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Biological Management of Damping-Off Disease in Tomato (*Solanum lycopersicum L.*)

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Tomato (*Solanum lycopersicum* L.) ranks among the most economically significant vegetable crops cultivated globally, accounting for substantial contributions to agricultural productivity and food security. Despite its agronomic importance, tomato production is frequently constrained by a range of biotic stresses, of which damping-off disease represents one of the most destructive in nursery and early seedling stages. The disease causes severe pre- and post-emergence mortality of tomato seedlings, resulting in considerable reductions in plant stand density, seedling quality, and ultimately field productivity (Agrios, 2005).

Conventional management of damping-off has relied heavily on synthetic fungicides such as captan, thiram and metalaxyl. However, the widespread and indiscriminate application of these chemical inputs has raised serious concerns regarding environmental contamination, disruption of non-target soil microbial communities, development of pathogen resistance, and residue accumulation in agricultural produce (Pal & McSpadden Gardener, 2006). In this context, biological disease management — employing naturally occurring antagonistic microorganisms — has emerged as an ecologically sound, cost-effective, and sustainable alternative. Biological control agents (BCAs) not only suppress soilborne pathogens but also stimulate plant growth, enhance soil biological activity, and contribute to long-term soil health, rendering them highly compatible with integrated pest management (IPM) frameworks.

Damping-Off Disease: Etiology and Symptomatology

Damping-off is a polyphagous nursery disease incited by a complex of soilborne oomycetes and true fungi. The principal causal agents include *Pythium aphanidermatum* (Edson) Fitzp., *Rhizoctonia solani* Kühn (teleomorph: *Thanatephorus cucumeris*), *Phytophthora parasitica* Dastur and *Fusarium oxysporum* Schlechtend.:Fr., which may act individually or in synergistic combination depending on prevailing soil temperature, moisture conditions, and seedling age (Damicone & Iles, 2011). These pathogens are ubiquitous in agricultural soils and persist as resting structures (oospores, sclerotia, chlamydospores) for extended periods, rendering complete eradication impractical.

The disease manifests in two epidemiologically distinct phases:

- Pre-emergence damping-off: Pathogen infection occurs at the seed or radicle stage before seedling emergence. Colonization of the embryo and cotyledonary tissues leads to seed decay, necrosis of the radicle, and failure to germinate, resulting in poor plant stand establishment.
- Post-emergence damping-off: Infection occurs at the hypocotyl or collar region of emerged seedlings at or just below the soil surface. The affected tissue exhibits characteristic water-soaked lesions, followed by necrotic constriction and collapse of the stem, causing the seedlings to topple and die. High soil moisture, poor drainage, and overcrowded nursery conditions significantly predispose seedlings to post-emergence infection.

Biological Management Strategies

Biological management of damping-off exploits the antagonistic and plant growth-promoting properties of selected beneficial microorganisms to suppress pathogen populations and enhance seedling health. The principal strategies are described below.

Seed Biopriming with Biological Control Agents

Seed treatment (biopriming) with antagonistic microorganisms constitutes one of the most direct, economical, and targeted methods of biological disease management. Commercially formulated talc-based preparations of Trichoderma viride Pers. ex S.F. Gray, *Trichoderma harzianum* Rifai and *Pseudomonas fluorescens* Migula are applied to tomato seeds at recommended doses (4–10 g kg^{-1} seed) prior to sowing. Upon germination, these bioagents rapidly colonize the spermosphere and rhizosphere, forming a protective biological barrier against soilborne pathogens. *Trichoderma* spp. exert antagonism through mycoparasitism, competition for nutrients and space, and biosynthesis of antifungal secondary metabolites, whereas *P. fluorescens* suppresses pathogens via antibiosis, siderophore-mediated iron competition, and induction of systemic resistance in the host plant (Harman et al., 2004; Weller, 2007).

Enriched Organic Amendment Application to Nursery Beds

The incorporation of *Trichoderma*-enriched farmyard manure (FYM) or compost into nursery beds prior to sowing is an effective strategy for establishing a suppressive soil microbiome. The organic substrate serves as a carrier and nutritive medium that supports the proliferation and persistence of the introduced BCAs. The resulting biologically active soil environment competitively excludes pathogenic fungi through resource competition and the accumulation of antifungal metabolites, while simultaneously improving soil physical and chemical properties (Hoitink & Boehm, 1999).

Soil Treatment with Bioagent Formulations

Direct soil treatment through mixing of talc-based bioagent formulations with well-decomposed organic matter, followed by incorporation into the nursery bed, provides broad-spectrum suppression of soilborne pathogens. This practice reduces viable propagule densities of damping-off pathogens such as *Pythium* spp. and *R. solani*, while simultaneously enriching the native soil microbiome with beneficial organisms. Repeated application across successive nursery cycles has been shown to progressively enhance the disease-suppressive capacity of the treated soil (Cook & Baker, 1983).

Application of Vermicompost

Vermicompost — the product of earthworm-mediated decomposition of organic matter — has demonstrated considerable potential as a biologically active soil amendment for the suppression of damping-off. Its disease-suppressive properties are attributed to the presence of diverse populations of antagonistic bacteria and actinomycetes, high concentrations of humic acids, and elevated levels of available plant nutrients. Vermicompost application improves soil porosity, water-holding capacity, and aeration, thereby creating an edaphic environment less conducive to the proliferation of soilborne pathogens (Szczech & Smolinska, 2001). Moreover, it promotes vigorous root development, which confers enhanced tolerance to infection.

Integrated Nursery Management Practices

The efficacy of biological agents is substantially enhanced when integrated with sound cultural practices. Key nursery management measures include the use of raised beds with adequate drainage to prevent waterlogging, maintenance of optimal plant spacing to minimize humidity and foliar wetness, use of autoclaved or solarized nursery media to reduce initial pathogen load, and the adoption of certified disease-free seeds. The integration of these cultural practices with biological inputs constitutes a holistic approach to nursery disease management, consistent with the principles of integrated crop management (ICM).

Advantages of Biological Disease Management

The adoption of biological management strategies for the control of damping-off in tomato offers several distinct advantages over conventional chemical approaches:

- Environmental safety: BCAs are non-toxic to humans, animals, and beneficial soil fauna, and do not persist as hazardous residues in soil or water bodies.
- Reduction of chemical dependency: Regular use of bioagents diminishes the requirement for synthetic fungicides, thereby reducing input costs and mitigating the risk of chemical resistance development in pathogen populations.
- Soil health enhancement: Bioagent application enriches soil microbial diversity, promotes nutrient cycling, and enhances overall soil biological fertility.
- Plant growth promotion: Many BCAs, particularly *Trichoderma* spp. and *P. fluorescens*, produce phytohormones, solubilize phosphate, and synthesize iron-chelating siderophores, resulting in improved seedling growth and vigour.
- Sustainable and durable suppression: Unlike chemical fungicides, which offer transient control, biological management fosters lasting disease suppression by establishing self-perpetuating populations of antagonistic organisms in the soil ecosystem.

Conclusion

Damping-off disease constitutes a major constraint to tomato seedling production, necessitating reliable and environmentally responsible management interventions. Biological management, employing antagonistic microorganisms such as Trichoderma viride, T. harzianum, and Pseudomonas fluorescens — in conjunction with organic amendments and sound nursery management practices — represents a viable, sustainable, and ecologically compatible strategy for the suppression of this disease. The integration of bioagents within an IPM framework not only reduces disease-induced seedling mortality but also contributes to the enhancement of soil health, plant vigour, and the long-term productivity of tomato nurseries. Wider adoption of these biocontrol-based approaches is strongly advocated to support sustainable intensification of tomato production and to mitigate the adverse environmental impacts associated with excessive chemical fungicide use.

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