Entomopathogenic Fungi: Interactions and Applications

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Entomopathogenic fungi are a special group of soil-dwelling microorganisms that infects and kills insects and other arthropods through cuticle penetration. They are currently used as biocontrol agents against insect plant pests and play a vital role in their management. Regardless that entomopathogenic fungi are currently on the agriculture market, their full potential has not yet been utterly explored. Up to date substantial research has covered the topic revealing numerous uses in pest management but also on their ability as endophytes, assisting the plant host on growth and pathogen resistance. This article addresses the literature on entomopathogenic fungi through the years, noting their mode of action, advantages, potential applications, and prospects.

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Interestingly, the idea of implementing microorganisms for pest control is not a modern application. The first entomopathogenic fungus was discovered and described by Agostino Bassi (1773–1856) in 1835, causing white muscardine disease in insects and was later named *Beauveria bassiana* (Balsamo) Vuillemin (Hypocreales, Cordycipitaceae) [1]. Some years later, Elias Metschnikoff (1845–1916) discovered the green muscardine, a fungal disease attacking insects, induced by *Metarhizium anisopliae* Metschnikoff Sorokin (Hypocreales, Clavicipitaceae) [2]. In the late 19th century, the combination of these discoveries and the groundbreaking knowledge obtained by the father of microbiology Louis Pasteur (1822–1895), led to assays experimenting on fungi as potential microbial control agents [3]. Later, the entrance of chemical insecticides in the market held back the establishment of fungi in pest management. Also, the development of *Bacillus thuringiensis* (Baciliales, Bacillaceae) Berliner against insects, played an important role on the biological protection research. While it assisted acknowledging the potential use of exploiting microorganisms as pest control agents, it may have detained the advance of biological protection studies, as the scientific community focused on bacterial entomopathogens [4]. Nonetheless, to present, even though entomopathogenic fungi (EPF) have been commercialized in the last years, their broad potential applications have not yet been fully discovered.

The advances in molecular biology and DNA sequencing allowed the collection and classification of organisms and along with the symbiosis theory, provided a better comprehension on the interactions between plants, fungi, and insects. During the last years, because of the concerning environmental implications of the extensive use of synthetic substances, the interests of research was rotated on alternatives of chemical pest management and so the EPF came back on the scene. Up to date, numerous studies and reviews have documented the multifaceted roles of EPF as endophytes that antagonize plant diseases [5][6][7][8][9][10], promote plant growth [11][12][13][14], and benefit the rhizosphere through colonization [15][16][17]. The use of EPF so far has been limited to utilization as inundate biopesticides against insects [18], although the newly emerging attributes open the way to complementary roles as dual agents against both arthropods and plant diseases, as vertically transmitted endophytes, and as biofertilizers [12][19][20]. Some fungal endophytes establish themselves in plants naturally while others are introduced therein artificially [21] (**Figure 1**).

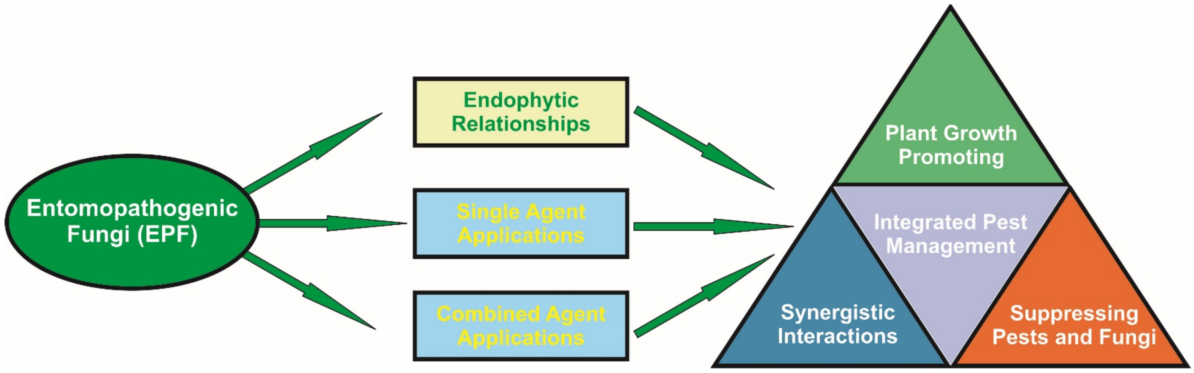

Figure 1. Applications of entomopathogenic fungi and the main effects.

Many EPF isolates have been recorded and tested throughout the years, some of them with thriving results. The ubiquitous soil-borne fungus, *B. bassiana* is recorded to infect more than 700 insect species. [22] Other examples of artificially inoculated endophytes are *Metarhizium brunneum* Petch (Hypocreales, Clavicipitaceae) in broad bean by [12], *M. anisopliae* in broad bean by Akello and Sikora (2012) [23] and cassava by Greenfield et al. (2016) [24]. *Beauveria brognartii* Sakkaro Petch was also tested in broad bean by Jaber and Enkerli (2017) [12]. Lastly, *Metarhizium robertsii* Metschnikoff Sorokin (Hypocreales, Clavicipitaceae) and *Isaria fumosorosea* Wie Brown and Smith (Hypocreales, Cordycipitaceae) was examined in sweet sorghum by Mantzoukas et al., 2015 [25].

Studies have provided data suggesting that fungal endophytes may act antagonistically against plant diseases, such as *Fusarium oxysporum* Snyder & Hansen (Hypocreales, Nectriaceae), *Botrytis cinerea* Pers. (Helotiales, Sclerotiniaceae), *Alternaria solani* Sorauer (Pleosporales, Pleosporaceae) [26] *Fusarium solani* f. sp. *phaseoli Sacc*. (Hypocreales, Nectriaceae) [7] and others. Fungal endophytes effects include mycoparasitism, antagonistic race for nutrition, and antibiosis. The effect on insects occurring upon infection includes physiological and behavioral changes, such as feeding deterrence, inertia, changes in oviposition etc., as possible consequences of the secondary metabolites secreted by fungi themselves [27].

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