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An Introduction to Microbial Control of Insect Pests of Potato

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ABSTRACT

A wide variety of insects are pests of potato plants and tubers. Several insect-specific pathogens have demonstrated efficacy for control of some of the more economically important insect pests of potato. *Bacillus thuringiensis* (*Bt*) and a granulovirus (PoGV) are effective in controlling potato tuber moth, *Phthorimaea operculella*, a serious pest of potato foliage and stored tubers in the tropics and subtropics. Naturally occurring PoGV has been reported in several countries where potato is grown. Colorado potato beetle (CPB), *Leptinotarsa decemlineata*, is a serious pest of potato in many countries worldwide. *Bt* var. *tenebrionis* effectively controls CPB when applied against first and second instar larvae. The fungus, *Beauveria bassiana*, has also been reported to control CPB under certain environmental conditions. Andean potato weevils, *Premnotrypes* spp., are pests of potatoes grown at high altitude in the Andes. An entomopathogenic nematode, *Heterorhabditis* sp., appears to be a potential candidate for microbial control of the weevil. A variety of other candidate entomopathogens are proposed for control of several additional insect pests including leaf miner fly, wireworms, lepidopterans, aphids, potato psyllid, leafhoppers, and other insects. The further development and use of microbial control agents will ultimately provide components for the integrated and sustainable control of insect pests of potato and in other agroecosystems. Although factors limiting the adoption and use of microbials include high cost and low efficacy, compared to most chemicals presently used, these costs could be offset by the premium price paid for safer food and a greener approach.

Keywords: Andean potato weevil, *Bacillus thuringiensis*, Baculovirus, *Beauveria bassiana*, Colorado potato beetle, entomopathogenic fungus, entomopathogenic nematodes, Hemiptera, *Heterorhabditis*, leafminer fly, Lepidoptera, *Leptinotarsa decemlineata*, *Liriomyza huidobrensis*, *Phthorimaea operculella*, potato tuber moth, wireworms

Abbreviations: APTM, Andean potato tuber moth; **APW**, Andean potato weevil; ***Bt***, *Bacillus thuringiensis*; ***Btt***, *Bacillus thuringiensis* var. *tenebrionis*; **CPB**, Colorado potato beetle; **CIP**, Centro Internacional de la Papa; **GPTM**, Guatemalan potato tuber moth; **IPM**, integrated pest management; **LMF**, leafminer fly; **PTM**, potato tuber moth

CONTENTS

THE POTATO AND ITS INSECT PESTS

The domestication of the potato, *Solanum* sp., started over 8,000 years ago around Lake Titicaca in modern-day Peru and Bolivia (CIP 2008). Today a multitude of potato varieties are grown throughout the world. Despite allelochemical defenses, *S. tuberosum* L. is attacked by a multitude of invertebrate pests including insects, mites, slugs, and nematodes (Zehnder *et al*. 1994; Berry 1998; CIP 2008). Insects feed on every part of the plant (leaves, stems, and tubers) and several of these pests also serve as vectors of plant pathogens (Radcliffe and Ragsdale 2002; Munyaneza *et al*. 2006; Hansen *et al*. 2008). Insect pests and their relative importance vary from region to region with highest numbers of economically important pest species occurring in potato agroecosystems of the neotropics in countries of potato origin (Kroschel *et al.* 2009). It is estimated that mean potato losses due to insect pests are about 16% worldwide (Oerke *et al.* 1994). However, if not routinely controlled, tuber yield and quality reductions are between 30-70% for various insect pests (Raman and Radcliffe 1992). Predominant means of control are through the use of broad spectrum chemical insecticides. According to the World Health Organization 2002 classification, highly hazardous class 1a and 1b pesticides are still widely distributed and used by small-scale potato farmers in developing countries (Arica *et al.* 2006). Over-reliance on broad spectrum insecticides in agroecosystems has often resulted in the develop-

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ment of resistance in targeted pest populations, safety risks to farm workers and the food supply; outbreaks of secondary pests normally controlled by natural enemies; environmental contamination; and a decrease in biodiversity (Lacey *et al*. 2001). An integrated pest management (IPM) strategy, in which natural enemies of pest arthropods and other alternative measures play significant roles in crop protection, should minimize these negative effects and provide a more sustainable approach for the control of insect pests of potato (Cisneros and Gregory 1994; Thurston 1994; Kroschel 1995; Kroschel and Sporleder 2006). Due to their selectivity and safety, microbial control agents (MCAs) appear to be ready made components of IPM systems that do not pose a threat to applicators or the environment and allow other natural enemies to function (Lacey *et al.* 2001; Kaya and Lacey 2007). In this review, separate presentations on the major potato insect pests and the potential for their microbial control are highlighted.

POTATO TUBER MOTH COMPLEX

The potato tuber moth complex consists of three species namely the common potato tuber moth *Phthorimaea operculella* (Zeller) (PTM), the Andean potato tuber moth (APTM) *Symmetrischema tangolias* (Geyen), and the Guatemalan potato tuber moth (GPTM) *Tecia solanivora* (Povolny). PTM is currently reported in more than 90 countries worldwide (Kroschel and Sporleder 2006) and is considered the most damaging potato pest in the developing world (Cisneros and Gregory 1994; CIP 2008). It is of economic significance in subtropical regions, but long cold winters in temperate regions generally restrict the development of PTM and reduce its pest status. Global warming may expand its current distribution by 400-800 km to the north in the northern hemisphere as well as to higher altitudes in tropical mountains. Further, PTM activity and hence its abundance and severity will very likely increase in all regions where the pest prevails today (Sporleder *et al.* 2007). Depending on the species, larvae mine in potato leaves and stems, but more important is the feeding damage of larvae of all three species in potato tubers, which also can cause rapid rotting by bacteria and fungi such as *Penicillium* spp. (Winning 1941). The APTM is widely distributed in mid-elevations in the Andes of Bolivia, Colombia, Ecuador and Peru. It has been also reported from Australia (Osmelak 1987), Tasmania (Terauds *et al.* 1984), New Zealand (Martin 1999) and Indonesia (Zeddam *et al.* 1999). The GPTM originates from Guatemala and is endemic throughout Central America. It has now invaded Venezuela, Colombia and Ecuador. In 2000, the moth reached the Canary Islands (Tenerife) and is considered the major threat to potato for southern Europe (EPPO 2005).

The PTM granulovirus has the potential to play a key role in the management of the common PTM in stored tubers. The granulovirus was first isolated from diseased larvae in Sri Lanka (Reed 1969) and showed high potential for PTM control in Australia (Reed and Springett 1971). Later it was isolated in various parts of the world, e.g. South Africa (Broodryk and Pretorius 1974), Peru (Alcázar *et al.* 1991), and the Republic of Yemen (Kroschel 1995). The International Potato Center (CIP), Lima, Peru developed a simple technique for multiplication and formulation of the virus (CIP 1992) and it is being produced in Bolivia and Peru using low cost propagation facilities. A detailed description of materials and methods for virus production is presented by Lacey and Kroschel in a separate paper in this series of reviews. The granulovirus is species specific and does not infect the APTM, which limits its use in those agroecosystems where mixed infestations occur. Instead, the lepidopteran-active *Bacillus thuringiensis* Berliner (*Bt*) var. *kurstaki* has proved effective in managing all three PTM species in potato stores. More details are presented on microbial control of potato tuber moths by Lacey and Kroschel, later in this series of reviews.

ANDEAN POTATO WEEVIL

The Andean potato weevil (APW), *Premnotrypes* spp., is another serious pest of potato in South America and is the most damaging insect pest at altitudes between 2,800 and 4,200 m in the Andean region of Bolivia, Peru, Ecuador, Colombia, and Venezuela (Alcázar and Cisneros 1998). Currently, 15-40% of high altitude tubers are commonly infested with weevil larvae at harvest time despite the use of insecticides. Adult weevils add to the damage by feeding on potato foliage. The fungus, *Beauveria bassiana* (Balsamo) Vuillmen, had been proposed as a potential microbial control agent for APW management in potato stores of Peru, Colombia, and Bolivia (Ewell *et al.* 1994; Raman 1994). However, it has not been widely made available and not readily used by farmers. Since potato tubers become infested by the APW during tuber development, they are therefore already infested when stored after harvest. Here, the application of the fungus to tubers during storage was able to reduce the weevil population but not tuber damage which was unacceptable for farmers.

Entomopathogenic nematodes (EPNs) have demonstrated good activity against other weevil species with soil dwelling larvae (Booth *et al.* 2007). In 2003, an EPN was isolated from infected APW larvae and pupae of *Premnotrypes suturicallus* (Kuschel) in a potato storage at 2750 m elevation, Junin, Peru and was identified as a putative new *Heterorhabditis* sp. (Alcázar and Kaya 2003). Its high potential to control APW under controlled (Parsa *et al.* 2006) and field conditions (Alcázar *et al.* 2007) was recently shown. More details on microbial control of APW are provided by Kaya *et al*. later in this series of reviews.

LEAFMINER FLY

The leafminer fly (LMF), *Liriomyza huidobrensis* (Blanchard), is a serious potato pest in coastal Peru and Chile and in certain areas of Brazil, Central America, and other countries when insecticides are used intensively and where particularly susceptible cultivars are planted (Ewell *et al.* 1994; Raman 1994). The LMF has recently appeared in Kenya, Indonesia, Israel, and Mauritius, where it has caused severe damage to diverse potato cultivars. In certain situations, LMF has reduced potato yield by 45-62%. For Peru, the recommended management strategy is based on the use of resistant cultivars and sticky yellow traps to capture adult flies. The use of insect growth regulators, when necessary, is a last option (Mujica and Kroschel 2005).

To take better advantage of the richness of parasitoids, habitat management and the use of biological control have been suggested (Kroschel *et al.* 2007). Natural epizootics of the fungus *Isaria fumosorosea* (formerly *Paecilomyces fumosoroseus*) (Wize) Brown and Smith on LMF adults have been observed in Peru. Its high pathogenicity was confirmed under laboratory conditions and recently, the entomopathogenic fungus is being field tested in Peru. LeBeck *et al.* (1993) demonstrated control of another leaf mining species, *Liriomyza trifolii* (Burgess), using EPNs. The IPM program in Peru for LMF is endangered due to a new emerging potato pest, the bud midge *Prodiplosis longifila* Gagné. No effective IPM tools including biological control have been developed for this pest so far.

COLORADO POTATO BEETLE

The Colorado potato beetle (CPB), *Leptinotarsa decemlineata* (Say), is a widespread defoliator of potato and other solanaceous vegetables and is considered a major pest in the Northern Hemisphere. It may have 1 to 3 generations per year depending on the latitude and weather and overwinters in the adult stage (Hare 1990). When infestations are high, the crop can be completely defoliated before tubers are large enough to warrant harvest (Hare 1980). Until the mid-1980s, the fungus *B. bassiana* was the only microbial control agent used against CPB. Control of CPB ranging from poor to excellent has been reported for the fungus (Hajek *et al.* 1987; Poprawski *et al.* 1997; Lacey *et al.* 1999; Wraight and Ramos 2002; Wraight *et al.* 2007). It offers the advantage of recycling in host cadavers and persisting in the soil beneath potato plants thereby affecting the survival of subterranean stages of the beetle.

The discovery of *Bacillus thuringiensis* var. *tenebrionis* (*Btt*) (Langenbruch *et al.* 1985) and other *Bt* toxins with activity against beetles, have broadened the options for microbial control of CPB. The bacterium provides excellent control of larvae, especially when applied against early instars. Timing and frequency of application, amount of inoculum, spray coverage, crop canopy, rainfall and UV inactivation can have strong influences on the efficacy of both *Btt* and *B. bassiana* (Bystrak *et al.* 1994; Lacey *et al.* 1999; Wraight and Ramos 2002). The Cry 3 toxin gene from this bacterium was used to produce transgenic potatoes resistant to attack by CPB. The modified potatoes were sold under the trade name NewLeaf™ in the United States and Canada from 1995 through 2001. Processors decided to discontinue the use of transgenic potatoes following the public debate over the risks and benefits of genetically modified food. (Thornton 2004).

EPNs and engineered spiroplasmas have also been proposed as microbial control agents of CPB (Hackett *et al.* 1992; Berry *et al.* 1997; Armer *et al.* 2004). Other reviews address the potential for biological control of CPB including the integrated use of entomopathogens, predators and parasites (Cloutier *et al.* 1995; Moldenke and Berry 1999). In depth coverage of microbial control of CPB is presented by Wraight *et al*. later in this series of reviews.

HEMIPTERAN PESTS

Several aphid species are pests of potato throughout the world. The green peach aphid (GPA), *Myzus persicae* (Sulzer), is especially important because of its role in transmitting *Potato leafroll virus* and other viruses (Radcliffe and Ragsdale 2002). In the potato growing areas of the Pacific Northwest of the United States, the focus of insect control efforts is primarily on GPA. Many other insect pests (CPB, lepidopteran pests, etc.) are coincidentally controlled by the broad spectrum insecticides that are used against aphids. The potato aphid, *Macrosiphum euphorbiae* (Thomas) and other aphids, can also be abundant on potato, but their role as vectors is less serious than that of *M. persicae* (Ragsdale *et al.* 1994; Radcliffe and Ragsdale 2002). Naturally occurring fungi are important regulators of aphid populations (Latgé and Papierok 1988; Nielsen *et al.* 2007), including aphids on potato in more humid areas (Soper 1981). The use of fungicides to combat late blight of potato, *Phytophthora infestans* (Mont) de Bary, has been correlated with aphid outbreaks due to the suppressing effects of the fungicides on entomophthoralean fungi that normally control the aphid (Lagnaoui and Radcliffe 1998). Although development of fungi as mycoinsecticides of aphids in potato has been studied (Soper 1981), no large scale implementation of artificially cultured fungus in aphid populations in potato has yet been attempted.

Other Hemiptera have also been responsible for economic losses in potato production. Leafhoppers can be abundant pests of potato and are responsible for transmitting diseases. For example, the beet leafhopper, *Circulifer tenellus* (Baker), transmits a phytoplasma that causes purple top in potato (Munyaneza *et al.* 2006). Similar to aphids in that they have piercing and sucking mouth parts, fungi are the only entomopathogens with potential for microbial control. McGuire *et al.* (1987) presented research findings on factors affecting the success of introductions of *Zoophthora* (*Erynia*) *radicans* (Brefeld) Batko for control of *Empoasca fabae* (Harris). Psyllids can also be significant pests of potato. The potato psyllid, *Bactericera* (*Paratrioza*) *cockerelli* (Sulc), has recently been incriminated in the transmission of a new *Candidatus* species, *C. Liberibacter psyllaurous*, resulting in disease in tubers known as zebra chip (Munyaneza *et al.* 2007; Hansen *et al*. 2008). Although there are no microbial control agents yet developed for this pest, several fungi have been evaluated against pear psylla, *Cacopsylla pyricola* (Förster) (Puterka *et al.* 1994). More recently, Asian citrus psyllid, *Diaphorina citri* Kuwayama, was found naturally infected with *I. fumosorosea* in Florida citrus groves (Meyer et al. 2008). Wraight *et al*. provide greater detail on fungal pathogens for the control of hemipteran potato pests in another paper in this review.

WIREWORMS

The larvae of click beetles (*Agriotes*, *Limonius*, Coleoptera: Elateridae), also known as wireworms, can be locally important pests of potato tubers (Jansson and Seal 1994; Vernon *et al.* 2005), especially if potato is rotated with crops preferred by the beetle, such as grains. Relatively little research on the microbial control of these pests has been conducted. Toba *et al.* (1983) attempted unsuccessfully to infect larvae of *Limonius californicus* (Mannerheim) with EPNs. The fungus, *Metarhizium anisopliae* (Metschnikoff) Sorok., has been reported from wireworms and is currently under development for control of these potato pests. Field trials of *M. anisopliae* by Kabaluk *et al.* (2005) resulted in a 30% reduction in wireworm damage to potato tubers and resulted in significant in-field infection and mortality of wireworms. The testing of new isolates of the fungus bioassayed against three wireworm species produced LT_{50} values as short as 8 days using 10^6 conidia/g of soil. Adults were also found to be highly susceptible to infection by *M. anisopliae*.

OTHER INSECT PESTS OF POTATO

Several other insect species are regarded as potato pests, but their economic importance varies from region to region. These comprise: several lepidopteran species in the family Noctuidae including loopers (*Autographa californica* (Speyer)), armyworms (*Spodoptera praefica* (Grote)), cutworms (*Agrotis ipisilon* (Hufnegal), *Peridroma saucia* (Hübner)) and the potato stemborer (*Hydraecia micacea* (Esper)); potato flea beetle (*Epitrix cucumeris* (Harris)), Coleoptera: Chrysomelidae); tuber flea beetle (*Epitrix tuberis* Genter, Coleoptera: Chrysomelidae); rootworms (*Diabrotica* spp., Coleoptera: Chrysomelidae); white grubs (*Melanothus* sp., *Polyphylla* sp., Coleoptera: Scarabaeidae); blister beetles (*Epicauta* spp., Coleoptera: Meloidae); potato stalk borer (*Trichobaris trinotata* (Say), Coleoptera: Curculionidae); potato scab gnat (*Pnyxia scabiei* (Hopkins), Diptera: Sciaridae); whitefly (*Bemisia tabaci* (Gennadius), Hemiptera: Aleyrodidae) and grasshoppers (*Melanoplus* spp., *Aulocara elliotti* (Thomas), Orthoptera: Acrididae)

Table 1 Entomopathogens proposed for microbial control of miscellaneous insect pests of potato.

Insect pests	Microbial control agents
Loopers, army worms	*Bt*[1], baculoviruses (GV & NPV)[2]
Cutworms	EPNs[3], *Bt*, baculoviruses
Potato leafhopper	*Zoophthora radicans*[4]
Potato psyllid	*Isaria fumosorosea*[5]
Whiteflies	*I. fumosorosea*, *Lecanicillium* spp.[5], *Beauveria bassiana*[5]
White grubs	EPNs, *Bt*, *Paenibacillus* spp.
Grasshoppers	*Nosema locustae*[6], *Entomophaga grylli*[4], *Metarhizium acridium*[5]
Root worms	*Steinernema carpocapsae*[3]
Flea beetles	EPNs, *B. bassiana*
Wireworms	*Metarhizium anisopliae*[5]
Leafminers	EPN, *I. fumosorosea*

[1] *Bacillus thuringiensis*
[2] granuloviruses and nucleopolyhedroviruses
[3] entomopathogenic nematodes (Steinernematidae and Heterorhabditidae)
[4] Fungus: Entomophthorales
[5] Fungus: Hypocreales
[6] Microsporidia

(Zehnder *et al.* 1994; Berry 1998). Other invertebrate pests of potato are presented by Berry (1998). Entomopathogens with potential for control of some of these species are presented in **Table 1**.

CONCLUSIONS

The further development and use of microbial control agents will ultimately provide components for the integrated and sustainable control of insect pests of potato and in other agroecosystems. Although factors limiting their adoption include high cost and low efficacy, compared to most chemicals presently used, these costs could be offset by the premium price paid for safer food and a greener approach. Efficacy could be improved for several microbial control agents through selection of better strains, improvements in formulations and methods of application as well as integration with other interventions that have low mammalian toxicity and less impact on the environment (Lacey *et al.* 2001). In addition to grower acceptance, the public will also have to support a greener approach to pest control that includes microbial and other biological control agents (Eilenberg and Hokkanen 2006).

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