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Entomopathogenic Fungi as Biological Regulators of Crop Pests: Integrating Molecular Mechanisms and Ecological Applications

Ayse Torres Agama

Field Crops Central Research Institute (TAGEM)

Introduction

- Entomopathogenic fungi (EPF) such as *Metarhizium anisopliae* and *Beauveria bassiana* are key biological control agents used against a wide range of agricultural insect pests.
- Unlike chemical insecticides, EPF act through natural infection processes and can persist in agroecosystems.
- However, field performance remains variable due to environmental stress, host defenses, and inconsistent establishment.
- Understanding EPF infection biology across molecular and ecological scales is essential for improving reliability under real agricultural conditions.

Methods

- A literature synthesis was conducted using recent studies.
- Focus on:
  - fungal genomics and transcriptomics
  - laboratory infection assays
  - greenhouse and field evaluations.
- Emphasis on studies linking molecular traits with ecological performance

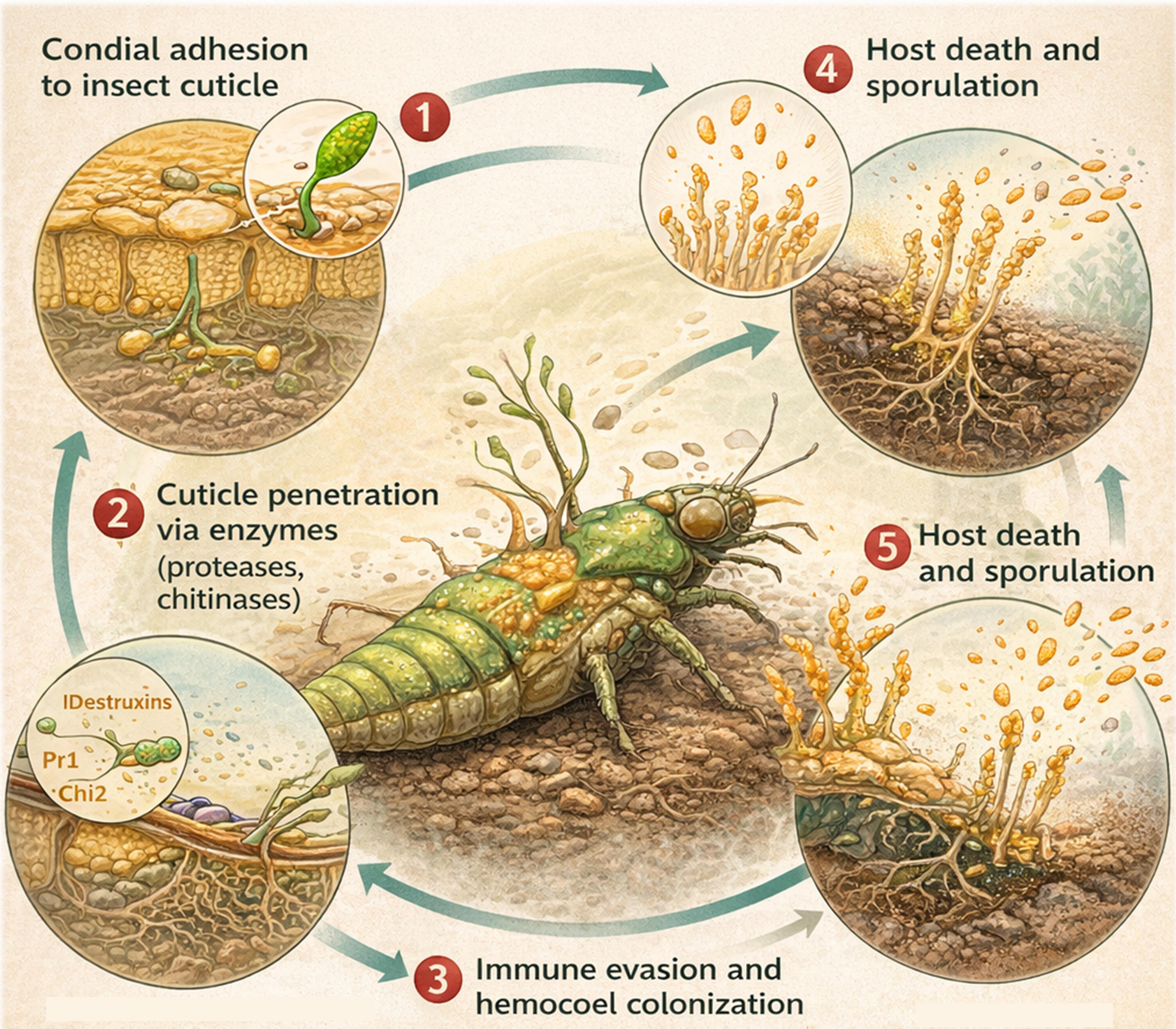

Figure 1. Generalized infection cycle of entomopathogenic fungi highlighting key biological control intervention points

Objectives

- Summarize infection mechanisms of entomopathogenic fungi
- Identify molecular traits associated with virulence and stress tolerance
- Examine ecological and agronomic factors affecting field performance
- Propose an integrated framework for improving EPF-based management

Table 2. Ecological and Agronomic Factors Affecting EPF Performance

Factor	Mechanism	Effect on EPF
Formulation type	Oil-based, encapsulated spores	Improves persistence and infectivity
Soil microbiome	Beneficial microbial interactions	Enhances establishment
Host plant traits	Plant architecture, resistance	Alters insect exposure
Climate conditions	Temperature, humidity	Determines infection success
Application timing	Crop phenology	Aligns with pest vulnerability

Table 1. Molecular Determinants of EPF Virulence

Category	Mechanism	Example	Functional Role
Cuticle degradation	Proteases, chitinases	*Pr1, Chi2*	Penetration of insect cuticle
Secondary metabolites	Destruxins, beauvericin	*Metarhizium, Beauveria* spp.	Immune suppression, host mortality
Stress tolerance	Antioxidant enzymes	Catalase, SOD	Survival under UV and temperature stress
Host adaptation	Effector-like proteins	Host-specific gene expression	Infection specificity

Results and Discussion

- Molecular studies reveal that virulence alone does not predict field success.
- Ecological compatibility and formulation strongly influence persistence.
- EPF perform best when integrated with resistant crops and supportive soil microbiomes.
- Similar to rust pathosystems, targeting multiple stages of the biological cycle reduces system failure.

Conclusions and Future Prospects

- EPF effectiveness depends on multi-level biological integration.
- Future research should focus on:
  - linking genomics with field performance
  - EPF-plant-microbiome interactions
  - climate-robust formulations
- Integrating infection biology with agroecological management can position EPF as reliable components of sustainable pest control..

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Contact: aysetorresagama@gmail.com

Full references via QR