Microbial Control of Arthropods

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Summary and Introduction. Serious efforts to develop pathogens as biocontrol agents for arthropods began in the 1930's and 40's and were aimed primarily at developing insect-specific viruses and bacteria as classical biological control agents and microbial insecticides. Only one pathogen, the nuclear polyhedrosis virus of the European spruce sawfly, turned out to be effective as a classical biological control agent, meaning that after introduction it provided continuous control for more than several decades. Subsequent studies focused on development and commercialization of a range of different pathogens – various viruses, bacteria, fungi and microsporidia – as microbial insecticides. By the middle of the last century several were registered and used effectively, even though the markets were small. The most successful of these was an insecticide based on the bacterium, *Bacillus thuringiensis* (Bt), which was developed for use to control lepidopteran pests in forestry, and vegetable, field, and tree crops. Numerous commercial products based on *B. thuringiensis* remain in use around the world today, the primary reason for their success has being that they are cheap and easy to produce using commercial fermentation methods, with the cost of production being in the range of $1/acre treatment. Viruses and fungi proved much more cumbersome to produce, which inhibited there commercial development. The advent of recombinant DNA technology and genetic engineering techniques in the 1970's provided impetus for improving microbial insecticides and other uses of these organisms, such as the development of transgenic insect-resistant crops, such as Bt cotton and corn, and improved recombinant strains of Bt and certain fungi, namely *Metarhizium anisopliae*. At present, several engineered microbial insecticides based on Bt and and *M. anisopliae* related species show good promise for use as microbial insecticides, but their ultimate use and commercialization will depend on successful completion of non-target studies. Below I briefly summarize the advantages and disadvantages of each of the major insect pathogens, and suggest ways these can be used more effectively, including how changes in regulations could optimize their development and use.

Viral Biocontrols. The two types of viruses that have received the most attention as microbial biocontrol agents are both baculoviruses, (1) nuclear polyhedrosis viruses (NPVs), and (2) granulosis viruses (GVs). Both types are highly infectious *per os* (via feeding). Several have been developed and registered for insect control, including the NPVs for controlling important caterpillar pests (*Heliothis* spp.) that attack cotton and other field crops, or those (*Spodoptera* spp.) that attack vegetable crops, and in some cases forest pests (*Orgyia* spp.). With respect to GVs, the most successful viruses used as a microbial biocontrol agents are the GVs of the codling moth and potato tuberworm, both of which are used in many countries around the world. The advantage of these viruses, which also serves as a disincentive to large-scale commercialization, is that they are highly specific. But in crop systems where their hosts are key pests, development and use is justified, even if this is done with governmental support, the justification being the benefit to the environment and non-target insects of not using broad-spectrum synthetic chemical insecticides. Two other problems that have inhibited greater use and success of these viruses is that other specific pathogens, mainly B. thuringiensis, are cheap and compete with them, and the viruses must be produced in vivo, i.e., in live caterpillars. The efficacy of one virus that has a relatively broad target spectrum, the *Autographa californica* multinucleocapsid (M) NPV, has been improved though genetic engineering, but not to the extent that improves its ability to compete with other technologies, such as Bt products, including Bt crops. For these reasons, NPVs and GVs will remain niche markets for the foreseeable future. Their record of vertebrate and invertebrate safety is exceptional, and their use as pest control agents could be enhanced if they were treated from a regulatory perspective like insect-parasitic nematodes.

Bacterial Biocontrols. Two species of bacteria have been successful as biocontrol agents and insecticides, *Bacillus popilliae* and *B. thuringiensis*. The former is a highly fastidious species used for control of scarab larvae, such as those of the Japanese beetle, which feed on the roots of grasses. Products based on B. popilliae reamin a small niche business because this bacterium must be grown *in vivo*, i.e., in scarab lavae collected in the field. This species and its various products will not be discussed here other than to say these products are highly efficacious, with a single application providing effective scarab control for from five to ten years. With respect to *B. thuringiensis*, four strains have been developed as insecticides, and three of these constitute the most successful pathogens developed as biocontrol agents. These are *B. t.* subspecies *kurstaki*,

B. t. subsp. *aizawai*, and *B. t.* subsp. *israelensis*. The first two are used widely to control various types of lepidopteran pests in agriculture and forestry, whereas *B. t.* subsp. *israelensis*, discovered during the 1970's, has been used virtually worldwide to control the larvae of nuisance and vector mosquitoes and blackflies, as well as to control certain dipteran (nematoceran) pests in horticulture. The market for products based on Bt is estimated to be in the range of $100 – 200 million/year. The reason Bt has been so successful commercially is that these products are easy to mass produce at a relatively low cost using large-scale commercial fermentation methods. In addition, as their insecticidal activity is initiated by protein endotoxins they produce, these can be manipulated using genetic engineering techniques. Thus, while wild type strains are the most successful now, improved strains developed through genetic engineering techniques could enhance commercial use of Bt. It should be noted that government support for research on Bt was ultimately responsible for the development of the first genetically engineered crops, namely Bt cotton and corn, which now annually are a multibillion dollar business. To some extent, Bt crops compete with Bt insecticides, but the use of the latter will likely continue to expand due to the development of new Bt biocontrol products.

Fungal Biocontrols. Although many fungi have been investigated for the potential as biocontrol agents, the two that have received the most attention over the past several decades are *Metarhizium anisopliae* and related species, and *Beauveria bassiana*. These fungi occur widely in soils throughout the world, but not at levels to routinely control arthropod pests. Thus, they may must be mass produced and the conidia, the stage most widely used for control, disseminated. Fungi have an advantage over viruses and Bt in that they can penetrate directly through the cuticle. However, until recently fermentation methods where not cost-effective and the amount of conidia needed for control made the fungi uncompetitive (requiring one to two pounds of conidia/acre for control). Over the past decade, fermentation methods have improved, and the amount of conidia required for effective control has been reduced significantly through genetically engineering strains of *M. anisopliae* to produce various enzymes and neurotoxins effective against insects. At present, the future for fungal insecticides looks very bright, and they could prove quite useful for control of agriculture pests, especially sucking insect pests, if there target spectrum can be successfully limited.

Conclusions

NPVs, GVs, and *Bacillus thuringiensis* have a remarkable vertebrate and non-target invertebrate safety record spanning more than 50 years, justifying simplification of regulations for registration and use. Better public awareness of this record could enhance their acceptance.

Genetically engineered NPVs and strains of *Bacillus thuringiensis* have improved efficacy and cost-effectiveness, and appear to maintain a high degree of specificity, but invertebrate non-target studies are warranted.

Insect-pathogenic fungi such as *Metarhizium anisopliae* and *Beauveria bassiana* have the advantage over viruses and *Bacillus thuringiensis* of infecting insects via the cuticle, making them useful against both chewing and sucking insect pests, but many strains have a relatively broad host range, and thus require more rigorous non-target spectrum studies, especially for genetically engineered strains.

Recognized and reasonable vertebrate and invertebrate non-target studies of genetically engineered microbials will assist regulators in assisting and registering these potentially safe and useful products.

More specific fungi, including entomophthoraceous fungi (with a few exceptions), should be treated by regulators more like insect-parasitic nematodes, which should also be considered for wild type NPVs, GVs, and most strains of Bt.

References

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