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EDITORIAL

The dual impact of *Trichoderma* on soil microbial communities: beneficial or disruptive?

El doble impacto de *Trichoderma* en las comunidades microbianas del suelo: ¿beneficioso o disruptivo?

The global population is projected to grow from 7.8 billion to 10 billion by 2050, significantly increasing the demand for agricultural products—whether for human and animal consumption or as raw materials for biofuels and industrial production. To feed this expanding population, overall food production must rise by approximately 60–70%. Achieving this goal will require the adoption of efficient, and preferably sustainable, agricultural practices. Over the past half-century, improvements in food production have largely been driven by a surge in the global use of chemical pesticides, which has led to increasingly negative environmental and health impacts.[5]

The key to sustaining agriculture is soil health, which depends on the functioning of the soil life system, driven by the ecological, environmental, and immune roles of soil microorganisms. These microbes regulate soil functional diversity, participate in the carbon cycle, decompose plant residues, enhance soil fertility, and improve nutrient availability.

To foster sustainable agriculture, *Trichoderma* spp. undoubtedly represent a group of advantageous soil-borne microorganisms. This genus exemplifies beneficial fungi that serve as effective biocontrol agents against various plant pathogens. Certain characteristics of this group enable them not only to combat a wide range of organisms, including bacteria, fungi, nematodes, and insects, but also to act as biostimulants. They promote plant growth, enhance stress tolerance, facilitate nutrient uptake, and strengthen the plant's immune system.[1] *Trichoderma* has been applied to agricultural field crops using various methods that directly involve the soil, such as seed treatment, soil drenching, and drip irrigation. Seed treatment with some species of this genus enhances seedling vigor and reduces seedling diseases, while soil drenching promotes root growth and improves nutrient uptake. Drip irrigation allows for the direct delivery of *Trichoderma* spp. to the roots, enhancing root colonization and disease control.

However, while *Trichoderma* is widely recognized for its beneficial effects on plant health, its impact on the resident soil microbial community remains a subject of debate. Through direct antagonism and competition, particularly within the rhizosphere, this fungus orchestrates microbial interactions, thereby shaping the soil microbiome. Many studies investigate soil microbial communities following *Trichoderma* application; however, consensus on its impact on diversity is still limited. Inoculation with these agents can alter soil microbial composition, raising concerns about the environmental safety of introducing microorganism-based formulations. Even if such changes are temporary, they may still impact native microbial communities. A recent meta-analysis of 143 studies by Cornell et al., [3] underscores the need to understand how inoculation events modify soil microbial communities, as well as the implications of these changes for overall soil ecosystem health. Several studies evaluating the impact of these fungi on soil microbial communities have yielded conflicting results, showing reductions, increases, or no effect on resident microbial diversity. For instance, some studies have reported a decline in bacterial and fungal diversity due to competitive exclusion by *Trichoderma* spp., as observed in the reduction of *Fusarium* populations. In contrast, other research has demonstrated that this fungus can promote beneficial microbial groups, such as plant growth-promoting rhizobacteria (*Pseudomonas* spp.) and mycorrhizal fungi, leading to greater microbial diversity. On the other hand, some studies have found no significant changes in microbial composition.[5]

Most of the research investigating the effects of *Trichoderma* on soil microbes focuses on taxonomic community responses, rather than on functional changes. The few recent studies examining the functional response of soil communities suggest that biocontrol agents vary in their

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capacity to reshape microbial community structure and that these alterations appear to be strain-specific, depending on both the strain used and the plant species involved.[4] Additionally, the extent of these effects is likely influenced by factors such as soil type, environmental conditions, and the resident microbial composition before inoculation. These conflicting results highlight the need for a deeper understanding of the ecological consequences of *Trichoderma* application.

Another key challenge is the need for advanced techniques to comprehensively assess the impact of beneficial microorganisms on soil microbiota. Advances in high-throughput sequencing of phylogenetically informative loci have provided valuable insights into the composition and dynamics of plant-associated microbiomes under diverse conditions. These studies have revealed the significant influence of rhizosphere microbiomes on crop yield, quality, and resilience to biotic and abiotic stressors. Given their essential role in plant growth and health, strategic manipulation of the rhizosphere and bulk soil microbiomes offers a promising pathway toward more sustainable agriculture.[2] High-throughput sequencing, also known as next-generation sequencing, which includes amplicon sequencing (Marker Gene Sequencing), automated ribosomal spacer analysis (ARISA), quantitative PCR (qPCR), along with integrated metagenomic and metabolomic approaches, offer enhanced analytical capabilities. A precise integration of these techniques is essential to gain deeper insights into how *Trichoderma* influences microbial community composition and activity in the soil, shedding light on its potential applications in plant disease management and soil health improvement. [5]

In conclusion, to harness the full potential of *Trichoderma* without unintended ecological disruptions, further research is required to clarify its interactions within soil microbial communities. Long-term field studies, high-throughput sequencing technologies, and metagenomic approaches can provide valuable insights into how this fungus reshapes soil microbial networks. Additionally, understanding the conditions under which *Trichoderma* exerts beneficial versus disruptive effects will aid in developing targeted applications that enhance soil health without compromising microbial diversity.

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