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Editorial: Microbial-based inoculants for agriculture: production and improvement of commercial formulations

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Editorial on the Research Topic
Microbial-based inoculants for agriculture: production and improvement of commercial formulations

Introduction

Agriculture is undergoing a paradigm shift. With increasing urgency to meet global food demand while preserving environmental integrity, sustainable intensification has become a central objective across international research and policy agendas. In this context, microbial-based inoculants (i.e., beneficial bacteria, fungi, yeasts, and algae) are gaining widespread recognition as promising tools for enhancing crop productivity, improving nutrient use efficiency, and reducing dependence on synthetic agrochemicals.

These microbial solutions offer multifunctional benefits. They can promote plant growth through phytohormone production, biological nitrogen fixation, nutrients (phosphate, potassium, zinc, iron etc.) solubilization, and the activation of systemic resistance against biotic and abiotic stressors. Their deployment is also aligned with the principles of regenerative agriculture and circular economy models, both of which emphasize biodiversity, resource efficiency, and closed-loop systems. Importantly, microbial inoculants play a central role in restoring and sustaining soil health, an increasingly vital consideration given widespread soil degradation and the need for climate-resilient farming practices.

Yet, despite their potential, the transition from research prototypes to commercially viable, field-ready products remain complex. Challenges include the selection of robust and synergistic strains, scalable and cost-effective production, formulation stability, regulatory compliance, and adoption by farmers in diverse agro-ecological environments. Addressing these challenges requires an integrative approach that connects microbial ecology, bioprocess engineering, agricultural sciences, and innovation ecosystems.

This Research Topic brings together five contributions that exemplify the scientific, technological, and applied dimensions of microbial inoculant development. The articles span original research on strain co-culturing, valorization of industrial by-products, advanced production systems for mycorrhizal fungi, and in-field biostimulant efficacy, along with a comprehensive review of microbial biostimulants as agents of agroecological transition. Collectively, these works reflect a global research momentum dedicated to harnessing microbiological innovations for a more sustainable, resilient, and productive agriculture.

Farda et al. discussed both the technical and economic challenges in developing microbial consortia. They took an approach to develop a co-culturing protocol that would enable them to grow these strains together, *Azospirillum brasilense, Burkholderia ambifaria, Gluconacetobacter diazotrophicus*, and *Herbaspirillum seropedicae*. Inoculations were scheduled based on individual growth kinetics resulting in formulations of high density and viability for commercial application. This will reduce the production costs as well as make downstream processing easier (Farda et al.).

Ghorui et al. investigated the different methods for large scale mass production of arbuscular mycorrhizal fungi (AMF) for agricultural applications. Their paper details ways to produce it, like substrate-free bioreactors, synthetic media, and encapsulation technologies. Also, it talks about problems with life ability, storage time, and carrier fit. This work also explains the rules and business settings needed for more use of AMF as a soil addition (Ghorui et al.).

Adedayo and Babalola highlight the role of microbial biostimulants as a soil restoration agent and in the transition of agroecology. Their review tells us how microbial inoculants help in nutrient cycling, biodiversity, and resilience in farming systems. It relates their discussion to international policy frameworks that define such roles, including the European Green Deal and FAO soil management guidelines (Adedayo and Babalola).

Palraj et al. studied the *Desertifilum* sp. PSL17, a fresh-water cyanobacterium, which is quite proficient at producing indole-3-acetic acid and is also capable of promoting plant growth. This strain enhanced rice and green gram germination percentages along with biomass accumulation; therefore, it can be applied to legume cultivation. Such results help widen the range of extremophile microorganisms being considered for bio-based inputs (Palraj et al.).

Overall, the Research Topic reflects the growing scientific evidence on microbial inoculant field. Starting from basic microbiology and bioprospecting to bioprocess engineering and market deployment, all these contributions underscore the need for an interdisciplinary approach to unveil the potentialities of these bioformulations. The Research Topic and the articles published are in line with global policy frameworks promoting agroecological intensification and climate-resilient farming systems. They might inspire further research, public-private collaborations, and policy support to advance the integration of microbial technologies into global agricultural practices.

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Conflict of interest

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