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Successes and failures in the use of parasitic nematodes for pest control

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Abstract

Advances in mass-production and formulation technology of entomopathogenic nematodes, the discovery of numerous isolates/strains and the desirability of reducing pesticide usage have resulted in a surge of scientific and commercial interest in these nematodes. The lessons learned from earlier problems have encouraged scientists and leading commercial companies to increase their efforts toward improving cost efficiency and better product positioning in the market within the confines of product capabilities. The successes or failures of the nematodes against 24 arthropod pest species of agriculture and animals and against a major slug pest in agriculture are discussed in this review. Commercial successes are documented in markets such as citrus (Diaprepes root weevil), greenhouses and glasshouses (black vine weevil, fungus gnats, thrips, and certain borers), turf (white grubs, billbugs, and mole crickets), and mushrooms (sciarid flies). In addition, the successful commercialization of a nematode (*Phasmarhabditis hermaphrodita*) against slugs in agricultural systems is presented. Despite this progress, the reality is that nematode-based products have limited market share. Limited share is attributed to higher product cost compared to standard insecticides, low efficacy under unfavorable conditions, application timing and conditions, limited data and cost benefit in IPM programs, refrigeration requirements and limited room temperature shelf life (product quality), use of suboptimum nematode species, and lack of detail application directions. One or more of these factors affected the market introduction of the nematodes despite promising field efficacy against insects such as black cutworm in turf, sugar beet weevil in sugar beet, sweet potato weevil in sweet potato, and house fly adult in animal-rearing farms. Insects such as cabbage root maggots, carrot root weevil, and Colorado potato beetle are listed on the label of certain commercial products despite low efficacy data, due to insect susceptibility, biology, and/or behavior. To make entomopathogenic nematodes more successful, realistic strategies through genetic engineering, IPM programs, and new delivery systems and/or training programs to overcome their inherent cost, formulation instability, and limited field efficacy toward certain insects are needed.

Keywords: Entomopathogenic nematodes; *Steinernema*; *Heterorhabditis*; *Phasmarhabditis*; Slug nematode; Field efficacy; Commercialization

1. Introduction

The development of large-scale production and ease-of-use formulations created marketing opportunities for entomopathogenic nematodes of the genera *Steinernema*

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and *Heterorhabditis* (Georgis, 2002). However, commercialization of entomopathogenic nematodes has experienced both successes and failures (Shapiro-Ilan et al., 2002). Successes include control of the Diaprepes root weevil *Diaprepes abbreviatus* L. in citrus, the black vine weevil *Otiorhynchus sulcatus* (Fabr.) in cranberries and greenhouses, billbugs *Sphenophorus* spp. in turf, fungus gnats (sciarid flies) *Bradysia* spp. in greenhouses and mushroom flies *Lycoriella* spp. in mushrooms. Yet, these successes often did not lead to capture of a significant share of the pesticide market for these pests. Even where promising efficacy against some insects has been achieved under filed conditions (e.g., artichoke plume moth, *Platyptilia carduidactyla* (Riley), the black vine weevil in mint, and cockroaches in urban industrial environments) under field conditions, commercial sales of nematodes were minimal at best or never realized. Although the host range of entomopathogenic nematodes includes more than 200 insect species, nematodes have only been successfully marketed for a small fraction of these insects. Accordingly, we have selected certain insect pests of animals and crops to address the factors that influence the success or failure of commercial entomopathogenic nematodes.

2. Commercial assessment

The adoption of entomopathogenic nematodes as pest control agents by growers depends upon numerous factors beyond acceptable efficacy. Factors such as cost, shelf life, handling, mixing, coverage, competition, compatibility, and profit margins to manufacturers and distributors contributed to the failure of nematodes to penetrate many markets or to gain significant market share (Tables 1 and 2). Most of the current markets are limited to specific insects such as those of citrus, turf, and ornamentals (Table 1). Unfortunately, due to insect susceptibility, behavior and/or biology, many insects listed on the product labels of certain commercial companies are improper targets (e.g., corn rootworm, cucumber beetles, flea beetles, carrot weevil, root maggots, wireworms, shore flies, and imported fire ants) for nematodes (Georgis, 2004). These insects have a significant market share of the pesticide market (Georgis, 2004).

Georgis and Gaugler (1991) noted that successful market penetration of nematode-based products depends upon providing predictable control. Because of the complex interplay of abiotic and biotic factors, achieving predictability is probably the greatest intellectual challenge facing biological control today. Although nematodes can successfully infect and develop in many different host species, hosts in which optimal infection and development occurs differ with the nematode species or strain. Therefore, screening several different nematode species and strains against a particular target host is essential in development of any control program. The biology and behavior of the nematode and the target host and the environment in which the nematodes are to be applied must also be considered carefully when designing a control strategy.

A large number of field trials are necessary to design and optimize protocols that achieve consistent and satisfactory control. Based on 82 field trials, Georgis and Gaugler (1991) described how factors such as moisture (irrigation frequency and rainfall), thatch depth, soil type, seasonal temperature, nematode strain, and nematode application method could be used to predict failure or successful control of larval scarabaeids.

Recently, Mráček (2002) summarized the results of 70 field tests that were conducted between 1988 and 2002. This summary provides a comprehensive summary of field efficacy of various nematode species against a wide range of insect species in various crops and habitats. Most of these insects live in soil, although some, such as the artichoke plume moth and larval sesiids and cossids, inhabit cryptic environments. Both soil and cryptic habitats protect nematodes from desiccation and UV light, buffer temperature extremes, and promote contact between nematodes and the target insects. Out of the 70 tests, only 12 showed high efficacy. In other tests, the control was inconsistent or ineffective. Those insects that were not controlled successfully usually inhabited an environment hostile to nematodes (e.g., fly maggots in chicken manure, foliar habitats where nematodes desiccate, or sites with high temperatures), were physiologically resistant to nematodes (e.g., the immune response of mosquito larvae), possessed morphological barriers to nematode penetration (e.g., exclusion of nematodes by spiracular plates of certain scarabaeids) or exhibited behavioral traits that allow them to evade or exclude nematodes (e.g., fire ants moving their colonies away from nematodes).

The use of entomopathogenic nematodes against aboveground insects has also been analyzed by Arthurs et al. (2004). They analyzed 136 published greenhouse and field trials that used *Steinernema carpocapsae* (Weiser), and through the use of a general linear model showed that the nematode treatment efficacy depended on the target insect's habitat (bore holes > cryptic foliage > exposed foliage) and trial location (greenhouse > field studies). Relative humidity and temperature during and up to 8 h after application influenced the nematode infection rates, but the addition of spray adjuvants and nematode concentration did not explain a significant amount of variability in the efficacy of *S. carpocapsae*.

3. Effectiveness against nursery and greenhouse insects

The total annual crop sales for the greenhouse and nursery industry in the USA were estimated at over \$6.2 billion in 1998 (van Tol and Raupp, 2005). Hardy nursery stock in the Netherlands and the United Kingdom—having the largest production areas in Europe—has an annual crop value of \$1.1 billion (van Tol and Raupp, 2006). The nursery industry relies heavily on chemical pesticides. In contrast to greenhouse production, there are only few