Despite clear benefits, field performance of biofertilizers remains inconsistent, especially under diverse soil and climate conditions typical of vegetable production regions. Meta-analytical and review work emphasizes that the effectiveness of a given inoculant depends strongly on crop species, soil physicochemical properties, native microbiota, and climate; strain-environment mismatches can result in weak or negligible responses under farmer conditions. Large-scale field syntheses also caution that current data mostly reflect real-world but sub-optimal formulations and management, implying that observed benefits may underestimate biological potential while still displaying substantial variability across sites and crops.

A second major challenge is the translation of laboratory and greenhouse successes into robust, scalable technologies suitable for commercial vegetable systems. Reviews on formulation and commercialization highlight that poor survival of inoculants during storage, transport, and application, lack of quality control, and inadequate regulatory frameworks all contribute to variable outcomes and limited farmer trust. Regional assessments (e.g., Iran) further show that low soil organic matter, strong reliance on chemical fertilizers, and weak coordination among research, industry, and extension institutions have slowed adoption, underscoring that socio-economic and institutional bottlenecks are as important as technical ones.

Future work on biofertilizers in vegetable production needs to integrate multi-omics and systems approaches with agronomic experimentation to better match strains, formulations, and management to specific soils and crops. Advances in metagenomics, transcriptomics, and metabolomics are already clarifying how microbial consortia assemble in the rhizosphere and influence nutrient cycling; leveraging these tools can guide the design of targeted, crop and region specific biofertilizers with improved colonization and function. Large meta-analyses also suggest that trait-based selection (e.g., N fixation, P solubilization, stress tolerance) aligned with soil P levels, organic matter content, and pH can markedly increase success rates, providing a quantitative framework for precision biofertilization in intensive vegetable systems.

At the application level, research should prioritize long-term field trials in vegetable rotations, testing integrated strategies that combine microbial consortia with organic amendments, reduced mineral fertilization, and agroecological designs (e.g., push-pull, diversified rotations). Recent reviews argue that coupling biofertilizers with such systems can enhance soil health, pest regulation, and resilience to climate stresses, but require refined delivery methods, robust formulation technologies, and stringent quality control to ensure consistent performance . Strengthening links between microbiologists, agronomists, industry, and extension services will be crucial for scaling up these innovations, improving farmer awareness, and positioning biofertilizers as cornerstone inputs for climate-smart, high-quality vegetable production.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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