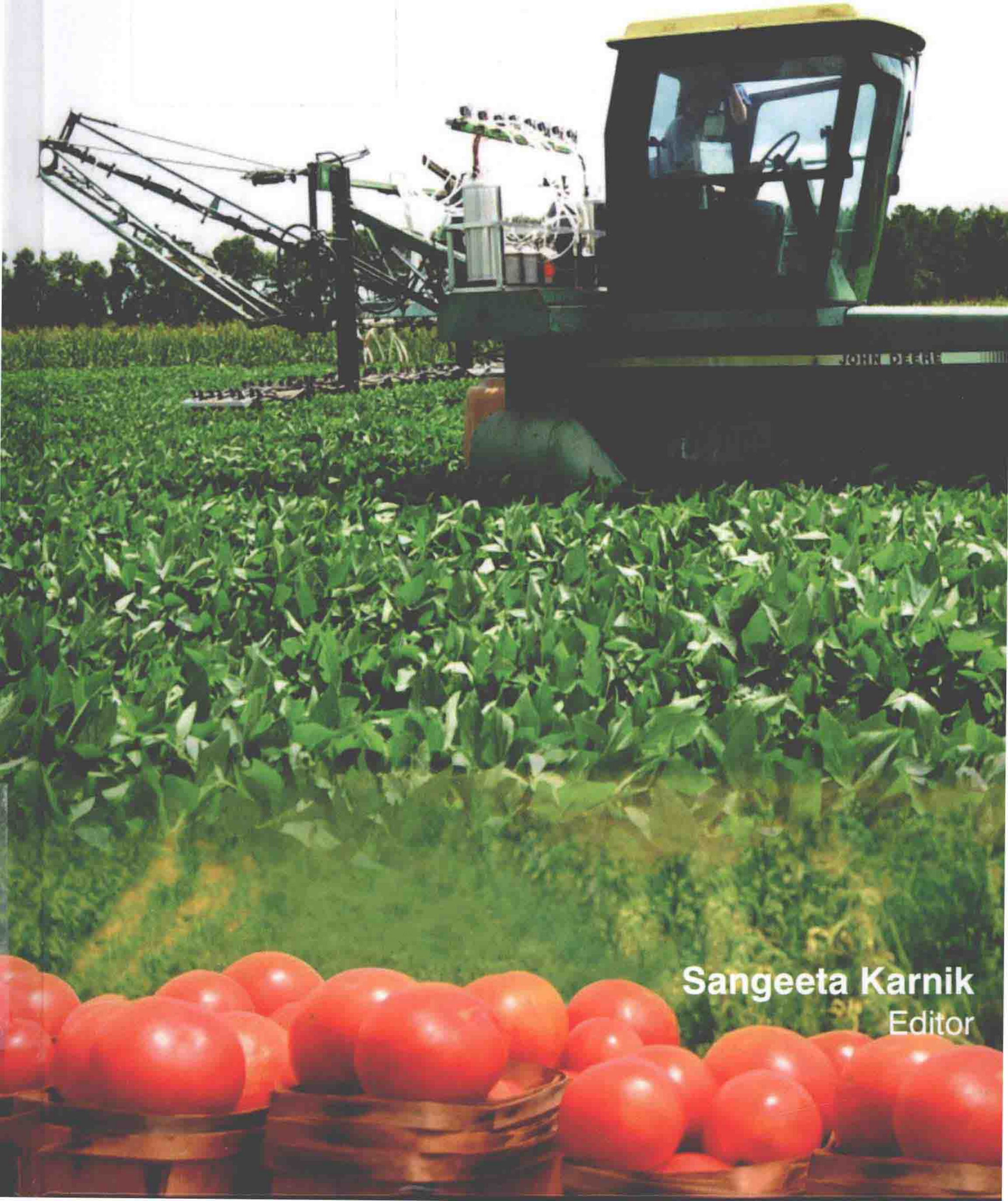
Handbook of
Biopesticides and Alternative Agriculture

New Technologies, Applications, Markets and Potentials



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Editor

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Preface

All living organisms are subject to predation, parasitism or competition from other organisms. The study of these interactions has led to the identification of many potential opportunities for the use of living organisms as biopesticides to protect agricultural crops against insect pests, fungal, bacterial and viral diseases, weeds, nematodes and mollusc pests. In very general terms, according to the US EPA, biopesticides are pesticides derived from natural materials such as animals, plants, bacteria, and minerals. The two key categories focused on in this report include biochemical and microbial pesticides (reviewing the third category of biopesticides, transgenic crops, was outside the scope of this report). The subcategories of biochemical pesticides introduced in this report include insect pheromones, plant extracts and oils, plant growth regulators and insect growth regulators. Microbial pesticide subcategories discussed include bacteria, virus, fungus, and other less common microorganisms. A range of biopesticide products are now available commercially for control of insect pests, fungal and bacterial diseases and weeds. As a society we are receiving clear signals that some chemicals routinely used in conventional agriculture are associated with alarming health and environmental effects. From human to ecological health impacts, there are growing concerns about how we farm. Though green chemistry applications for sustainable agriculture are relatively few, there is a specific area within green chemistry that has direct implications for sustainable agriculture: the field of biopesticides. We have chosen to focus this book on biopesticides because the field is the most likely source for alternatives to some of the pesticides of greatest concern.

Several Presidential Green Chemistry Challenge Awards have been given for innovations in biopesticides. Also, the area of biopesticides is: a rapidly growing market; raises both optimism and concerns, and is a critical new issue area for anyone concerned with agriculture. A chief conclusion of this study, however, is that as it grows in scale, the field of biopesticides is ripe for green chemistry's broad, principles-based approach to stainability. The market for biopesticides is expanding rapidly: growing at some 10% per year, by 2010 global sales are expected to hit the $1 billion mark and make up 4.2% percent of the overall pesticides market. Much of this rapid growth is due to the fact that, perhaps surprisingly, more than 80 % of biopesticides are used, not by organic farmers, but by producers employing conventional farming practices. Orchard crops hold the largest share of total biopesticides use at 55%. It is hard to get current data on overall pesticide use; tracking this data is not in the purview of the USDA, and the EPA last reported on pesticide use data in 2001. Expert estimates, however, hold that overall pesticide use has been declining at a rate of some 1.3% per year over the last decade. This decline is attributed to increased concerns about health and environmental effects, the rise in organic agriculture, and the emergence of alternatives, including biopesticides. In fact, as we shall discuss, the banning of particular pesticides in some cases has been a direct driver of the discovery (and in some cases the rediscovery and development) of biopesticide alternatives Green chemistry and sustainable agriculture are both revolutionary fields with significant overlap, though the connections are not fully developed nor appreciated. Sustainable agriculture encompasses a wide variety of farming techniques and practitioners. Broadly speaking sustainable agriculture seeks to achieve three goals: farm profitability; community prosperity; and environmental stewardship. The latter includes: protecting and improving soil quality, reducing dependence on non-renewable resources, such as fuel, synthetic fertilizers and pesticides and minimizing adverse impacts on safety, wildlife, water quality, and other environmental resources.

The book will be an indispensable source for all professionals, researchers and students in this subject and for anyone working in the related areas for acquiring an up-to-date overviews.

—*Editor*

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Chapter 1

Biological Pest Control

Biological control of pests in agriculture is a method of controlling pests (including insects, mites, weeds and plant diseases) that relies on predation, parasitism, herbivory, or other natural mechanisms. It can be an important component of integrated pest management (IPM) programs.

Overview

Biological Control is defined as the reduction of pest populations by natural enemies and typically involves an active human role. Natural enemies of insect pests, also known as biological control agents, include predators, parasitoids, and pathogens. Biological control agents of plant diseases are most often referred to as antagonists. Biological control agents of weeds include herbivores and plant pathogens. Predators, such as lady beetles and lacewings, are mainly free-living species that consume a large number of prey during their lifetime. Parasitoids are species whose immature stage develops on or within a single insect host, ultimately killing the host. Most have a very narrow host range. Many species of wasps and some flies are parasitoids. Pathogens are disease-causing organisms including bacteria, fungi, and viruses. They kill or debilitate their host and are relatively specific to certain insect groups. There are three basic types of biological control strategies; conservation, classical biological control, and augmentation.

Effects on Future

With further research and more scientific experiments, biological control could potentially play a huge role in the future of pest prevention. Biological control is being used among society today;

however, it could someday reduce the use of many pesticides and herbicides. Since biological control could potentially have a large economic value, if found to be successful, research and job fields would increase continually. By increasing awareness of biological controls among more people, new successful biological controls could be discovered in the future. This could eliminate the overuse of chemicals. Biodiversity would increase, too, because of the reduction of chemical applications that often do affect not only the single species they are intended to kill, but other species as well.

Economic Effects

Biological control is heavily analyzed by the amount of economic gain that directly comes from biological control. Many of the known economics of biological control are related directly to agriculture practices. Since agriculture has a huge impact on biodiversity this could potentially increase the biodiversity among agricultural practices.

Figure: *A turnaround flowerpot, filled with straw to attract Dermaptera-species*

In order for agriculture to keep up with the growing population, many inputs are increased resulting in the loss of un-harmful species. Biological control use has been very minimal in agriculture. Less than 1% of global pest control sales of $30 billion involve biological methods.

Very few case studies on the cost-benefit analysis of biological control have been done however a few have taken place. A Critical evaluation of augmentative biological control has found four case studies.

In one case, "the releases of a parasitoid *Gryon pennsylvanicum* Ashmead to control the true bug *Anasa tristis* on pumpkins produced lower net benefit (in dollars) than applications of esfenvalerate (pesticide); 18% lower in one year and 120% lower in the next. In 1 year of the study, a combination of augmentative releases and use of a resistant pumpkin variety produced greater net benefit than pesticide alone, but not pesticide combined with the resistant variety".

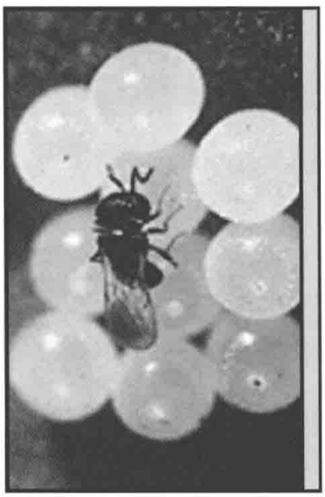

Figure: *A wasp parasitoid of stink bug eggs.*

Another case study found that releases of *T. nubilale* were considerably less cost-effective than pesticide applications used to control ECB on feed corn and fresh-market sweet corn. Pesticide applications produced 87% and 45% more net benefit (in dollars) than augmentation for feed corn and fresh market corn, respectively. In seed corn, however, *Trichogramma* releases produced essentially equivalent net benefits to pesticide treatments. In a third cost-benefit analysis of augmentation, Lundgren et al. (2002) showed that *Trichogramma brassicae* Bezdenko releases produced considerably less net benefit (94%; measured in cabbage head production) than methomyl treatments (Andow 1997). In two other studies, "biological control releases were about two times the cost of pesticide applications; this was true for releases of a parasitoid, *Choetospila elegans* Westwood, used to control a stored product pest, *Rhyzopertha dominica* (F.) (Flinn et al., 1996) and releases of green lacewings, *Chrysoperla* *carnea* Stephens to control leafhoppers in grapes. Finally Prokrym et al. (1992) suggested that *Trichogramma* releases were about six times as expensive as pesticide treatments for *O. nubilalis* in sweet corn," Another study shows that even though being possibly less effective, biological pest control still produces a benefit-to-cost ratio of 11:1. One study has estimated that a successful biocontrol program returns £32 in benefits for each £1 invested in developing and implementing the program, i.e. a 32:1 benefit-to-cost ratio. The same study had shown that an average chemical pesticide program only returned profits in the ratio of 13:1.

So while the exact numbers vary, the majority of these case studies shows that biological control is less cost effective than chemical applications and in result raises a flag that more research needs to be done. With progression in research, we can use more controls at a cheaper cost and increase the amount of biodiversity in areas because of the minimal use of chemicals that cannot target a specific species of pest.

Classical Biological Control

Classical biological control is the introduction of natural enemies to a new locale where they did not originate or do not occur naturally. This is usually done by government authorities. In many instances the complex of natural enemies associated with an insect pest may be inadequate. This is especially evident when an insect pest is accidentally introduced into a new geographic area without its associated natural enemies. These introduced pests are referred to as exotic pests and comprise about 40% of the insect pests in the United States. Examples of introduced vegetable pests include the European corn borer (*Ostrinia nubilalis*), one of the most destructive insects in North America. To obtain the needed natural enemies, scientists turned to classical biological control.

This is the practice of importing, and releasing for establishment, natural enemies to control an introduced (exotic) pest, although it is also practiced against native insect pests. The first step in the process is to determine the origin of the introduced pest and then collect appropriate natural enemies associated with the pest or closely related species. The natural enemy is then passed through a rigorous quarantine process, to ensure that no unwanted organisms (such as hyperparasitoids) are introduced, then they are mass produced, and released. Follow-up studies are conducted to determine if the natural enemy becomes successfully established at the site of release, and to assess the long-term benefit of its presence.

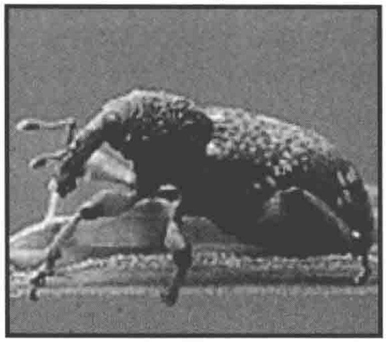

Figure: *A European weevil imported to attack purple loosestrife.*

There are many examples of successful classical biological control programs. One of the earliest successes was in controlling *Icerya purchasi*, the cottony cushion scale, a pest that was devastating the California citrus industry in the late 1800s. A predatory insect *Rodolia cardinalis* (the Vedalia Beetle), and a parasitoid fly were introduced from Australia. Within a few years the cottony cushion scale was completely controlled by these introduced natural enemies. Damage from *Hypera postica* Gyllenhal, the alfalfa weevil, a serious introduced pest of forage, was substantially reduced by the introduction of several natural enemies. About 20 years after their introduction, the population of weevils, in the alfalfa area treated for alfalfa weevil in the Northeastern United States, was reduced by 75 percent.

A small wasp, *Trichogramma ostriniae*, was introduced from China to help control the European corn borer making it a recent example of a long history of classical biological control efforts for this major pest. Many classical biological control programs for insect pests and weeds are under way across the United States and Canada. The population of *Levuana irridescens* (the Levuana moth), a serious coconut pest in Fiji was brought under control by a classical biological control program in the 1920s. Classical biological control is long lasting and inexpensive. Other than the initial costs of collection, importation, and rearing, little expense is incurred. When a natural enemy is successfully established it rarely requires additional input and it continues to kill the pest with no direct help from humans and at no cost. Unfortunately, classical biological control does not always work. It is usually most effective against exotic pests and less so against native insect pests. The reasons for failure are not often known, but may include the release of too few individuals, poor adaptation of the natural enemy to environmental conditions at the release location, and lack of synchrony between the life cycle of the natural enemy and host pest.

Parasitoid Insects

Most insect parasitoids are wasps or flies. Parasitiods comprise a diverse range of insects that lay their egg on or in the body of an insect host, which is then used as a food for developing larvae. Parasitic wasps take much longer than predators to consume their victims, for if the larvae were to eat too fast they would run out of food before they became adults.

Figure: *Encarsia formosa was one of the first biological control agents developed.*

Such parasites are very useful in the organic garden, for they are very efficient hunters, always at work searching for pest invaders. As adults they require high energy fuel as they fly from place to place, and feed upon nectar, pollen and sap, therefore planting plenty of flowering plants, particularly buckwheat, umbellifers, and composites will encourage their presence.

Four of the most important groups are:

- Ichneumonid wasps: (5-10 mm). Prey mainly on caterpillars of butterflies and moths.

- Braconid wasps: Tiny wasps (up to 5 mm) attack caterpillars and a wide range of other insects including greenfly. A common parasite of the cabbage white caterpillar-seen as clusters of sulphur yellow cocoons bursting from collapsed caterpillar skin.

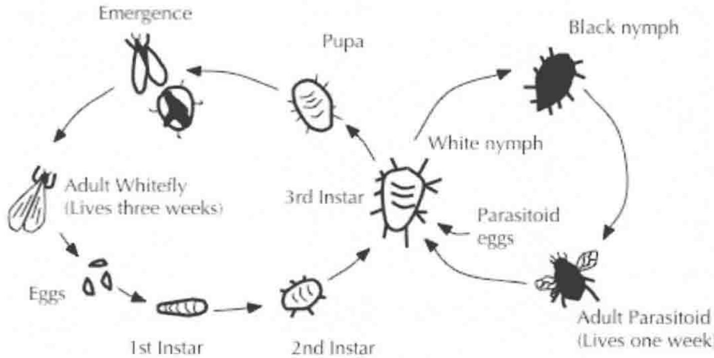

Figure: *Diagram illustrating the life cycles of Greenhouse whitefly and its parasitoid wasp Encarsia formosa*

- Chalcid wasps: Among the smallest of insects (<3 mm). Parasitize eggs/larvae of greenfly, whitefly, cabbage caterpillars, scale insects and Strawberry Tortrix Moth (*Acleris comariana*).
- Tachinid flies: Parasitize a wide range of insects including caterpillars, adult and larval beetles, true bugs, and others.

Biological Control with Microorganisms

Various microbial insect diseases occur naturally, but may also be used as biological pesticides. When naturally occurring, these outbreaks are density dependent in that they generally only occur as insect populations become denser.

Bacteria and Biological Control

Bacteria used for biological control infect insects via their digestive tracts, so insects with sucking mouth parts like aphids and scale insects are difficult to control with bacterial biological control. *Bacillus thuringiensis* is the most widely applied species of bacteria used for biological control, with at least four sub-species used to control Lepidopteran (moth, butterfly), Coleopteran (beetle) and Dipteran (true flies) insect pests.

Plants to Regulate Plants

The legume vine *Mucuna pruriens* is used in the countries of Benin and Vietnam as a biological control for problematic *Imperata cylindrica* grass. *Mucuna pruriens* is said not to be invasive outside its cultivated area.

Directly Introducing Biological Controls

Most of the biological controls listed above depend on providing incentives in order to 'naturally' attract beneficial insects to the garden. However there are occasions when biological controls can be directly introduced. Common biocontrol agents include parasitoids, predators, pathogens or weed feeders. This is particularly appropriate in situations such as the greenhouse, a largely artificial environment, and are usually purchased by mail order.

Some biocontrol agents that can be introduced include;

- *Encarsia formosa*. This is a small predatory chalcid wasp which is parasitical on whitefly, a sap-feeding insect which can cause wilting and black sooty moulds. It is most effective when dealing with low level infestations, giving protection over a long period of time. The wasp lays its eggs in young whitefly 'scales', turning them black as the parasite larvae pupates. It should be introduced as soon as possible after the first adult whitefly are seen. Should be used in conjunction with insecticidal soap.
- Red spider mite, another pest found in the greenhouse, can be controlled with the predatory mite *Phytoseilus persimilis*. This is slightly larger than its prey and has an orange body. It develops from egg to adult twice as fast as the red spider mite and once established quickly overcomes infestation.
- A fairly recent development in the control of slugs is the introduction of 'Nemaslug', a microscopic nematode (*Phasmarhabditis hermaphrodita*) which will seek out and parasitize slugs, reproducing inside them and killing them. The nematode is applied by watering onto moist soil, and gives protection for up to six weeks in optimum conditions, though is mainly effective with small and young slugs under the soil surface.
- A bacterial biological control which can be introduced in order to control butterfly caterpillars is *Bacillus thuringiensis*. This available in sachets of dried spores which are mixed with water and sprayed onto vulnerable plants such as brassicas and fruit trees. The bacterial disease will kill the caterpillars, but leave other insects unharmed. There are strains of *Bt* that are effective against other insect larvae. *Bt israelensis* is effective against mosquito larvae and some midges.
- A viral biological control which can be introduced in order to control the overpopulation of European rabbit in Australia is