The David Rosen lecture: biological control in citrus

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Abstract

David Rosen was a scientist, professor, administrator, philosopher, organizer, family man, and friend to many. He made numerous and remarkable contributions to biological control in citrus. Much of his research was on the biosystematics of *Aphytis* parasitoids, but he also held strong convictions about the importance of biological control in citrus integrated pest management (IPM), and carried out research on genetic improvement of parasitoids. David was the first incumbent of the Vigevani Chair of Agriculture and Professor of Entomology at the Faculty of Agricultural, Food and Environmental Quality Sciences at the Rehovot campus of the Hebrew University of Jerusalem. David served as an organizer of the XIV International Plant Protection Congress in Jerusalem, Israel, and his imprint on the congress was evident despite his absence. In addition to reviewing David’s scientific contributions, I present an overview of the challenges facing biological control in the USA, including many that concerned David: increased scrutiny from regulatory agencies regarding the effects of natural enemies on nontarget species, loss of taxonomic experts, concerns about the accidental introduction of plant pathogens with the importation of natural enemies of insect vectors, and challenges to the tradition of international cooperation. If the increased demand for biological control is to be met in 21st century agricultural IPM programs, several scientific, social, and legal issues must be resolved. © 2000 Published by Elsevier Science Ltd.

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1. Introduction

David Rosen made numerous and remarkable contributions to biological control in citrus and was always outspoken on matters of policy. In that tradition, I will review his contributions and then provide a personal perspective on issues facing practitioners of biological control. Practitioners of biological control of arthropod and weed pests face legal, ecological, and social challenges that must be resolved if we are to maintain and enhance the role of biological control in integrated pest management (IPM) programs.

2. David Rosen

David Rosen was a scientist, professor, administrator, philosopher, organizer, family man, and friend to many. He was born in Tel-Aviv, Israel, on April 20, 1936, obtained his Master of Science in Agriculture in Plant Protection (with Excellence) at the Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, in 1959, and his Ph.D. in Agricultural Entomology in 1964. His thesis research, “Parasites of the Coccoidea, Aphidoidea and Aleurodidea of Citrus in Israel”, earned him the Jacobson Prize in 1965. David then obtained postdoctoral training with Paul DeBach at the University of California at Riverside, which was the start of a long and productive collaboration. Together they published *Species of Aphytis of the World* in 1979, which summarized the taxonomy, biology, ecology and importance in biological control of these natural enemies. For this monumental contribution, they received a gold medal from the Filippo Silvestri Foundation in Naples in 1980. In 1991 they published a second edition of *Biological Control by Natural Enemies*. David was an excellent and meticulous editor, including the two volumes of *Armored Scale Insects: Their Biology, Natural Enemies and Control*, which was part of the World Crop Pest series published by Elsevier in 1990. While on sabbatical at the University of Florida, he co-edited (with Fred Bennett and John Capinera) two additional volumes, published in 1994 and 1996, *Pest Management in the Subtropics: Biological Control — A Florida Perspective and Integrated Pest Management — A Florida Perspective*. At the time of his death, he was editing his last book, *Readings in Biological Pest Control*.

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David’s academic career primarily was spent at the Hebrew University of Jerusalem’s Faculty of Agriculture in Rehovot, where he was the first incumbent of the Vigevani Chair of Agriculture and Professor of Entomology. David also served the University as an administrator, becoming Chairman of the Plant Protection Teaching Program and Chairman of the Entomology Department on three occasions. David was well known internationally, teaching and conducting research at the Universities of Ankara and Adana, Turkey (1978), University of California at Riverside (1966–70 and 1975–76) and at Berkeley (1982), the University of Maryland (1982–83), Texas A & M (1988) and the University of Florida (1990–91).

David’s research interests encompassed biological control and citrus IPM and the biology, ecology and population dynamics of arthropod pests, their parasitoids and predators. He especially was noted for his work on the biosystematics of Aphytis, but also carried out research on genetic improvement of Aphytis (Havron and Rosen, 1989; Havron et al., 1991a,b, 1995).

Professionally, David was a valued contributor to numerous international committees and panels. He served as Chairman of the Organizing Committee of the 14th International Plant Protection Congress in Jerusalem until he passed away on January 8, 1997. David also served on editorial boards and was active in scientific societies. He served on the editorial committee for the Annual Review of Entomology, Entomophaga and Journal of Hymenoptera Research and as a subject editor for BioControl. He was a member of the Entomological Society of America, The Royal Entomological Society of London, The International Organization of Biological Control, International Society of Chemical Ecology, Entomological Society of South Africa, Entomological Society of Israel, International Society of Citriculture, Ecological Society of Israel, Sigma Xi and International Society of Hymenopterists.

David leaves a lasting personal legacy. His marriage to Mazal produced three children, Orna, Nurit and Sefi, and in the last few years he also was able to cherish three grandchildren. David leaves a lasting scientific legacy with his numerous scientific papers, books, and students. He provided guidance to 20 Ph.D. and 33 M.Sc. students and influenced hundreds of students in the courses he taught on general entomology, introduction to pest management, orchard entomology, and biological control.

David could always be counted on to express his opinions in a forceful manner. Our discussions relating to classical biological control and genetic improvement were lively. I cannot judge his language skills in Hebrew, but he had a wonderful ability to express himself in both written and spoken English. David was a charming host and enthusiastic guest. As a speaker, we could always count on him to have at least one anecdote or joke to illustrate an important point. His courage and continued commitment to his work, despite his illness, were remarkable.

Additional information about David’s contributions can be found in obituaries published by Gerling and Wysoki (1997) and Gerson and Applebaum (1997). David was intensely interested in the future of biological control and IPM in citrus (Rosen, 1986,1993). I think he would like me to discuss this topic, even through he might not agree with all my opinions.

3. Biological control

Biological control is, in my opinion, at a turning point in its development as a discipline. It could become a more important component of agricultural IPM programs if we are able to resolve concerns about potential risks to biodiversity. If, however, we are unable to resolve those concerns, there could be less classical and augmentative biological control in agricultural IPM systems of the future, rather than more.

3.1. Definitions

Biological control has been defined, by entomologists, as the use of parasitoids, predators, pathogens, and entomopathogenic nematodes to control insect and mite pests and weeds. The tactics used include classical, augmentative, and conservation biological control. Classical biological control is the regulation of an exotic pest population by natural enemies (parasitoids, predators, pathogens, entomopathogenic nematodes) imported for this purpose. It includes the permanent establishment in the environment of one or more natural enemy species, which is expected to help suppress the target pest below the economic injury level. The definitions of augmentative and conservation biological control may overlap somewhat (Perkins and Garcia, 1999), but the goal is to manipulate resident natural enemies, native and exotic in origin, to increase their suppressive ability by providing favorable conditions. Most augmentative biological control involves mass rearing and release of natural enemies so that they can suppress pest populations, but permanent establishment is not expected.

3.2. An historical background

Because the present cannot be understood without reviewing the past, I believe a brief discussion of the history of biological control is relevant. During the 1950s, 1960s, 1970s, and 1980s in the USA, biological control scientists tended to be isolated from other pest management scientists because control of agricultural pests was based primarily on chemical control. The reliance on this single tactic was shaken by the publication of Silent Spring by Rachel Carson in 1962. Publication of
Most practitioners of biological control were convinced that classical biological control was a desirable alternative to toxic pesticides and that permanent establishment of natural enemies was both desirable and ensured the effectiveness of this tactic. Classical biological control programs, when practiced by trained professionals, were considered to involve little risk to the environment (DeBach and Rosen, 1991).

During the 1990s, concern about the negative effects of pesticides on the environment and on human health increased interest in alternative pest management tactics, including biological control (Benbrook et al., 1996). The US Congress reduced crop subsidies, which should encourage growers to reduce production costs, perhaps by making fewer pesticide applications. The Food Quality Protection Act, passed in 1996, was a response to concerns about pesticide residues in foods, especially foods consumed by children who are potentially vulnerable to possible negative effects on the abundance of native lady beetle species such as Coccinella septempunctata have raised concerns about the ability to suppress populations to a level lower than that which can be achieved by generalists (Rosen and Huffaker, 1983).

In the USA, an additional challenge is a legal one. Evaluations regarding approval to release natural enemies into the environment no longer are conducted by the US Department of Agriculture; this agency only provides permission to import a natural enemy into a quarantine facility. Evaluation of applications to release is now the responsibility of individual states and the agencies that employ biological control scientists. The lack of a federal evaluation system means there is no mechanism to resolve potential conflicts of interest between different states or regions. New legislation, developed with the contributions of biological control scientists, is required. Ideally, the evaluation of applications to release natural enemies in classical biological control programs will involve increased scientific peer review to ensure that classical biological control remains a relevant component of our response to invasive species.
Taxonomic problems are a continuing challenge when conducting classical biological control programs (Rosen and DeBach, 1973; Delucchi et al., 1976; Rosen, 1978). The taxonomy of both pest and beneficial species is critically important with regard to risk issues and efficacy, but fewer and fewer taxonomists are available or are being trained and taxonomists are themselves becoming endangered species. It is crucial to understand the taxonomy and distribution of both pest and natural enemies, if classical biological control is to be effective, appropriate, and safe. The importance of strains and biotypes has been emphasized in classical biological control for many years. To some degree, molecular tools promise to provide information on the availability of strains, biotypes or cryptic species (Hoy, 1994; Edwards and Hoy, 1995). Molecular methods also provide a tool to address other important issues in classical biological control, including an ability to identify loss of genetic variability or other genetic changes in natural enemy populations subsequent to their release and establishment in the environment. Molecular methods are powerful tools for investigating various fundamental questions relevant to improving reliability and decreasing risks associated with the introduction of natural enemies into the environment.

Another challenge is the risk that insect or plant pathogens will be introduced accidentally into new environments when natural enemies are imported in classical biological control programs. For example, we recently faced the task of confirming that parasitoids of the Asian citrus psylla, *Diaphorina citri*, were free of the greening disease agent, *Liberobacter asiaticum*. While we cannot totally eliminate risk nor prove a negative, we estimated that a polymerase chain reaction (PCR) protocol would allow us to detect as few as 100 copies of greening DNA when mixed with insect DNA. The negative PCR results from multiple generations of the parasitoid and its psyllid host in quarantine indicated that the risk of accidentally introducing this pathogen is low (Hoy et al., 1999).

### 3.4. Challenges to augmentation

Augmentation most often involves mass rearing and release of natural enemies, with the intent that the released organisms (or their progeny) will provide effective pest control. However, effective national or international guidelines designed to assure quality, reduce risk, and increase efficacy are needed. Presently, the consumer can purchase natural enemies (especially parasitoids and predators) and receive the wrong species for the target pest, fewer (or more) individuals than ordered and paid for, late shipments, little information (or none) on how many natural enemies to release and when, and little or no information as to the time required to achieve control of the target pest. Information on how to determine the number of natural enemies that should be purchased to achieve control rarely is provided. Producers are not required to certify the health, age, or genetic quality of the natural enemies they produce. Nor are they required to reveal if their colonies are contaminated with one or more extraneous arthropod species or pathogens. Again, appropriate and effective legislation developed with significant inputs from producers and consumers could result in augmentative biological control that is more reliable, cost effective, and effective.

The future of augmentative releases also may depend upon whether we can produce high-quality natural enemies more efficiently and much less expensively. Funding to conduct research on artificial diets and effective mass rearing methods has been limited, which is an enormous barrier to augmentative biological control. If such research is to be carried out by the private sector, it may have to be subsidized because many small producers of natural enemies lack the resources to carry out this work.

Finally, there is growing concern that augmentatively released natural enemies might out-compete or displace native populations of the same species, alter their genetic integrity, or have negative effects on nontarget species. Research to determine whether any of these fears are justified may dispel concern: for example, Walter et al. (1998) found that the exotic phytoseiid *Phytoseiulus persimilis* does not establish in rainforest in Queensland, Australia, but is limited to fields, glasshouses, gardens, weeds, roadsides and other disturbed habitats dominated by introduced plants. Similar data may reduce fears that augmentative releases of arthropod natural enemies may be harmful to biodiversity.

### 3.5. Challenges to conservation

One of the most important methods for conserving natural enemies is to modify pesticide applications so that effective natural enemies can be maintained in the pest management system (Hull and Beers, 1985). Pesticide toxicity to natural enemies can be acute or delayed. A pesticide can be so toxic to the target pest that no natural enemies are able to persist in the crop because the host- or prey-specific natural enemies lack food. Under these circumstances, the pesticide toxicity is indirect because the necessary hosts/prey are eliminated, and thus can induce cyclic pest outbreaks because natural enemy populations may recover more slowly from the pesticide application than the pest.

Pesticides often are labelled at rates significantly higher than necessary to suppress the pest by 50 to 80% (Hoy, 1995b). Changes in pesticide labels would encourage the use of “suppressive rates” (rather than eradicative rates) so that natural enemies, in combination with less toxic pesticides, could suppress the pest below the economic injury level. Another modification to the label would incorporate information regarding the toxicity of the product to natural enemies. Such data would have to be
obtained under realistic conditions and with appropriate concerns for indirect or chronic effects.

4. Transgenic crops and arthropod natural enemies

The compatibility of arthropod natural enemies and transgenic crops is uncertain. All of the insect-resistant transgenic plants currently on the market contain toxin genes derived from the bacterium Bacillus thuringiensis (B.t). The effects of the different toxins produced by the different strains of B.t vary with arthropod species. Schuler et al. (1999) concluded the effects of B.t toxins on natural enemies will be determined by the level of resistance expressed in the plant, the type of promoter regulating gene expression, potential changes in plant volatiles that the natural enemies use to detect their host/prey, presence of reservoirs of susceptible plants, crop size, susceptibility of the target pest to the toxin, presence of alternative host plants for the target pest, changes in behavior in the pest induced by the transgenic plant, nutritional quality of the pest, changes in volatiles produced by the pest that might affect the natural enemies, mobility of the target pest, and sequestration of the introduced toxin by the host or prey. The natural enemy type, its host or prey range, its mobility and susceptibility to the introduced toxin and its foraging efficiency also will affect how transgenic plants containing the B.t toxins affect arthropod natural enemies. Schuler et al. (1999) concluded “The subtle and sometimes inconsistent effects demonstrated to date emphasize the importance of vigorous and standardized methodologies for ecotoxicological evaluations...” and that “...it is probably impossible to encompass all possible interactions in preapproval trials, and long-term postapproval monitoring of natural enemies will be essential where transgenic plants are grown on a large commercial scale.”

When transgenic plants containing genes other than toxin genes from B.t. are commercialized, the unintended effects of these gene products will have to be monitored if we are to maintain natural enemies in agricultural IPM systems of the future (Bell et al., 1999). The benefits of integrating transgenic crops and arthropod natural enemies could include delaying the development of resistance in the target arthropod pest to toxin genes in the plants.

5. Genetic manipulation of arthropod natural enemies

Genetically manipulated arthropod natural enemies have been used only a few times in IPM programs (Hoy, 1996). Traditional breeding methods have yielded strains of natural enemies that are resistant to one or more pesticides or lack a diapause. The ability to develop genetically modified arthropods by recombinant DNA methods is almost a reality (Ashburner et al., 1998). However, a variety of scientific, regulatory, and political issues remain to be resolved before transgenic arthropod natural enemies can be used in practical pest management programs.

Scientific issues include identifying appropriate genes and regulatory sequences so that the genetically modified natural enemy actually performs better (Hoy, 1995a). We also need to resolve risk assessment procedures prior to releasing a transgenic natural enemy into the environment for permanent establishment (Hoy, 1996). At present, transgenic arthropods can be released into the environment in the USA, but released individuals must be contained in the release site and recovered at the end of the experiment. Information on regulations regarding temporary releases, applications for release, reports on the releases, and additional information about transgenic insects can be found at: www.aphis.usda.gov:80/bbep/bp/arthropod/#tgenadoc. Another issue to resolve includes the appropriate methods for containing transgenic arthropods in the laboratory until scientific and regulatory reviews are completed (Hoy et al., 1997).

6. Biological control in citrus

Biological control has a very long history, especially in citrus (DeBach and Rosen, 1991). For example, predatory ants (Oecophila smaragdina) were used to manage pests in citrus in China for hundreds of years (Doutt, 1964). Another landmark example is the control of the cottony cushion scale in California’s citrus by the Vedalia lady beetle (Rodolia (= Vedalia) cardinalis) (Caltagirone and Doutt, 1989). The importation of the Vedalia beetle into California was an outstanding success and has served as a model for what classical biological control should be: inexpensive, permanent, and highly effective. Unless Vedalia beetles are disrupted by the use of toxic pesticides (Stern et al., 1959), control of the cottony cushion scale has been stable in California. Vedalia beetles also have been transplanted successfully to other citrus-growing regions around the world. This remarkable success has led to a phenomenon I have called “Cottony Cushion Scale Syndrome,” because many researchers and funding agencies have developed the unrealistic expectation that classical biological control is rapid, relatively inexpensive, perpetual, and fully effective.

Considerable effort has been placed on the use of biological control in citrus in Florida, with the result that the integrated pest management (IPM) program utilizes biological control as a key tactic (McCoy, 1985; Browning and McCoy, 1994). However, even where biological control is used extensively, there are opportunities to increase its use. For example, pesticides still are used in Florida’s citrus, probably much more often than is
necessary. Although 80% of the citrus grown in Florida is processed as juice, many growers spray their groves for rust mites as though they were going to sell all their fruit for the fresh market, where rust mite blemishes are unacceptable. Pesticides also may be applied more often than necessary because we lack fundamental knowledge of the density at which each species becomes economically significant.

Within the past seven years, Florida’s citrus has been invaded by serious pests, including the citrus leafminer (Phyllocnistis citrella), the brown citrus aphid (Toxoptera citricida), and the Asian citrus psylla (Diaphorina citri). The aphid and the psyllid both vector serious citrus diseases, e.g., tristeza and Asian greening, respectively. As a result, it has been crucial to find methods for managing these pests that are compatible with the effective biological control of other citrus pests. While cultural practices, host plant resistance, and other IPM tactics will be necessary to manage these new invasive pests, classical biological control projects remain a necessary tactic. Classical biological control projects have been initiated against all three pests in order to reduce pesticide use that could disrupt the effectiveness of the already-established natural enemies (Hoy and Nguyen, 1997,1998; Hoy et al., 1999). Because the IPM program in Florida’s citrus is so heavily dependent on biological control, I believe we are on a “biological control treadmill,” rather than the more common “pesticide treadmill.”

International cooperation remains crucial to the success of classical biological control programs. Scientists in Australia, Taiwan, Thailand, Vietnam and Guam were instrumental in our ability to respond rapidly to these three invasive species in Florida’s citrus. They provided assistance, information, and resources that enabled us to respond rapidly to the threat of these invaders. Historically, classical biological control has depended on such generous international cooperation and it needs to be maintained. The belief that natural enemies are national resources that should be sold is detrimental to the continued success of classical biological control. Indeed, biological control scientists may wish to become even more proactive about cooperating in classical biological control of citrus pests and begin sharing information about the natural enemies of potential invaders in advance, perhaps using the worldwide web as a repository of information.

IPM of citrus pests should involve multiple tactics that are compatible. In my view, classical biological control, augmentation, and conservation will all have a role. In addition, we must utilize all other compatible methods and transmit the relevant information in a useful form to the end users. An exemplary example of a citrus pest management manual that reaches these standards can be found in Citrus Pests and their Natural Enemies, Integrated Pest Management in Australia. This volume, edited by Smith et al. (1997), is an outstanding example of an IPM manual that provides detailed information on how to use natural enemies in citrus crop management.

7. The future of biological control

It is ironic that, just when there is an increased focus on, and potential role for, biological control of arthropod pests, serious concerns about biodiversity could restrict its use. Current constraints also include the deployment of relatively few resources, at least compared to those available to develop new pesticides or transgenic crops. Most of the funding for classical and augmentative biological control is obtained from public sector sources, which have not had sufficient increases in their budgets to meet the current and potential demand.

The history of biological control of arthropod pests is filled with outstanding examples of successes and a remarkably low number of ecological problems (Bennett, 1993; Lai, 1988; Frank, 1998). Despite this, we will have to embrace increased oversight and consideration of ecological issues. The question then becomes, How best can we achieve appropriate oversight without hampering the benefits of biological control? One solution might be for practitioners of biological control to focus more frequently on natural enemy species that are narrowly host- or prey-specific.

Scientists working on biological control of weeds already have accepted this constraint, and undergo external reviews of the biology, behavior, and host specificity of the natural enemies they wish to release. It also will be useful to have more thorough scientific peer review before natural enemies are released for classical biological control of arthropod pests. Despite increased peer review, it may be impossible to eliminate all concerns about risk. Risk analyses are never simple or easy and it is critical “...that interested scientists and non-scientists alike have examined the components, uncertainties and perceptions of any particular risk. This in turn will focus attention on the relevant science” (Anonymous, 1997). Blanket criticisms of biological control are of little constructive value in the absence of comparative data on the alternatives, including doing nothing. Furthermore, biological control has numerous public benefits, including inexpensive and long term control and reduced pesticide applications, which can result in reduced negative effects on ground water, nontarget species, human health, and worker safety.

7.1. Combining tactics will be crucial

Not all citrus pests are suitable targets for classical biological control (or for augmentative or conservation biological control). Ideally, a citrus IPM program will be truly multitactic, enabling the user to correctly identify pests and natural enemies by appropriate monitoring
methods. Adequate economic injury information will be available to allow the pest manager to make an appropriate decision about the need for pesticide applications. Pesticides that are selective (or least disruptive to natural enemies and the environment) will be used more or less as a “last resort”. This approach depends, in part, on a philosophy based on the assumption that pesticides should be applied only by prescription. Ideally, the toxicity of the pesticide product to natural enemies will be available to growers, either on the label or in easily accessible databases. The focus should further be that all appropriate actions are taken to maintain healthy plants, so that the focus is on crop management — not PEST management.

8. Conclusions

Our collective responses to these, and other, challenges will determine how effectively biological control is incorporated into agricultural IPM programs in the next millennium. We have valuable new tools, including molecular genetic methods, that will allow us to answer previously intractable questions in systematics, ecology, behavior, and quality control. The use of pesticides no doubt will decline and the ones used may be less hazardous to the environment. The demand for biological control could increase in the 21st century, especially if we respond effectively to concerns regarding potential negative environmental consequences attributed to biological control. When risks and benefits are compared appropriately, biological control should fare very well in comparison to the risks and benefits associated with other pest management tactics such as chemical control, cultural practices, host-plant resistance including the use of transgenic crops, and genetic control.

The potential risks and benefits of classical and augmentative biological control must be calculated in a realistic manner because it is not possible to manage pests without any risk. As pointed out by Lubchenco (1998), our world is changing and we now live on a “...human-dominated planet. The growth of the human population and the growth in amount of resources used are altering Earth in unprecedented ways.” Lubchenco (1998) concluded that the role of science now includes “...knowledge to reduce the rate at which we alter Earth’s systems, knowledge to understand Earth’s ecosystems and how they interact with the numerous components of human-caused global change, and knowledge to manage the planet.” This change in perception of the status of ecosystems must become widespread among scientists and others if appropriate policy decisions are to be made. To increase awareness of this change in perception, perhaps a new term should be coined to describe our role and responsibilities as “planet ecosystem management” or “PEM.” I think David might have agreed that humans are, in fact, remodeling the entire global ecosystem.

David Rosen’s intelligence, courage, diligence, and enthusiasm for life and for biological control in citrus have left a powerful and lasting legacy. We can, and should, meet the challenge to maintain and enhance biological control’s contributions to citrus crop management.

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