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Risks and Safety of Insecticides: Chemicals vs. Natural and Recombinant Viral Pesticides

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ABSTRACT

Health safety and environmental problems associated with chemical pesticides are currently being addressed world-wide through changes in regulatory policies. The resulting increased costs associated with the development and commercialization of chemical pesticides has created a renewed interest in biopesticide products. While most biopesticide technologies are currently judged as safe, their marginal commercial efficacy (cost/benefit ratios) has slowed their development. Recombinant DNA technologies have recently been used to improve the pesticidal properties of several biopesticides, particularly the viral insecticides and entomopathogenic nematodes. It is considered, however, that the recombinant biopesticides may not share all of the inherent safety associated with naturally occurring biopesticides. In the absence of clear understanding of the risks associated with the commercialization of recombinant pesticides, genetic engineering strategies have been developed to circumvent potential environmental problems.
Keywords: pesticide, biosafety, baculovirus, nematodes, biological control

INTRODUCTION

Over the past thirty years, there has been a growing awareness and concern about the toxicological problems, real and potential, which chemical pesticides pose to human health and the environment as a whole. During this time, biological control agents, have been explored as possible alternatives to chemical pesticides. However, because of both biological and economic obstacles, biocontrol agents have never attained their expected potentials in agriculture and forestry. In order to overcome some of these obstacles, recombinant DNA technologies have recently been used to produce biocontrol agents with enhanced pesticidal properties. Clearly, there are material differences in the risks and safety associated with chemical pesticides, naturally occurring biopesticides and recombinant biopesticides. Each has its benefits and drawbacks. The purpose of this paper is to discuss briefly the benefits and risks of these pesticidal agents.

RISKS AND BENEFITS

Among the widely recognized issues associated with the use of synthetic chemical pesticides are their toxicological problems, ranging from applicator and environmental exposure to ground water and food contamination. Less publicized have been problems associated with the development of resistance and the broad action spectrum of many pesticides. With most chemical insecticides, prolonged usage has led to the development of resistant insect populations. The general agronomic response has been first to increase the application rates to overcome the resistance and, when this was no longer feasible, to change to a newer generation product.

We have also come to the realization that when beneficial insects are killed by wide spectrum pesticides, minor insect pests, previously controlled by beneficial insects, can become major pests thereby creating the need for more pesticide usage. A recent example of this is the intensive chemical pesticide strategy employed against the cotton boll weevil. The weevil control program was very successful at controlling the cotton boll weevil in cotton growing regions of the U.S., but it also eliminated many beneficial insects. In the absence of these beneficial insects, large outbreaks of the beet armyworm occurred in cotton throughout the southwest U.S. This has cost farmers millions of dollars.

Since the publication of Rachel Carson's Silent Spring, we have developed a clearer understanding of the potential health safety and environmental problems associated with some chemical pesticides. However, because of nutritional and economic factors, pesticide usage worldwide over the past 30 years has increased rather than decreased. Even with the current use of chemical pesticides, it is estimated that pre- and post-harvest pests account for approximately 30% loss in crops worldwide. So we have been forced to balance the
risks, benefits and costs associated with our current pest control strategies.

The latest response to balancing these risks and benefits is the U.S. Food Quality Protection Act of 1996. This act mandates that the pesticide registration process now include considerations of all non-occupational exposures with an explicit determination of tolerance levels that are safe for children. This new law eliminates the multiple standards for pesticides in raw and processed foods and requires that all currently registered pesticides must be re-evaluated during the next 10 years.

In a similar effort to improve the safety of registered pesticides, the U.S. Congress mandated in 1988 that pesticides registered under the older and less restrictive requirements must undergo a re-registration process. In 1988, there were 45,000 active product registrations. Since 1988, more than 32,000 of these registrations have been canceled. As one might expect, pesticides have only been re-registered for use on major crops. Accordingly, farmers of minor crops have fewer and fewer pesticide strategies available.

The Food Quality Protection Act of 1996 attempted to address the problem of availability of pesticides for minor crops by the establishment of minor use pesticide program. As part of this act, a grants program was initiated to assist in the development and registration of minor use pesticides. In addition, a new U.S. Environmental Protection Agency program, the minor pesticide program, was established to expedite the registration process of minor use pesticides through greater flexibility in and waivers of data requirements.

Because of these current regulatory and economic factors, the pesticide industry has begun to undergo some dramatic changes. Among these changes has been a renewed interest in using biological control agents as alternatives to chemical pesticides. There are thousands of parasites, predators and microbes which kill insect pests. In many instances these agents play an integral role in the natural regulation of insect populations.

Beginning in the 1950's, widespread interest developed in use of naturally occurring biological control agents to control agronomically and medically important insect pests. Since that time, extensive studies have been conducted to evaluate the potential hazards associated with these biopesticides. Unlike the synthetic chemical pesticides, biopesticides have not been found to pose any problems with respect to human health or the environment as a whole. The importation of biological control agents has also been very successful; however, there have been a few instances in which these agents had negative environmental impacts (Office of Technology Assessment, 1993).

Basically, biopesticides, particularly microbial biopesticides, have virtually all of the health safety and environmental properties that one would desire in a pesticide. Despite this state, these pesticides have not been widely used in agriculture and forestry. The
reason for this is that they have had rather poor agronomic and economic properties. Typically, biopesticides have production costs which are much higher than chemical pesticides, and act very slowly compared to the typical chemical poisons used to control insect pests.

Through biotechnology it is now possible to overcome the slow speed of action of many of these agents. This is accomplished by insertion of foreign pesticidal genes into the biocontrol agent which allows the agent to either kill the pest faster or, more importantly, to quickly cause the pest to stop feeding. This approach has been used successfully with baculoviruses.

Baculoviruses have host ranges restricted to invertebrate species, many of which are major agricultural pests. They have large, circular DNA genomes which can be easily engineered. Accordingly, many types of genes have been inserted into baculoviruses in an attempt to improve their pesticidal activity. The most significant improvements have been achieved following the insertion and expression of insect specific neurotoxins from a scorpion (McCutchen et al., 1991; Stewart et al., 1991), mite (Tomalski and Miller, 1991; 1992), hornet (Tomalski et al., 1993), and spider (Hughes et al., 1997). While these neurotoxins have no known vertebrate toxicity and the non-recombinant parental viruses are considered to pose no risks, there are concerns that the recombinant viruses could have an environmental impact.

Unlike chemical pesticides, viral pesticides replicate and, therefore, can increase in concentration and area of contamination following application. This feature is central to considerations of potential risks with recombinant viral pesticides.

One of the major risk considerations is the potential for recombinant viral pesticides to have a negative effect on beneficial or other non-target invertebrate species. Most virus infections are symptomless. Accordingly, the infection and replication of baculoviruses in non-target species could be inapparent. However, following the insertion and expression of pesticidal genes in recombinant viral pesticides, the previously inapparent infection could be highly pathogenic due to action of the foreign pesticidal protein.

Another risk consideration is the genetic stability of recombinant viruses. Replication of the recombinant virus in an insect infected with a second virus could result in the transfer of the foreign gene to the second virus. The consequences of this action would be difficult to predict.

Of equal concern is that certain recombinant viruses have been shown to have properties which cannot be explained based on insertion of the foreign gene. For instance, a recombinant virus expressing a juvenile hormone esterase was reported to have a 4.6 fold higher efficiency of infection than the parental virus (Bonning et al., 1992). The insertion
of the foreign gene should only have effected biological processes after infection. One explanation for this phenomenon is that additional, undocumented genetic alterations occurred during the construction of the recombinant virus resulting in alteration in the ability of the virus to attach, penetrate or uncoat. Clearly, viruses with higher efficiencies of infection would have a selective advantage in nature. One could predict that they would build up rapidly in the environment and could easily compete with the natural virus populations.

Of greatest concern is that, if a recombinant virus is found to have undesirable properties following its release into the environment, environmental decontamination would be almost impossible. This potential problem is compounded by the fact that very little is known about the ecology of baculoviruses and their persistence in nature.

Obviously, the commercialization of genetically modified viral pesticides as alternatives to chemical pesticides will not be possible without some level of risk. However, the acceptable level of risk should be lower than the risk factors associated with the alternative chemical pest control strategies. Unfortunately, it is not the level of risk which is the sole controlling factor. Economics is the major determinant of agronomic practices.

Because of the difficulty in assessing risk level, genetic engineering strategies have been develop and field tested to address the potential risks associated with genetically enhanced viral pesticides. The first strategy to be field tested was the co-occluded virus strategy. Based on laboratory-based studies (Hamblin et al., 1990) and as demonstrated in a field release experiment (Wood et al., 1994), the co-occlusion strategy resulted in a recombinant virus population that was continuously diminished during successive passages to insect hosts.

A second recombinant strategy was developed and field tested which provided almost zero risk levels. It was called the pre-occluded virus (POV)(Wood et al., 1993; Wood, 1997) strategy. The POV could infect insect larvae in the field and, soon after death of the larvae, all of the virus progeny were inactivated. There was no residual environmental contamination.

A third strategy which has been field tested depends on the relative replicative rates of recombinant baculoviruses (Cory et al., 1994). Certain recombinant baculoviruses expressing insect specific neurotoxins produce 5-10 times less progeny virus than the parental wild-type virus. This feature ensures that the genetically enhanced virus could not compete with natural virus populations and that there would be a reduced level of environmental contamination.

Currently, it is important to use these or other recombinant strategies to minimize the potential ecological perturbations that might result from the wide spread usage of
recombinant virus pesticides. If we had a better understanding of the ecological properties of naturally occurring baculoviruses, we could make a better assessment of the risk levels posed by the recombinant viruses. It is conceivable that these genetically enhanced viral pesticides may have ecological properties which require no use of special containment properties. This would certainly enhance their attractiveness as commercial products, reducing production costs and potential product liability.

Recently, a second type of recombinant pesticide, transgenic entomopathogenic nematodes, has been developed and field tested (Hashmi et al., 1995; Gaugler et al., in press). The transgenic nematodes contained a heat-shock protein gene taken from a second type of nematode. Although extrachromosomal, the transgene was stable and heritable over 15 generations in these hermaphroditic animals. The overexpression of the heat-shock protein following brief exposures to elevated temperatures resulted in higher survival rates of the transgenic nematodes compared to wild-type nematodes. This feature may be important for survival during application of nematodes for the control of insect pests. However, once in the soil, the buffering of temperature changes by the soil resulted in no selective advantage of the transgenic nematode compared to the parental nematodes (Gaugler et al., 1997). As with the baculoviruses, the use of recombinant technologies holds promise for the pesticidal improvement of entomopathogenic nematodes. However, it is currently difficult to assess with a high degree of certainty the potential environmental risks.

CONCLUSION

Because of changing economic, agronomic, and regulatory requirements associated with the use of pesticides, dramatic changes are taking place in the pesticide industry worldwide. The use of transgenic plants expressing insecticidal proteins is leading the way in this agricultural revolution. Clearly, increased public acceptance and market potentials for genetically improved pesticides in agriculture and forestry will be the driving forces.

However, we should not lose sight of the potential environmental impacts associated with recombinant pesticides. As long as closely related weedy plants are not in close proximity, crop plants expressing pesticidal proteins are generally accepted as environmentally safe. However, crop plants have many properties which limit their potential environmental impacts, and, if their use results in an undesirable environmental impact, the remedy is simply discontinuance. However, with recombinant microbial pesticides mitigation typically could not be achieved. Accordingly, the commercialization of recombinant microbial pesticides will require a greater breadth of knowledge regarding their ecological interactions. If unforeseen problems arise from the commercialization of a biological control agent, the field of biological control could suffer a severe setback.

There is an additional problem which has developed since the first recombinant organisms
were released into the environment in the mid 1980's. Because there have been no significant problems arising from hundreds of field releases, a complacency among regulators and the public has developed. We should keep in mind that these first releases were performed using approaches which were simple to evaluate and were designed to satisfy nervous regulatory and environmental action communities. In the 1990's we have performed hundreds of field experiments with greater uncertainties associated with them. For instance, the first recombinant viral insecticides were deletion mutants; the current releases involve viruses expressing scorpion neurotoxins. These two types of releases cannot be properly evaluated with the same types of data. As the genetic engineering strategies become more sophisticated, the criteria used to evaluate their potential risks should be similarly upgraded. "All products of biotechnology are not created equal" (R.F.W. Hardy, personal communication).

In conclusion, the need for alternative pesticide strategies in agriculture and forestry has created opportunities for the development and commercialization of both wild-type and genetically enhanced viral pesticides. The current economic trends and evolving scientific advances make the use of these biological control agents promising from the health/environmental perspective as well as from an economic standpoint.

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