Insect pathogenic fungi in biological control: status and future challenges

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Abstract: In Europe, insect pathogenic fungi have in decades played a significant role in biological control of insects. With respect to the different strategies of biological control and with respects to the different genera of insect pathogenic fungi, the success and potential vary, however. Classical biological control: no strong indication of potential. Inundation and inoculation biological control: success stories with the genera *Metarhizium*, *Beauveria*, *Isaria/Paecilomyces* and *Lecanicillium* (previously *Verticillium*). However, the genotypes employed seem to include a narrow spectrum of the many potentially useful genotypes. Conservation biological control: *Pandora* and *Entomophthora* have a strong potential, but also *Beauveria* has a potential to be explored further. The main bottleneck for further exploitation of insect pathogenic fungi in biological control is the limited knowledge of host pathogen interaction at the fungal genotype level.

Key words: insect pathogenic fungi, Hypocreales, Entomophthorales, biological control

Biological control strategies:

Biological control includes four complementary strategies: 1) Classical biological control, 2) Inundation biological control, 3) Inoculation biological control and 4) Conservation biological control (Eilenberg *et al.*, 2001). Despite their complementarity, inundation and inoculation are often treated simultaneously (sometimes called ‘augmentation’). Here, we treat them together. Below we present an overview of the status of insect pathogenic fungi in these strategies with particular emphasis of new discoveries of relevance for conservation biological control.

Classical biological control

The release of exotic fungal species or strains for insect pest control has never received much attention in Europe. A study in Iceland on Green spruce aphid (*Sitobion avenae*) and its fungal pathogens from Entomophthorales documented that release of the pathogens (*Entomophthora planchoniana* and *Pandora neoaphidis*) could be worthwhile (Nielsen *et al.*, 2001). However, the observational studies have so far not been accompanied by experimental work to prove the hypothesis that a long lasting control can be accieved by a single release of these fungi at selected places.

Inundation and inoculation biological control

Since decades, fungi from Hypocreales have been marketed for biological control of pest insects in Europe.

One major bottleneck is the registration. This aspects will be covered by Hermann Strasser (ibid). A second bottleneck is studies to prove efficacy of different formulations. A third bottleneck is the reluctance of companies to develop and market products for use. European agriculture and forestry is characterized by a variety of crops and climatic conditions, resulting in a variety of pest insects of importance. Thus, the potential of success of a product can be hampered by the small market (regional or even local problems only). The success of fungi in glasshouses can partly be attributed to the limited number of major vegetable crops being common throughout Europe (above all tomatoes and cucumber) and the uniform set of pest insects to be controlled. A fourth major bottleneck is the limited knowledge about ecology of the used fungi. Major improvement have, however, occurred recently by the emplyoment of specific molecular methods to determine host pathogen interaction at the genotype level (Schwarzenbach *et al.,* 2007; Meyling *et al.,* 2009). Such studies will both ease the possibility to study fate and effect of released fungi as well as they will allow us to evaluate the potential for conservation biological control.

Conservation biological control

Conservation biological control have received increasing interest over the last years. Insect pathogenic fungi offer a high potential for usage as part of a conservation strategy. Also, conservation biological control goes well in hand with the recent attempt to develop 'low input' or 'organic' agriculture. The current knowledge of the potential of insect pathogenic fungi is limited. However, recent approaches have given significantly novel insight, for example studies on a) genotype characterization from natural field infections (Jensen *et al.*; 2006, Meyling *et al.*, 2009), b) transmission of disease between different hosts (Baverstock *et al*., 2008b; Jensen *et al*., 2006) as well as c) interactions between fungi, insects and enviroment (Baverstock *et al*.; 2008a; Roy and Cottrell, 2008), also with the inclusion of specific molecular methods of both host and pathogen populations (Jensen *et al*.; 2008, Fournier *et al.,* 2008). A summary of known knowledge and potential of three species is listed in table 1.

Table 1: Comparison of characters of three fungal species with reference to conservation biological control

Fungus species	**Host range at fungus genotype level**	**Suggested conservation strategy**	**References**
Beauveria bassiana sensu lato	Broad (each genotype can naturally infect speciea from several insect orders)	Establish hedges and other semi-natural habitats to enhance genetic diversity of fungus	Meyling *et al.,* 2007; Meyling *et al*., 2009
Pandora neoaphidis sensu lato	Semi-narrow (each genotype can naturally infect several aphid species)	Establish habitats for alternative aphid hosts for population build-up of the fungus	Ekesi *et al.,* 2005, Enkerli *et al.,* 2008 Baverstock *et al*., 2008a
Entomophthora muscae sensu lato	Narrow (each genotype can naturally infect only one host species)	Establish possibilities for the fungus to develop in host population	Jensen *et al.,* 2006

Conclusion

In summary we can characterize the potential of the main insect pathogenic fungal genera as presented in Table 2. We recommend future research projects to include studies at species and genotype level and also studies which include elucidation of several biological control strategies. Through such approaches we may get more benefit from insect pathogenic fungi.

Table 2: Main insect pathogenic fungal genera with potential for biological control in the EU

Fungus genus or species	**Hosts**	**Main environment**	**Inundation/ inoculation**	**Conservation**
Metarhizium	Various arthro-pods, including weevils	Soil, insects and lower parts of vegetation	Products in EU for a number of years	Limited documented potential
Beauveria	Various arthro-pods, including scarabs	Soil, insects and vegetation	Products in EU for a number of years	Studies indicate strong potential
Isaria/ Paecilomyces	Various arthro-pods and ne-matodes	Soil, insects and vegetation	Products in EU for a number of years	Limited documented potential
Lecanicillum (previously *Verticillium*)	Aphids and whiteflies	Insects and vegetation	Products in EU for a number of years	Limited documented potential
Aschersonia aleyrodis	Whiteflies	Insects and vegetation	Product in EU has disappeared	No documented potential
Pandora neoaphidis	Aphids	Insects, vegetat-ion, top soil layer	No product have been marketed	Studies indicate strong potential
Entomophthora muscae s.l	Flies, including root flies	Insects, vegetat-ion, top soil layer	No product have been marketed	Studies indicate strong potential

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References

Baverstock, J.; Clark, Pell, J.K. (2008a): Effect of a seasonal abiotic conditions and field margin habitat on the activity of *Pandora neoaphidis* inoculum on soil. Journal of Invertebrate Pathology **97**: 282–290.

Baverstock, J.; Baverstock, K.E.; Clark, S.J.; Pell, J.K. (2008b): Transmission of *Pandora neoaphidis* in the presence of co-occurring arthropods. Journal of Invertebrate Pathology **98**: 356–359.

Eilenberg, J.; Hajek, A.E.; Lomer, C. (2001): Suggestions for unifying the terminology in biological control. BioControl, **46**: 387-400.

Ekesi, S.; Shah, P.A.; Clark, S.J.; Pell, J.K. (2005): Conservation biological control with the fungal pathogen *Pandora neoaphidis*: implications of aphid species, host plant and predator foraging. Agricultural and Forest Entomology **7**: 21–30.

Fournier, A.; Enkerli,, J.; Keller, S.; Widmer, F. (2008): A PCR-based tool for the cultivation-independent monitoring of *Pandora neoaphidis.* Journal of Invertebrate Pathology **99**: 49–56.

Jensen, A.B.; Thomsen, L.; Eilenberg, J. (2006): Value of host range, morphological, and genetic characteristics within the *Entomophthora muscae* species complex. Mycological Research **110**: 941-950.

Jensen, A.B.; Hansen, L.M.; Eilenberg, J. (2008): Population differentiation, clonal distribution and fungal pathogen infections in the cereal aphid *(Sitobion avenae* F.) in Denmark. Agricultural and Forest Entomology **10:** 279-290.

Meyling, N.V.; Eilenberg, J. (2007): Ecology of the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* in temperate agroecosystems: potential for conservation biological control. Biological Control **43**: 145-155.

Meyling, N.V.; Lübeck, M.; Buckley, E.P.; Eilenberg, J.; Rehner, S.A. (2009): Community composition, host range and genetic structure of the fungal entomopathogen *Beauveria* in adjoining agricultural and seminatural habitats. Molecular Ecology (in press)

Nielsen, C.; Eilenberg, J.; Harding, S.; Oddsdottir, E.; Haldorsson, G. (2001): Geographical distribution and host range of Entomophthorales infecting the green spruce aphid *Elatobium abietinum* Walker in Iceland. Journal of Invertebrate Pathology, **78**: 72-80.

Roy, H.E.; Cottrell T.E. (2008): Forgotten natural enemies: Interactions between coccinelids and insect-parasitic fungi. European Journal of Entomology **105**: 391-398.

Schwarzenbach K.; Widmer F.; Enkerli, J. (2007): Cultivation-independent analysis of fungal genotypes in soil by using simple sequence repeat markers. Applied and Environmental Microbiology **73**: 6519-6529.