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Editorial

The Utilization of Microorganisms for Controlling Fungal Root Diseases in Legume Crops

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Legume crops such as faba bean, chickpea, lupine, soybean, and lentil are critical components of sustainable agriculture due to their significant contributions to food and ecosystem services [1]. Legume crops are a vital source of protein for human consumption because of their high protein content (16 - 50%) [2]. Furthermore, legume crops are a source of fodder widely cultivated on a large scale in the semi-arid tropics [3]. One of the most important functions of legumes is to fix atmospheric nitrogen through symbiosis with rhizobia, which improves soil fertility [4]. Incorporating legume residues into soil after harvest can further enhance the productivity of subsequent crops [5]. Nonetheless, legumes offer multiple environmental advantages, including lowering agricultural production energy costs, reducing the risk of global warming, and minimizing ozone layer depletion [3]. Furthermore, legume species contribute to agroecosystem services by lowering greenhouse gas (GHG) emissions, increasing soil carbon absorption, and reducing reliance on synthetic nitrogen inputs. Consequently, legumes, with their multifunctionality and environmental benefits, should be recognized as key components in the development of sustainable agriculture [1].

Soil-borne pathogens that cause root rot, wilt, and stem rot diseases are among the most important limiting factors in crop productivity worldwide. These pathogens are responsible for substantial economic losses, with yield decreases ranging from 10% to more than 50%. Among the most destructive soil-borne pathogens that affect legume crops are *Rhizoctonia solani*, *Fusarium solani,* as well as several *formae speciales* of *Fusarium oxysporum*, *Sclerotinia sclerotiorum*, and *Macrophomina phaseolina* [6].

Managing these diseases is especially difficult since no single control measure provides complete or consistent efficacy. Common approaches, including adjustments to sowing dates, breeding for resistance, and implementing diverse cultural practices, often provide only limited success. Developing disease-resistant cultivars remains the most efficient and economically effective technique; however, resistant varieties are not yet available for many of these soil-borne pathogens [7]. Although many chemical treatments can effectively control soil-borne diseases, their high cost, environmental hazards, and potential health risks, such as water contamination and carcinogenicity, limit their sustainability and widespread use [9].

Plant growth-promoting microorganisms (PGPMs) have recently received attention and appear to be a promising alternative for disease management and soil health improvement. PGPMs enhance plant growth by solubilizing nutrients, improving soil structure, increasing water uptake, fixing atmospheric nitrogen, and producing phytohormones. Furthermore, several PGPMs display biocontrol activity through antagonism, competition, or by inducing systemic resistance in host plants [9-11]. PGPMs are classified into plant growth-promoting rhizobacteria (PGPR), including species such as *Bacillus, Paenibacillus, Pseudomonas*, *Streptomyces, Azospirillum, Azotobacter,* and symbiotic N-fixing microbes such as *Rhizobium, Bradyrhizobium, Sinorhizobium,* and *Mesorhizobium*; plant growth-promoting fungi (PGPF), including many species of *Trichoderma*, *Gliocladium,* and *Chaetomium;* arbuscular mycorrhizal fungi (AMF) [9]. In the European

Union, AMF is classified as a bio-stimulant product alongside PGPR and PGPF. In addition to its bio-stimulant properties, AMF can activate defensive systems, resulting in "mycorrhiza-induced resistance [12].

An increasing number of studies emphasize the importance of PGPMs in managing soil-borne diseases affecting legume crops [9,13-15]. This tendency is also visible in our research, which regularly confirmed the biocontrol potential of *Paenibacillus polymyxa*, *Pseudomonas fluorescens*, *Trichoderma harzianum*, and AMF against damping-off, root rot, and wilt diseases. For example, seed treatment of soybean with *P. polymyxa* and *P. fluorescens* significantly reduced damping-off caused by *R. solani* and improved plant survival, growth, and yield [16]. Similarly, in faba bean, the application of *P. polymyxa* and *T. harzianum* offered protection against *R. solani* and *Fusarium solani* f. sp. *fabae* under both greenhouse and field conditions, and enhanced defense enzyme activities [17]. Comparable disease suppression was observed in lupine against *R. solani* and *F. oxysporum* f. sp. *lupini* [18]. A triple inoculation of *P. polymyxa*, *P. fluorescens*, and AMF reduced damping-off in soybean and improved biochemical markers, including phenolic content and oxidative enzymes [19]. Furthermore, co-inoculation of *Methylobacterium nodulans* and *Rhizobium leguminosarum* biovar *viciae* in combination with reduced nitrogen fertilization effectively controlled root rot in faba bean and served as a promising biofertilizer strategy [20]. Combining *P. polymyxa* with *Rhizophagus intraradices* efficiently prevented root rot in chickpea caused by *R. solani* and enhanced defense responses and nutrient accumulation, leading to improved yield [21]. These results support the utilization of PGPMs in suppressing diseases and improving crop productivity, indicating a move toward sustainable strategies in legume production.

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