INTRODUCTION

Numerous species of nematodes and microorganisms have potential for use as commercial products (Starnes et al. 1993). Successful commercial development of pathogens for augmentative biological control involves: agent selection (to obtain the best species and strains for the target pest); development of cost-effective methods for mass rearing; effective methods for storage and shipping of the agent; creation of formulations to protect and deliver the agent to the target pest’s location; field testing of the product’s efficacy and methods for its application; economic factors affecting product development and markets; and demonstration of safety of products to man and the environment.

AGENT SELECTION

Selection of a pathogen for the control of a target pest involves choices at two levels. First, a choice may be possible among different agent groups (viruses, bacteria, fungi, protozoa, and nematodes). Second, within a given group of agents, the particular species, strain, or isolate must be identified that has the best properties for the desired use. Patent and registration requirements may differ among agents, also affecting choice of agent.

Choosing Among Groups of Pathogens

Choice among agent groups, given that candidates exist for a given target pest, can be guided by three factors: ease and cost of production; degree of pathogenicity and host specificity; and environmental or habitat features influencing effectiveness.

Ease and Cost of Rearing. The most basic factor affecting differences in ease and cost of rearing of different organisms is whether or not living hosts are required for pathogen production. The microbial pesticide of greatest commercial application in the United States, Bacillus thuringiensis, for example, can be grown on fermentation media. In contrast, Bacillus popilliae which requires living hosts for effective production, has not been as successful commercially. Some bacteria, fungi, and nematodes can be grown in nonliving media, a factor promoting their use. Other species within these groups, for example, many species of Entomophthoraceae
fungi, require living hosts. However, all viruses and the protozoa (principally, microsporidia) of biological control interest must be grown in living hosts or host cell cultures, increasing the cost of producing these agents and limiting their use. Other aspects of production, such as use of liquid media in place of solid media, or development of simple systems of on-farm pathogen production by farmers, can also affect the cost of labor and machinery needed for production. Ease of production is a function of the technology available for the task, which is subject to improvement. Development of higher yielding cell lines for virus production, for example, might in the future reduce the cost of virus production enough to make commercial in vitro production feasible. Similarly, development of rearing media that employ cheaper ingredients, such as locally produced cereals, in place of chemically-defined but more costly media, can reduce the cost of the production of fungi (Hoti and Balaraman 1990).

Degree of Pathogenicity and Host Specificity. In choosing a pathogen for development as a commercial product, the degree of pathogenicity and level of host specificity of any particular agent are important considerations (Charudattan 1989). The degree of pathogenicity directly affects the cost of pathogen-based pesticides by determining the quantity that must be applied to achieve control. Because production costs of many pathogens are relatively high, selecting a highly pathogenic strain, which is effective in smaller doses, is essential to increasing the cost competitiveness of the pathogen. High levels of pathogenicity may also be important for controlling a range of instars of a pest, as some strains of a pathogen may be more effective than others in killing less susceptible stages. Such characteristics can be important in making the use of a product commercially successful.

The host specificity of a pathogen is important in that it determines the size of the potential market for the product. For highly specific agents to have commercial value, they must attack pests affecting widely grown or high-value crops to support sufficient sales. Many viruses, for example, are relatively host specific. Many are limited to hosts in just one or a few genera, for example, the virus of the brown tailed moth, *Euproctis chrysorrhoea* (Linnaeus), which is limited to a single host (Kelly et al. 1988). Such viruses currently have no commercial potential (unless their host is a major pest in a high-value crop) because their markets are typically too small to permit economies of large-scale production. Viruses with broader host ranges do exist, such as the *Autographa californica* nuclear polyhedrosis virus which attacks at least six species (rigorously confirmed) and perhaps up to 43 species in 11 families of insects (Payne 1986). Genetic engineering can be used to broaden the host spectrum of some types of pathogens. This has been done for the bacterium *Bacillus thuringiensis*. Strains that are specific for certain types of hosts (subsp. *kurstaki* for Lepidoptera, subsp. *israelensis* for Diptera, subsp. *ten­brionis* for Coleoptera) can be genetically manipulated so that the host ranges of several strains are combined in the newly created form (Grickmore et al. 1990; Gelernter 1992).

Environmental or Habitat Features Affecting Effectiveness. The choice between major groups of agents may be dictated in some cases by similarities in environmental conditions in the pest's microhabitat to those favoring pathogenicity or reproduction of the agent. Nematodes, for example, have enjoyed greatest success in moist habitats such as soil and, to a lesser degree, inside plant tissues for control of leafminers or stem borers. While means may be found in the future to make nematodes work in drier environments such as on leaf surfaces, current circumstances dictate that the ecological requirements of the agent be met by developing products targeted at pests in favorable microhabitats. In other cases, formulation methods may be developed that overcome some of the environmental limitations of agents. Viruses, for