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Synergistic Effects of Entomopathogenic Fungi and Microbial Biofertilizers on Soybean Growth and Pest Control

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Abstract:

Soybean (*Glycine max* L.) is a vital oilseed crop facing challenges from pest infestations and nutrient deficiencies, which significantly limit yield potential. Traditional pest management and fertilization strategies often rely on synthetic chemicals, leading to environmental concerns and pest resistance. Entomopathogenic fungi (EPF), such as *Beauveria bassiana* and *Metarhizium anisopliae*, offer an eco-friendly alternative for biological pest control, while microbial biofertilizers, including *Rhizobium*, phosphate-solubilizing bacteria, and mycorrhizal fungi, enhance nutrient uptake and plant health. Recent studies suggest that the combined application of EPF and microbial biofertilizers can produce synergistic effects, improving both pest resistance and crop productivity. The interaction between these biological agents enhances induced systemic resistance (ISR), root architecture, and nutrient assimilation, leading to healthier plants with increased resilience against biotic stress. This review explores the mechanisms of EPF and microbial biofertilizers, their synergistic benefits in soybean production, field application strategies, and the challenges associated with their use. Understanding these interactions can pave the way for more sustainable and high-yielding soybean cultivation systems.

1. Introduction:

1.1 Overview of Soybean Cultivation and Its Economic Significance

Soybean (*Glycine max* L.) is one of the most widely grown oilseed crops, contributing significantly to global food security, livestock feed, and industrial applications. The crop is valued for its high protein (35–40%) and oil content (18–22%), making it a major commodity in international trade. Leading producers include the United States, Brazil, Argentina, China, and India, collectively accounting for over 85% of global production.

The economic importance of soybean extends beyond direct consumption, as it plays a crucial role in biofuel production, pharmaceuticals, and functional foods.

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Its nitrogen-fixing ability, due to symbiosis with *Bradyrhizobium japonicum*, enhances soil fertility, making it an integral component of sustainable agricultural systems. However, despite its agronomic advantages, soybean productivity is often constrained by biotic and abiotic stress factors.

1.2 Challenges in Soybean Production: Pest Infestations and Nutrient Management

Soybean crops face multiple challenges that hinder productivity:

1.2.1 Pest Infestations

Soybean pests cause significant yield losses, with the most notorious being:

1. **Helicoverpa armigera (Soybean Pod Borer):** Causes damage to pods, reducing seed quality and yield.
2. **Aphis glycines (Soybean Aphid):** A sap-sucking insect that transmits viral diseases and weakens plants.
3. **Spodoptera litura (Tobacco Cutworm):** Defoliates soybean leaves, leading to poor photosynthesis.
4. **Bemisia tabaci (Whitefly):** Induces sooty mold development and transmits viruses.

Chemical insecticides are commonly used for pest control, but their overuse leads to resistance development, environmental contamination, and adverse effects on beneficial organisms.

1.2.2 Nutrient Deficiencies and Soil Health Issues

Soybean growth requires adequate nitrogen, phosphorus, and potassium. However, intensive cropping leads to:

1. **Nitrogen depletion** despite its N-fixing ability, requiring additional biofertilizer inputs.
2. **Phosphorus immobilization**, reducing its availability for root uptake.
3. **Soil degradation** due to synthetic fertilizer overuse, affecting microbial diversity and nutrient cycling.

1.3 Role of Biocontrol Agents and Biofertilizers in Sustainable Agriculture

Biocontrol agents and biofertilizers offer eco-friendly alternatives for soybean pest control and nutrient management.

1. **Entomopathogenic fungi (EPF)** such as *Beauveria bassiana* and *Metarhizium anisopliae* infect insect pests, reducing their populations naturally.
2. **Microbial biofertilizers** including *Rhizobium*, plant growth-promoting rhizobacteria (PGPR), and mycorrhizal fungi enhance nutrient availability and stress tolerance.
3. **Integrated use** of these microbes enhances plant growth, improves soil health, and minimizes chemical dependency.

1.4 Hypothesis: Synergistic Effects of Entomopathogenic Fungi (EPF) and Microbial Biofertilizers on Soybean Growth and Pest Control

The hypothesis of this study is that the combined use of EPF and microbial biofertilizers creates a **synergistic interaction**, leading to:

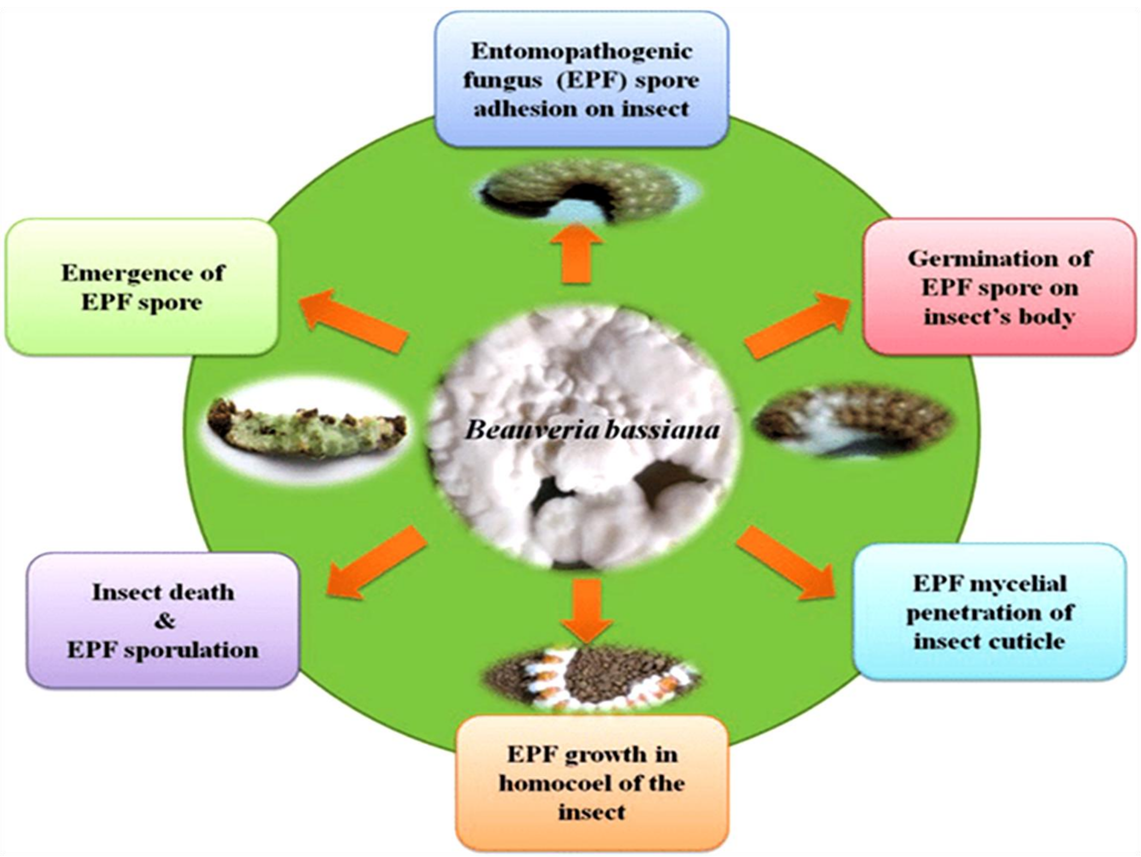
1. **Enhanced pest control:** EPF reduce insect populations while biofertilizers strengthen plant resistance.
2. **Improved nutrient uptake:** Biofertilizers aid in nutrient assimilation, promoting plant vigor and resilience.
3. **Sustainable productivity:** Integrated biocontrol and fertilization strategies contribute to eco-friendly and high-yield soybean production.

2. Entomopathogenic Fungi (EPF) in Pest Control

2.1. Definition and Key Species

Entomopathogenic fungi are microbial pathogens that infect and kill insect pests. Key EPF species used in soybean pest management include:

1. **Beauveria bassiana**: Effective against aphids, whiteflies, and lepidopteran larvae.
2. **Metarhizium anisopliae**: Controls



soil-dwelling insects like root grubs and beetles.

3. **Lecanicillium lecanii**: Targets sap-sucking pests, including aphids and thrips.

2.2 Mechanism of Action Against Insect Pests

EPF infect insect pests through direct contact and penetration of the exoskeleton:

1. **Spore adhesion and germination:** Fungal spores attach to the insect cuticle.
2. **Cuticle penetration:** Hyphae penetrate through enzymatic degradation.
3. **Internal colonization:** Fungi proliferate inside the insect, disrupting physiological processes.
4. **Toxin production and mortality:** Toxins such as destruxins (produced by *Metarhizium*) contribute to insect death.
5. **Sporulation:** Dead insects serve as a reservoir for fungal sporulation, spreading infection.

2.3 Effectiveness of EPF in Controlling Major Soybean Pests

1. *Beauveria bassiana* reduces aphid populations by **70–90%** under optimal conditions.
2. *Metarhizium anisopliae* achieves **80% control of root grubs** in soybean fields.
3. Combining EPF with botanical insecticides enhances efficiency and persistence in the field.

2.4 Limitations and Challenges of Using EPF Alone

1. Sensitivity to **UV radiation, temperature, and humidity**.
2. Slower action compared to synthetic insecticides.
3. Inconsistent field efficacy due to environmental variability.

3. Microbial Biofertilizers for Soybean Growth Enhancement

3.1 Definition and Classification

Biofertilizers are living microorganisms that enhance plant nutrition. Major types include:

1. **Nitrogen-fixing bacteria** (*Rhizobium japonicum*, *Azospirillum*).
2. **Phosphate-solubilizing bacteria** (*Bacillus*, *Pseudomonas*).
3. **Mycorrhizal fungi** (*Glomus* species) for root enhancement.

3.2 Role in Nutrient Uptake and Growth

1. Increase **N-fixation** efficiency.
2. Enhance **P solubilization** and root absorption.
3. Produce **phytohormones** (IAA, gibberellins) for better plant development.

3.3 Influence on Root Architecture and Nodulation

1. *Rhizobium* inoculation improves nodulation and nitrogen availability.
2. Mycorrhizae increase root surface area, improving drought tolerance.

3.4 Limitations of Biofertilizers Alone

1. Poor survival in stressed soils.
2. Competition with native microbes limits effectiveness.

4. Synergistic Effects of EPF and Microbial Biofertilizers

4.1 Mechanistic Interaction in Plant Defense

1. EPF and biofertilizers **trigger induced systemic resistance (ISR)** against pests.
2. **Enhanced plant immunity** reduces herbivory impact.

4.2 Improved Nutrient Uptake and Plant Resilience

1. Mycorrhizae assist EPF in penetrating insect cuticles via root exudates.
2. Stronger plants withstand pest attacks more effectively.

4.3 Enhancement of Secondary Metabolites and ISR

1. Increased flavonoids and alkaloids deter pests.
2. PGPR boost antifungal and antibacterial activity.

4.4 Case Studies Supporting Synergy

1. Trials show **30% increase in pest mortality** with EPF-biofertilizer combination.
2. **Soybean yield improved by 15–20%** with integrated bioinoculation.

5. Field Applications and Practical Implementation

5.1 Formulation Strategies and Delivery Methods

1. **Co-inoculation of EPF and biofertilizers** in carrier-based formulations.
2. Seed coating and foliar sprays for effective field application.

5.2 Compatibility and Persistence in Soil

1. Maintaining microbial viability in bioformulations.

5.3 Best Agronomic Practices for Integration

1. **Optimal timing of application** for maximum effect.

5.4 Cost-Effectiveness and Scalability

1. Lower input costs compared to chemical treatments.
2. Potential for commercialization in sustainable agriculture.

Conclusion

The integration of entomopathogenic fungi and microbial biofertilizers presents a promising strategy for sustainable soybean production. EPF effectively control major pests like *Helicoverpa armigera* and *Aphis glycines*, while biofertilizers improve nutrient acquisition and plant health. Their combined application enhances plant defense mechanisms, increases secondary metabolite production, and improves resilience to environmental stress. Despite challenges such as formulation stability, environmental variability, and regulatory constraints, advancements in microbial technology and field application methods offer viable solutions. Future research should focus on optimizing co-formulation strategies, field validation of synergistic effects, and scaling up for commercial use. Adopting these biological solutions can reduce reliance on chemical inputs, promote ecological balance, and improve soybean productivity in a sustainable manner.

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