THE POTENTIAL OF MICROBIAL AGENTS IN MANAGING POPULATIONS OF THE FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE)

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ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is susceptible to at least 20 species of entomogenous pathogens. Some of these have the potential for a significant role in the management of the fall armyworm. Potential strategies include utilization of natural epizootics, application or introduction of pathogens as insecticidal agents, and use of pathogens in combination with other biological or chemical control agents. The nuclear polyhedrosis virus (NPV) of the fall armyworm has considerable potential for use in such strategies because of its high natural prevalence in fall armyworm populations and the possibility of epizootic enhancement through cultural manipulations of pasture systems. The potential of *Bacillus thuringiensis* Berliner, *Nomuraea rileyi* (Farlow) Sampson, *Vairimorpha necatrix* armyworm in agricultural systems also should be evaluated.

RESUMEN

El gusano cogollero, *Spodoptera frugiperda* (J. E. Smith), es susceptible al menos a 20 especies de patógenos entomogénicos ("entomogenous"). Algunos de estos tienen la capacidad de controlar significativamente el gusano cogollero. Posibles estrategias incluyen el uso de epizoóticos naturales, la aplicación o introducción de patógenos como agentes insecticidas, y la combinación de patógenos con otros agentes de control biológico o químico. Debido a su gran frecuencia natural en poblaciones de gusanos cogolleros y la posibilidad de engrandecimiento epizoótico a través de manipulaciones culturales de sistemas de pastos, el virus nuclear 'polyhedrosis" (NPV) del gusano cogollero tiene considerable potencial de usarse en estrategias similares. *Bacillus thuringiensis* Berliner, *Nomuraea rileyi* (Farlow) Sampson, *Vairimorpha necatrix* (Kramer), y otros patógenos con potencial de controlar el gusano cogollero en los sistemas agrícolas también deben de ser evaluados.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a serious pest of several graminaceous crops in the southeastern and central United States (Luginbill 1928). Grain sorghum planted late (July-August) and bermudagrass are particularly susceptible to damage from mid-summer until frost. Larvae are most commonly found on grain sorghum in plant whorls where they may reduce leaf surface and/or destroy the growing point, but they also destroy seedlings and attack developing grain. In bermudagrass pastures, larvae normally feed on leaves thereby reducing hay yield and quality (Martin et al. 1980). Current control tactics include

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application of chemical insecticides, manipulation of cultural variables, and, to a lesser extent, utilization of natural enemies and diseases.

Gardner and Fuxa (1980) listed 16 species of entomopathogens to which the FAW is susceptible. These included 5 viruses, 5 fungi, 3 protozoa, 2 nematodes, and the bacterium *Bacillus thuringiensis* Berliner. Additional reports have expanded this list to include *Aspergillus flavus* Link (Lacayo 1977), the nuclear polyhedrosis virus (NPV) of *Heliothis armiger* (Hübner) (Hamm 1982a), the granulosis virus (GV) of *H. armiger* (Hamm 1982b), *Vairimorpha heterosporum* (Kellen and Lindegren), and *Vairimorpha* sp. from *Alabama argillacea* (Hübner) (Hamm and Lynch 1982).

Although several of these entomopathogens occur naturally in FAW populations, this insect remains an economically important pest. Diversified management strategies including those incorporating effective use of entomopathogens should be developed for the FAW. Prediction and manipulation of natural epizootics, application of entomopathogens as insecticidal agents, and the use of pathogens with other control agents have considerable potential for development as management strategies for grain sorghum and pasture systems. Therefore, this paper summarizes published information relating to the control of FAW with entomopathogens and further assesses the potential role of entomopathogens in the management of the FAW. Criteria employed in these assessments include effectiveness of the entomopathogen, production and/or propagation, compatibility with other control agents, and economic considerations.

NATURAL OCCURRENCE OF ENTOMOPATHOGENS

Although several pathogens including viruses, fungi, nematodes, and protozoa occur naturally in FAW populations, only the *S. frugiperda* NPV (SfNPV), *Nomuraea rileyi* (Farlow) Sampson, *Entomophaga* (=*Entomophthora*) *aulicae* (Reichardt), and *Erynia radicans* (Brefeld) Humber, Ben-Ze'ev & Kenneth (=*Entomophthora sphaerosperma*) have caused natural epizootics (i.e., unusually high morbidity). Of these pathogens, the SfNPV is most prevalent in FAW infesting grain sorghum, corn, and bermudagrass with the other pathogens causing epizootics only sporadically or in localized areas.

Based upon high infection rates observed in southeastern Louisiana (Fuxa 1982), the SfNPV appears to be quite effective against the FAW in coastal bermudagrass pastures. In this study, SfNPV accounted for more FAW mortality than any other natural enemy or disease in the pastures. Infection by the SfNPV averaged 50.8% in mid-August and peaked at 60 to 68%. Regression models indicate that cultural manipulations of the bermudagrass pasture, i.e., fertilizing or seeding to increase ground cover, moving cattle or machinery through the pastures, keeping grass shorter by grazing or harvest, etc., could enhance SfNPV epizootics (Fuxa and Geaghan 1983). In addition, SfNPV inoculum in the pasture could be increased by artificial introduction. Prediction of the occurrence of epizootics and the effects of cultural manipulations could help maintain FAW populations in bermudagrass below economic densities.

Infection rates by SfNPV in FAW infesting corn and sorghum were initially lower than in bermudagrass pastures, but % mortality was similar after late July in Louisiana (Fuxa 1982). Schwehr and Gardner (1982) also found SfNPV prevalent in FAW collected from grain sorghum in central Georgia. However, peak infections occurred from late August to mid-September (38 to 50% mean mortality) in larvae infesting plant whorls and in late September (50% mean mortality) in collections from grain heads. This lag in SfNPV prevalence in these crops limits the effectiveness of naturally-occurring SfNPV as a control agent of FAW in corn and whorl-stage sorghum. Larval behavior, i.e., feeding in protected locations in plant whorls, and the relative lack of natural contamination of leaf surfaces with SfNPV apparently contribute to this lag. Therefore, strategies employing the SfNPV for FAW control in these crops might include artificial introduction of the virus into the system.

Artificial Introduction or Application of Entomopathogens

There are no published reports on the application of SfNPV to bermudagrass pastures or grain sorghum. However, it has been applied as a microbial insecticide for control of FAW in corn. Application of SfNPV with high clearance sprayers demonstrated the importance of late-whorl or early-tassel treatment in preventing damage to corn ears by FAW (Young and Hamm 1966, Hamm and Young 1971). Application of the virus through overhead irrigation systems produced infections in FAW larvae infesting corn whorls, and epizootics of SfNPV were initiated by only 2 applications of the virus (Hamm and Hare 1982). Although SfNPV can be mass-produced in live hosts (Ignoffo and Hink 1971) and can be propagated in cell culture (Gardiner and Stockdale 1975), production and propagation of this virus and characterization of geographical strains currently limit development of the pathogen as a microbial insecticide.

Plant coverage, contact of the target pest with an effective inoculum, and larval age apparently limited control of FAW with commercial formulations of *B. thuringiensis* (*Bt*) when applied as an aqueous spray to whorl-stage sorghum (Gardner et al. 1982). Addition of various spreaders and adjuvants to the spray and/or increasing the volume of carrier applied per unit of surface area failed to increase efficacy. Foliar sprays of *N. rileyi, V. necatrix* Kramer, or *Metarhizium anisopliae* (Metchnikoff) Sorokin also failed to control FAW in sorghum whorls (Schwehr 1981).

FAW control has been achieved with foliar sprays of *Bt* to corn and cabbage when timing of application was scheduled to contaminate leaf surfaces before larvae began to burrow and feed within plant structures (Gardner and Fuxa 1980). Foliar sprays of *Neoaplectana carpocapsae* Weiser (Landazabal et al. 1973) and application of a granular formulation of *M. anisopliae* (Villacorta 1976) also provided effective control of FAW in corn. *Vairimorpha* sp. and *V. heterosporum* were infective to FAW in corn when the pathogens were applied in irrigation water; however, these 2 species were not as effective as SfNPV in preventing crop damage because they did not kill FAW until the late larval or pupal stages (Hamm and Hare 1982). *Bt* and *N. carpocapsae* are commercially produced in the USA, but additional evaluation is required to assess the effectiveness of these agents against FAW in agricultural systems.

Pathogens were applied in these field tests by systems developed primarily for application of conventional chemical insecticides. Pathogen effectiveness might be improved by more work on formulations, application equipment, and methodology because most equipment and procedures do not provide optimum target coverage with an effective inoculum of the pathogen (Smith and Bouse 1981). Pathogens also might be introduced into the FAW habitat by spread of cadavers or other contaminated materials (i.e., frass), release of infected live hosts or contaminated parasites or predators, or transplantation of contaminated host plants (Ignoffo 1978, Ignoffo et al. 1980). Introduction methods such as these have considerable potential in increasing entomopathogen effectiveness especially with agents capable of autodissemination at sub-economic FAW densities on crops that will tolerate some FAW damage.

Compatibility of Entomopathogens with Other Control Agents

Compatibility with other agents applied for pest control or with naturally-occurring mortality agents is important in developing strategies for use of entomopathogens in integrated pest management systems. Deleterious effects or enhanced activity resulting from integration of control agents will have a major impact on the potential of an entomopathogen in IPM systems. However, there is little published information on either laboratory bioassays or field tests evaluating these interactions with FAW as the target pest.

Reviews by Benz (1971) and Jaques and Morris (1981) indicate that chemical pesticides have little or no effect on insect viruses or *Bt*. In fact, mixtures of low dosages either viruses or *Bt* with chemical insecticides have provided pest control or crop protection superior to that obtained with higher dosages of either the chemical or pathogen alone. Such combinations could decrease expenses for insect control, reduce environmental contamination and adverse effects on predaceous and parasitic arthropods, reduce the rate of development of insecticide resistance in target species, and/or avoid phytotoxicity.

In general, *N. rileyi* and other entomogenous fungi which infect the FAW are adversely affected by many fungicides but not by most insecticides (Benz 1971, Roberts and Campbell 1977). Potentiation of insect fungi by utilization in combination with chemical insecticides also appears less probable than for bacteria or viruses (Jaques and Morris 1981).

Little is known about the compatibility of protozoans and nematodes with chemical pesticides. However, benomyl inhibited various microsporidia in laboratory assays (Hsiao and Hsiao 1973, Brooks et al. 1978) and might suppress them in field habitats.

Interactions between entomopathogens may be antagonistic, synergistic, additive, or innocuous. Double infection by different types of pathogens in the laboratory usually results in increased mortality, especially when the infections are sequential rather than simultaneous (Jaques and Morris 1981). The effects of interactions between *V. necatrix* and 3 other pathogens in *Heliothis zea* (Boddie) were additive with *Bt*, additive with *N. rileyi*, and antagonistic with *Heliothis* NPV, thus demonstrating that *V. necatrix* has the potential to synergize or antagonize any control agents which act on the midgut epithelium of the host (Fuxa 1979).

We found that the effects of simultaneous exposure of 3rd-instar FAW larvae to *N. rileyi* and *Bt* were additive (Table 1). This interaction was determined from expected mortality if the 2 pathogens acted independently

TABLE 1. INTERACTION OF *Bacillus thuringiensis* AND *Nomuraea rileyi* IN 3RD-INSTAR *Spodoptera frugiperda*.

Thuricide dose (ng/mm_2)*	*N. rileyi* dose (conidia/mm^2)*	Expected % mortality**	Observed % mortality	Chi-square value†
0	600	—	8.0	
0	6,000	—	63.0	
0	60,000	—	87.5	
500	0	—	41.2	—
500	600	45.9	38.7	1.129
500	6,000	56.4	54.1	0.094
500	60,000	92.6	94.2	0.028
1,000	0	—	46.2	—
1,000	600	50.5	41.8	1.499
1,000	6,000	80.1	70.0	1.275
1,000	60,000	93.3	97.8	0.217
2,000	0	—	53.4	—
2,000	600	57.1	54.5	0.118
2,000	6,000	82.8	68.3	2.539
2,000	60,000	94.2	98.4	0.187
4,000	0	—	54.0	—
4,000	600	57.7	49.2	1.252
4,000	6,000	83.0	78.5	0.244
4,000	60,000	94.2	96.6	0.061

*Applied to 11-mm^2 diam. leaf disc.

**$E = 0_f + 0_b\,(1\text{-}0_f)$, where E = expected mortality, 0_f = observed mortality produced by the fungus alone. 0_b = observed mortality produced by the bacterium alone (Finney 1977).

†No significant differences between expected and observed mortality levels ($P = 0.05$; 1 df).

of each other: $E = 0_f + 0_b(1\text{-}0_f)$, where E = expected percentage mortality, 0_f = observed percentage mortality produced by *N. rileyi* alone, and 0_b = observed percentage mortality produced by *Bt* alone (Finney 1977). Observed combined mortality was compared to expected mortality by the Chi-square test ($P = 0.05$; 1 df). If the values were not significantly different, it was concluded that the observed combined mortality was within a range expected from additive effects. Any significant differences would indicate synergistic or antagonistic interactions. Lethal times from exposure to death also were significantly shorter in larvae treated with both pathogens than in larvae treated with either pathogen alone.

Synergism of the *Pseudoplusia includens* NPV by a GV in the armyworm, *P. includens* (Haworth), has been confirmed (Tanada and Hara 1975). Although such an interaction between 2 types of viruses has not been demonstrated in the FAW, it remains of considerable interest in FAW management because a NPV and a GV occur naturally in FAW populations (Gardner and Fuxa 1980, Fuxa 1982, Schwehr and Gardner 1982).

Artificial introduction of compatible pathogens into an agroecosystem also should be considered for FAW management. For example, mixtures of viruses and *Bt* were more effective in controlling *Trichoplusia ni* (Hübner) than the components used alone (Jaques 1973, 1977). The technique of applying *Bt* and viruses separately at strategic intervals is receiving increased attention (Jaques and Morris 1981). Theoretically, the virus should provide long-term suppression while *Bt* provides short-term control. These strategies could prove useful in managing FAW, especially in crops where epizootics of SfNPV are prevalent.

Entomopathogens have adversely affected parasitic arthropods by infecting the parasite, producing toxins, or killing the host before the parasite completes its development (Jaques and Morris 1981). *Vairimorpha* sp. and *V. heterosporum* interfered less with the production of hymenopterous parasites than SfNPV when applied in irrigation water to control FAW in corn (Hamm and Hare 1982). The SfNPV often killed the host before the parasites could complete development. Hamm et al. (1983) also determined in laboratory bioassays that the *Vairimorpha* sp. does not reduce the effectiveness of *Microplitis croceipes* (Cresson) and *Cotesia marginiventris* (Cresson) in *H. zea*. In addition, interactions between entomopathogens and parasitic arthropods may be advantageous because of possible transmission of the disease by the parasites. Therefore, the abundance of natural enemies attacking the FAW (Ashley 1979) warrants further investigation of the possible occurrence of these interactions in FAW populations.

Economic Considerations

Economic considerations include cost-benefit relationships for the grower and the competitiveness of alternative chemical insecticides or other control tactics. Marketability and public reaction also are important considerations in the development of a microbial insecticide. Cost-benefit relationships may have either a negative or positive influence in the grower's decision to implement a microbial control program against the FAW. For example, enhancement of the natural SfNPV epizootic in coastal bermudagrass pastures with selected cultural manipulations could be relatively inexpensive as a control tactic, especially if the cultural manipulations are routine cropping practices (i.e., fertilization, grazing, harvest, etc.). On the other hand, application of a microbial insecticide (i.e., *Bt*) for FAW control will include the cost of the material as well as the expense of application. The action threshold for the crop must be given major consideration and may need to be lowered when using microbial control because of the lag between the suppressive action and control of the pest.

Cost of production of microbial insecticides is at least the same, and usually more, than for conventional chemical insecticides, and their shelf-life is generally shorter. However, several characteristics of microbials such as the narrow host range and the relative lack of human and wildlife hazards and environmental contamination may also be important considerations in the decision to utilize microbial control strategies.

Conclusions and Research Needs

Based upon the criteria of effectiveness, production and propagation, compatibility with other control agents, and economic factors, the naturally occurring SfNPV has great potential for use in a FAW management strategy in bermudagrass pastures. Its natural prevalence in this system might be enhanced by various cultural manipulations. Although the SfNPV also is prevalent in FAW attacking corn and grain sorghum, artificial introduction of the virus into these systems will be required to induce epizootics before economic injury levels are reached. SfNPV is not commercially available at this time, although some basic techniques have been developed for its mass-production. Field and laboratory development of the SfNPV and other candidate pathogens (i.e., *Bt*, *V. necatrix*, *N. rileyi*, etc.) should continue with appropriate attention to strain selection, formulation, and application methodology. Searches should continue in this and other countries for pathogens and strains with great virulence for the FAW.

In addition, further research is needed on: 1. the basic biology of FAW, including behavior and population dynamics; 2. definition of action thresholds for use of microbial agents, and; 3. compatibility of microbials with other FAW control tactics such as other natural enemies, host plant resistance, and chemical insecticides.

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