

## **Microbial biostimulants: From traditional to nanomaterial-based formulations**

Fabrizio De Cesare, DIBAF University of Tuscia, VT

Microbial-based biostimulants, a key player in sustainable agriculture, are designed to enhance plant health and productivity. When applied to plants or soils, these products, containing live microorganisms like bacteria, fungi, or algae, significantly improve nutrient uptake, enhance resistance to abiotic stresses, promote root development, and stimulate beneficial interactions within the plant microbiome. Unlike fertilisers or pesticides, microbial-based biostimulants indirectly support plant growth by optimising the plant's natural biological processes and improving soil health. Microbial-based biostimulants are not one-size-fits-all. They are available in diverse commercial formulations, each designed to suit different application methods and environmental conditions. These formulations, including granules, powders, suspensions, solutions, tablets, coated seeds, and soil amendments, offer various options, empowering agricultural operators to choose what best suits their needs. Several companies have already been manufacturing microbial-based biostimulants in Europe, mainly in Spain and Italy. Various factors can drive the selection of the suitable formulation of microbial-based biostimulants: i) application method, ii) microbial viability, and iii) environmental conditions. In addition, the choice of formulation will depend on the agricultural process to use, including the type of crop, soil conditions, and application equipment available. However, the performances of the aforementioned typical formulations can be affected by adverse conditions (physical, chemical and biological) occurring during i) the preparation of the final products, ii) their application, or iii) after this process. Of the multiple variables influencing the effectiveness and efficiency of the biostimulants, the most crucial are all those influencing microbial viability during the steps of these products' value chains. Different nanomaterials can further improve the performances of the typical formulations of microbial-based biostimulants.

We will discuss how harnessing the characteristics of each nanomaterial can help address shortcomings or adverse events and then influence the overall performances of the various functional microbial-based biostimulants, with a particular emphasis on those maintaining microbial viability.