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FACTORS AFFECTING THE EPIZOOTICS OF ENTOMOPATHOGENIC FUNGI-A REVIEW

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ABSTRACT

Entomopathogenic fungi (EPF) specifically infect and kill insects can serve as a potential biological control agent. Several biotic and abiotic factors affect their occurrence, persistence, and epizootics caused by them. In biotic factors, fungi characters (host range, latency, spore density and dispersal, mainly host-pathogen compatibility), insect host factors (behavioral, morphological, and physiological), plant-mediated effects (plant architecture, surface chemistry, and leaf topology) are included supports or causes the barrier to mycobiopesticide. Abiotic factors which affect the EPF field persistence are mainly environmental (temperature, sunlight, humidity, rainfall) physical and chemical soil properties (soil texture, pH, E.c, moisture, C/N content, and organic matter) that greatly influence the entomopathogenic fungi. To use them as biocontrol agents, we have to overcome these factors by providing them nutrients, protectants, and using different control practices.

Keywords: Entomopathogenic fungi, biotic factors, abiotic factors, epizootics, biocontrol agent.

INTRODUCTION

Entomopathogenic fungi specifically infect and kill insects can serve as a potential biological control agent. EPF are environmentally sustainable because they have goal-specific behaviour, high reproductive abilities, and no effects on beneficial and non-target species. They also have resting stage or saprobic process generation abilities, allowing them to survive for long periods of time without a host (Mudgal et al., 2013). EPF can be present in a variety of environments (from terrestrial to aquatic, arctic to temperate climate, and arid to tropical), infect a wide variety of insects and colonize a wide range of plant species (Mantzoukas et al., 2015). There are several biotic and abiotic factors that affect their occurrence, persistence, and epizootics of EPF (Sharma et al., 2020). Biotic factors directly effects the EPF also includes insect host factors and plant-mediated effects (Cory and Ericsson, 2009; Herlinda, 2010; OrtizUrquiza and Keyhani, 2013). Abiotic factors like environmental factors including temperature (Bayissa et al., 2017), sunlight (Fernandes et al., 2007), humidity, rainfall (Inglis et al., 2001), and soil properties (Quesada Moraga et al., 2007) cause damage directly to the fungal spores. In this review, we focused on all the expected factors in detail which affect the epizootics caused by EPF.

Fungal Pathogen

Epizootics by the fungal pathogen mainly depend upon the host-pathogen compatibility, spore density (Herlinda, 2010), dispersal, persistence, virulence, genetics, host range, and latency (Zaki, 1998; Cory and Ericsson, 2009; Jaronski, 2010). Fungal spore efficacy requires a critical concentration to cause infection and mortality of insects (Kirkland et al., 2004). High spore density increases the chances of insect disease by the production of adequate infective propagules (Butt and Goettel, 2000). Virulent fungal strains must be consistent with the target insect host, which is based in part on the pathogen's ability to detect and conquer the host's defensive barrier (van Baarlen et al., 2007). The environmental factors impact host-pathogen interaction influencing the pathogen's ability to induce disease (Butt et al., 2016). The strains that survive well in the field are ecologically fit and can effectively penetrate a host (Butt, 2002). Higher environmental persistence also increases the odds of a susceptible insect getting in contact with ample inoculum quantities to induce illness.

The Insect Host

The susceptibility of EPF against insect pest is greatly influenced by a diverse set of physiological, behavioral, and morphological influences including insect number, diet, ecdysis, developmental stage, preening, basking, and mechanical, chemical, or microbial agent-induced injury (Shapiro et al., 1999; Jaronski, 2010; Ortiz-Urquiza and Keyhani, 2013). Stress has been accepted as a consideration that may improve insect vulnerability to entomopathogens. Stress factors are diet, chemical pesticides, and the environment (Meikle et al., 2003; Rangel et al., 2008; Sain et al., 2019). They also stated that the sensitivity of the insect pest to the fungus is increased by insufficient nutrition (Shapiro et al., 1999; Inglis et al., 2001).

The research was performed to test the impact of chemical and botanical pesticides on spore development and mycelial growth, with the effect of pesticides ranging from 169- 94.1 % and 25.6- 87.6 % on the reduction of mycelial growth and conidial production (Sain et al., 2019) in comparison, the insecticidal stress in the formulated bait caused by sublethal Fipronil, weaken the termites and decreased their defense mechanism promoting their fungal infection (Yii et al., 2015). Increased host density enhances the interaction between infected and non-infected populations, facilitates the infection and development of substrates and nutrients for the pathogen. This raises the amount of inoculum available to help induce infection in the habitat.

The developmental stage of the insect played an important part in the epizootics of EPF. Young larvae (1st and 2nd instar) were more vulnerable to infection than older ones (3rd instar). When EPF is applied, the mortality is up to 71.6% in older larvae and 79.8% mortality in young larvae (Dannon et al., 2020). On the other hand, *Glossina morsitans* aged < 1 day, have more immunity to the *M. anisopliae* infection than over 20 to 40-days-old life stage (Maniania and Odulaja, 1998). Certain insects appear to function differently once the insect pests have been exposed to the EPF. Infected insects express some behavioral response to EPF by increasing their thoracic temperature to 30-32.6°C and also through basking in higher temperature places (Sangbaramou et al., 2018).

A striking death grip has also been found in carpenter ants (*Camponotus* spp.) after parasitic fungus infection (Andersen et al., 2009). The odor of *Metarhizium* fungal spores caused behavioral resistance to the infection in honeybees, ants, and termites (Yanagawa and Shimizu, 2007; Ugelvig and Cremer, 2007). Some pest cuticles have physicochemical properties that influence the mechanism of infection, and some insects cover their cuticles with antimicrobial-containing gland secretions. As a defence mechanism, once the fungus

enters the hemolymph, several immune responses are activated (Vega et al., 2012). For example, in one study, all 26 species of ant tested wiped secretions into their bodies formed by thoracic metapleural glands (Fernández-Marín et al., 2006).

Intrinsically, the dark cuticle of some insects provides a level of resistance to EPF (Dubovskiy et al., 2013). It has been observed that cuticular darkness coincides with the titers of circulating phenol-oxidase and immuno-competence in *Tenebrio flour* beetles (Armitage and Siva-Jothy, 2005). For example, Conidial germination of *B. bassiana* was inhibited by cuticular extracts from larval *Helicoverpa zea*, whereas those of *Nazera viridula* decreased the conidial germination of *M. anisopliae* and these have been related to aldehyde involvement, (E) 2-decenal (Jaronski, 2010).

The Host Plant

Plant-mediated impact on EPF includes plant architecture that modifies spore survival, surface chemistry and leaf topology that affect the process of fungal spore recruitment by the insect pest and plant soluble fibers that directly affect the conidia (Cory and Ericsson, 2009). Hountondji et al., (2005), studied the volatiles emanating from green mite-infested cassava plants (*Mononychellus tanajoa*) induce sporulation in three isolates of *Neozygites tanajoae* acaropathogenic fungus. Fungal germination on the plant epicuticular waxes, which contain fungistatic compounds, is quicker and greater. The percentage of conidia germination and virulence of *M. anisopliae* was improved by surface leachates and soluble leaf extracts against mustard beetle, *Phaedon cochleariaea* (Inyang, Butt, Doughty, et al., 1999).

Indirect effects include plant composition (e.g. allelochemicals and nutrients) that alters the insect condition (e.g. immunity), insect disease tolerance, affects insect activity and spores encountered rate (Cory and Ericsson, 2009). *Phaedon cochleariaea* plant contains Phenylethyl- 3-butenyl isothiocyanates, when *M. anisopliae* inoculated insects exposed to these vapours decreased its pathogenicity (Inyang, et al., 1999). The insects which feed on the protein-poor and carbohydrate-rich caterpillars were slightly lower than those eating a high protein diet (Lee et al., 2006).

Soil Properties

The occurrence and distribution of EPF in the soil is strongly affected by different soil factors. Soils good in acidity, the heaviness of soil texture and high organic matter content led to the higher percentages of harbouring of EPF (Quesada Moraga et al., 2007). *B. bassiana* frequently present in different habitats but it prefers forests. *I. fumosorosea* most often detected in hedgerows soils, but *I. farinosa* was only present in forest habitat. *M. anisopiliae* occurrence not affected by intensive agriculture and it is also present in the natural habitats (Medo and Cagán, 2011). They surveyed the occurrence of insect pathogenic fungi in various botanical and soil ecoregions. The most frequently EPF isolated was *B. bassiana* 34 %, *Fusarium oxysporum* 14 % and *M. anisopiliae* 2 %. Conical correspondence analysis of soil abiotic variables had 96 % variability of the insect pathogenic fungi (Bueno-Pallero et al., 2020).

Environment

Sunlight, temperature, relative humidity, rainfall, and wind are some of the main climatic factors that influence the effectiveness of EPF against insects. These parameters can be addressed interactively to affect entomopathogens since they align with other environmental factors (e.g., soil and crops) (Inglis et al., 2001).

Temperature

Temperature is one of the key factors that influence the effectiveness of EPF. It impacts the disease development and the timing of mortality. EPF strains from warmer environments perform better at higher temperatures, while those from cooler climates perform better at lower temperatures (Inglis et al., 2001). The six isolates of *M. anisopliae* were applied against the three species of African tephritid fruit flies, the optimal temperature 30 °C was recorded (Dimbi et al., 2004), while for other fungal isolates optimum temperature were 25 to 30 °C (Bayissa et al., 2017). Bugeme et al., (2009) evaluated most of *B. bassiana* and *M. anisopliae* isolates, developed better in the temperature range of 25 to 30 °C. Species such as *B. bassiana* can grow at a wide temperature range (8 to 35 °C) with a maximum threshold of 37 °C (Fernandes et al., 2008). Despite the ability of *B. bassiana* and *M. anisopliae* isolates to germinate at low temperatures of 5 °C and as high as 35°C and above, the optimal temperature range for germination has consistently been found to be 20 °C to 30 °C (Fargues and Luz, 2000; Dimbi et al., 2004; Fernandes et al., 2008).

On the other hand, many isolates germinate quicker at 25 °C than at 20 °C or 30 °C (Luz and Fargues, 1997). With the exception of *B. bassiana* isolate TP-GHA, which germinated best at 30 °C, Ekesi et al., (1999) found this highest germination rate (80-100 %) for *B. bassiana* and *M. anisopliae* isolates. Incubation of *B. bassiana* F-263 at 25 °C to 33 °C resulted in nearly 100 % germination in 20 hours (Shimazu, 2004). At a temperature interval of 35/25 °C, fourteen of the fourteen showed > 90 % germination, while just nine of the fourteen germination rates remained similar when the temperature was increased to 38 °C.

Rainfall

In a relatively short time, Conidia from plant and insect surfaces can be dislodged and dispersed by rain (Inyang et al., 2000). Conidia of *B. bassiana* and *M. anisopliae* can be removed in large quantities from plant surfaces (Inglis et al., 1995). However, precipitation has beneficial effects on fungal epizootics (Inglis et al., 2001). Precipitation plays a vital role in the dispersion of conidia from substrates, but there is strong evidence that, despite the hydrophobic mechanisms of conidial adhesion, large quantities of spores and conidia may be removed from the cuticle during precipitation (Inglis et al., 2001). Rain strength seems to be higher with oil carriers than with aqueous carriers (Wraight and Carruthers, 1999).

Solar Radiation

The EPF ability to survive in the field is influenced by solar radiation. Conidia viability is inhibited by solar UVA (320-400 nm) and UVB (290-320 nm) (Moore et al., 1993), possibly caused by lethal and mutagenic DNA damage. Significant damage caused by conidial UV penetration, such as degradation of cytoplasmic membranes and organelles and direct and indirect damage to DNA, results in delayed germination or complete conidia inactivation, thus decreasing the effectiveness of bio-insecticides (Chelico et al., 2006; Rangel et al., 2006). After being exposed to UV radiation, living fungal conidia must regenerate and resume the germination process over a long period.

Even a few hours of exposure to sunlight, especially the UV-B portion of the spectrum (285315 nm), wilfully inactivate *Metarhizium* infectious conidia (Braga et al., 2001). Genetic resistance to UV radiation among EPF species is variable (Fernandes et al., 2007). Conidia can be exposed to indirect solar radiation effects also including thermal stress and desiccation (Rangel et al., 2006). The impact of solar radiation is determined by the intensity and duration of conidia's exposure to it (Fernandes et al., 2007). Inter- and intra-specific differences have frequently been documented in fungal solar radiation tolerance.

Spore germination and germ-tube elongation are best when the RH is near saturation (> 95.5 percent RH) (Hallsworth and Magan, 1999). Moisture > 96 percent is necessary for spore germination and mycelial development for most fungi (Ibrahim et al., 1999). Fargues and Luz, (2000), found that for the processing of *B. bassiana* conidia on *Rhodnius prolixus*, relative humidity of at least 97 % was needed. Dry conditions are less detrimental during or shortly after the application of fungal propagules, *B. bassiana* and *M. anisopliae* can infect their respective hosts under low atmospheric humidity conditions, possibly due to adequate humidity within the microhabitats (Ferron, 1977; Fargues et al., 1997).

CONCLUSION

As a result of insect pest disease problems in agriculture and environmental considerations, myco-biocontrol of insects has been deemed a significant substitute for conventional chemical pesticides and a key component of eco-friendly pest management. It is important to comprehend the ecological and environmental parameters associated with EPF for both scientific research into the evolution and conservation of pathogenesis in these species and insect pest biological management applications in the field.

EPF are a relatively uncommon and highly advanced group of microbes with a number of favourable characteristics that make them ideal candidates for bio pesticide growth. Indeed, a thorough understanding of the ecology of fungal entomopathogens can pave the way for new bio pesticide formulations. Furthermore, promote the widespread use of biopesticides dependent on fungal entomopathogens. In addition their genetically modified insecticidal potency, increased persistence, improved distribution mechanisms, and microbial products with action against multiple pests are required. Following these developments, further research and industrial activity in entomopathogenic fungi is required, and discoveries of improved compatibility, increased effectiveness, increased investments, and expanded entomopathogen formulations for integrated pest management are expected in the near future.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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