plant development and health, offering a rich source of potential improvements for agricultural practices. In this innovative approach, microbial products such as biofertilizers, biopesticides and biostimulants take center stage. Microbes also play a crucial role in accelerating traditional breeding programs. They can facilitate the expression of molecular markers, expediting the identification of desirable traits and aiding in the selection of superior plant varieties. This integration of microbial assistance not only streamlines breeding processes but also contributes to developing more resilient and high-performing crops. Understanding the broader context, terms like microbiota, microbiome and holobiont become central to this field. Microbiota refers to the collective microorganisms in a given environment, encompassing bacteria, viruses and fungi. The microbiome, on the other hand, represents the entirety of microbial genomes within a well-defined habitat characterized by distinct physio-chemical properties. The concept of holobiont emphasizes the association between a host (such as a plant) and other organisms, exemplified by microorganisms or microbiota. Within the plant-microbe dynamic, the notion of a core microbiome gains significance. This core microbiome, intricately linked through evolutionary mechanisms with the plant holobiont, is tightly associated with the plant genotype. It provides a repository of functional genes crucial for plant fitness, further underlining the potential of microbe-assisted plant breeding to unlock novel avenues for sustainable and efficient agriculture.

Holobiont

A holobiont is a term used to describe the concept of a host organism and all of its associated symbiotic microorganisms, collectively forming a functional ecological unit. This includes bacteria, fungi, viruses and other microorganisms that live in or on the host organism and contribute to its overall biology and ecology. The holobiont concept emphasizes the interconnectedness and interdependence of the host and its associated microbial community. In the context of plants, the plant holobiont refers to a plant and the diverse array of microorganisms that inhabit its various tissues and organs. These microorganisms can have significant effects on the plant's growth, development and overall health. The interactions within the holobiont are dynamic and can influence various aspects of the host organism's physiology, including nutrient acquisition, defense against pathogens and response to environmental stress. Understanding the holobiont concept is crucial in fields like microbiome research and microbe-assisted plant breeding, where the goal is often to manipulate or enhance the interactions between the host organism and its associated microorganisms for improved agricultural outcomes. Recognizing the holobiont as a unit of selection and adaptation highlights the importance of studying not just the host organism but also its entire associated microbial community in ecological and evolutionary contexts (Wille *et al*., 2019).

Requirements for Microbial Breeding

Microbial breeding encompasses establishing a central regulator for microbiota and identifying interactive hubs through network analysis. Understanding microbial interaction mechanisms is vital and amplicon sequencing facilitates fast and comprehensive microbial composition analysis. Improving culture collections for enhanced genomic resolution and developing synthetic communities (SynCom) are essential steps. Identification of molecular markers linked to external traits and conducting field trials for trait validation are pivotal. Linking host genes to microbial community structure adds value, providing a holistic understanding for efforts like massive cataloging of crop wild relatives. Overall, these prerequisites form the foundation for effective microbial breeding strategies, optimizing plant-microbe interactions for improved agricultural outcomes (Kroll *et al*., 2017).

Microbiome Offers Genetic Variability to Plants

The microbiome plays a pivotal role in providing genetic variability to plants through various mechanisms. The holobiont theory, an inheritable trait conferred by the plant microbiome, underscores the interconnectedness of the host and its associated microorganisms. Seed endophytes emerge as promising carriers of the core microbiome, contributing to the transmission of beneficial traits across generations. The rhizosphere microbiome introduces heterogeneity in plants, influencing their health and productivity and providing an adaptive advantage. Epigenetics and horizontal gene transfer (HGT) within the rhizosphere environment further contribute to the genetic diversity of plants. Additionally, the synthetic ecology of designing microbial communities offers innovative avenues for shaping plant traits. Notably, altering flowering time in cold climates holds significant implications for plant phenotypic plasticity, potentially opening new trajectories for plant neo-domestication. Overall, the complex interactions within the plant microbiome contribute significantly to the genetic variability and adaptability of plants (Lyu *et al*., 2021).

Microbiome-Supported Resistance Breeding

Microbiome-supported resistance breeding focuses on countering fungal pathogens that are drawn to susceptible genotypes, resulting in severe infections and stunted plant growth. In contrast, the resistant genotype releases compounds, depicted in yellow, that either directly suppress pathogens or attract beneficial microbes. These beneficial microbes, in turn, aid in the plant's defense against pathogens. The process involves root exudates, which can both stimulate or suppress soil-borne pathogens, highlighting the intricate interplay between these exudates and the microbial community. Genotypic variations in root exudation further contribute to the effectiveness of resistance breeding strategies by influencing the dynamics of plant-microbe interactions (Wille *et al*., 2019).

Breeding for Plant-Microbe Interactions

In the pursuit of breeding for plant-microbe interactions, there is a need to disentangle environmental effects by moving beyond the traditional G×E (Genotype by Environment) interaction to a more intricate G×E′×MB framework, where G represents the host genotype, E' encompasses climate and physicochemical soil conditions and MB denotes the soil and/or plant microbiome. This approach is essential for distinguishing the influence of the microbiome (MB) from the broader environmental factors (E) due to its dynamic and evolving nature. Such a framework proves to be a valuable tool for capturing the complexity of ecological interactions, thereby enhancing the predictability and effectiveness of microbe-assisted plant breeding strategies. By incorporating the microbiome into the breeding pattern, this approach acknowledges the nuanced interplay between genetics, environmental conditions and microbial communities, paving the way for more informed and targeted breeding efforts (Wille *et al*., 2019).

Workflow of MA Plant Breeding

The workflow begins with the identification of target traits, followed by the careful selection of microbial candidates. The chosen microbes undergo thorough characterization, ensuring a comprehensive understanding of their attributes. Subsequently, microbial inoculation takes place, introducing these beneficial microorganisms to the plants. The next step involves the evaluation of plant performance, where the impact of microbial interactions on desired traits is assessed. Breeding and selection follow, incorporating the insights gained from the microbial-influenced plant performance. Field testing serves as a crucial phase, validating the success of the breeding efforts under real-world conditions. Finally, upon successful outcomes, the process concludes with commercialization, bringing the developed plant varieties to the market. This systematic workflow ensures a comprehensive and effective approach to harnessing microbial assistance in plant breeding.

Holobiontomics

Holobiontomics approaches involve employing similar -omics techniques for the comprehensive characterization of both plant and microbe features. Utilizing sequencing techniques, the microbial profile and specific isolates are thoroughly characterized, providing insights into the composition and diversity of the microbiome. Metabolomics and Volatilomics approaches are then employed to identify key metabolites involved in the intricate interactions between microbes and their hosts. Once the core microbiota is selected, the focus shifts to evaluating plant growth-promoting features and the biological control potential within this holobiont system. Finally, phenomics is employed to detect and analyze plant responses, completing a holistic approach that integrates molecular and phenotypic data to understand the dynamic interactions within the plant-microbe holobiont (Marco *et al*., 2022).

Breeding for Soil-Borne Pathogen Resistance Impacts the Active Rhizosphere Microbiome of Common Bean

The pursuit of soil-borne pathogen resistance in common beans has notable implications for the active rhizosphere microbiome. The presence of the soil-borne pathogen *Fusarium oxysporum* has been observed to influence gene expression within the rhizosphere microbiome. In particular, the Fox-resistant cultivar exhibits an increased abundance of Bacillus and Pseudomonas, known for their proficiency in producing phenazine and rhamnolipids. Despite both cultivars maintaining complex microbial diversity, the Fox-resistant variant demonstrates the prevalence of Paenibacillus, which contributes to antibiotic production and the inhibition of pathogenic fungi. Additionally, in the resistant cultivar, there is a distinctive impact on cell motility and chemotaxis, influencing the overall assemblage of the rhizosphere microbiome. These findings underscore the intricate interplay between plant resistance traits and the dynamic composition of the rhizosphere microbial community (Mendes *et al*., 2018).

Conclusion

In conclusion, microbial-mediated breeding represents a groundbreaking approach that seeks to recreate the natural microbial communities associated with plants. This innovative strategy establishes a crucial link between the beneficial functions of individual microbes or entire microbiomes and specific plant traits. By directly intervening in plant physiology, microbial-mediated breeding has demonstrated its capacity to increase plant yield while generating a new range of phenotypes without altering the plant's genomic information. This targeted approach allows for the precise improvement of specific traits, such as nutrient use efficiency and disease resistance. Importantly, the adoption of microbial-mediated breeding not only enhances agricultural efficiency but also contributes to the stability of farming practices by reducing reliance on synthetic fertilizers and pesticides. Furthermore, the positive impact extends to soil fertility, highlighting the multifaceted benefits of integrating microbial interactions into plant breeding methodologies.

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