

## POPULATION-LEVEL OUTCOMES OF DIFFERENTIAL SUSCEPTIBILITY AMONG LIFE STAGES OF THE APHID PARASITOID *DIAERETIELLA RAPAE* TO PESTICIDES

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### INTRODUCTION

The integration of biological and chemical controls is a common objective of integrated pest management (IPM). However combining these two pest control methods is still a difficult task even though more selective pesticides are now available (Wennergren and Stark, 2000). Recent studies suggest that estimating the impact that pesticides have on nontarget organisms may be more complex than previously imagined (Banken and Stark, 1998; Kjær *et al.*, 1998).

Factors such as routes of exposure (Longley and Stark, 1996; Banken and Stark, 1998), acute versus chronic exposure, pesticide persistence (Wennergren and Stark, 2000), organism behavior (Jepson and Thacker, 1990), sublethal effects (Stark *et al.*, 1997), indirect effects (Hull and Beers, 1985), differential susceptibility among life stages (Stark and Wennergren, 1995) and population structure at the time of pesticide application (Chi, 1990; Stark and Banken, 1999) may all have an influence on the impact that a pesticide will have on nontarget organisms. Therefore, simplistic measures of effect such as lethal dose or lethal concentration estimates may not provide enough information to make a judgment about pesticide compatibility with a biological control agent (Stark *et al.*, 1995).

In most studies dealing with the toxicity of pesticides to biological control agents, one life stage is evaluated (Tillman and Mulrooney, 2000; Elzen, 2001). However, recent studies have indicated that pesticides exhibit differential toxicity among various life stages within a species (Ahn *et al.*, 2001; Usmani and Knowles, 2001). An important question then is what does this mean to a population that one wants to protect. This study was conducted to test the hypothesis that differential susceptibility among life stages to pesticides and population structure at the time of pesticide application have a significant impact on populations of biological controls. The parasitoid *Diaeretiella rapae* (M'Intosh), a common parasitoid of the cabbage aphid, *Brevicoryne brassicae* (L.), was used as a model.

### MATERIALS AND METHODS

Individual broccoli leaves containing batches of 50 mummified *B. brassicae* were placed on a moist section of paper towel in petri plates, and various concentrations of formulated imidacloprid (17.4% active ingredient, Bayer Corporation, Kansas City, Missouri, USA) were applied with a Potter tower. The field rate (FR) for imidacloprid was 50 g ai/ha, and three modifications of this concentration—1/2 FR (field rate), 1/4 FR and 1/8 FR—were used in addition to a water control. Each leaf received 300  $\frac{1}{4}$  l of pesticide solution in water. Emergence of *D. rapae* was recorded for two weeks after sprays were applied. Three replicates were performed for each concentration tested; each replicate performed on a different day and with different generations of *D. rapae*.

A simulation model based on an age-structured Leslie projection matrix (Leslie, 1945; Caswell, 1989; Carey, 1993) was developed to estimate the impact that exposure to imidacloprid would have on populations of *D. rapae*. The model consisted of a primary matrix that contained the life-history characteristics (survivorship and fecundity) of a *D. rapae* population. A starting vector,  $n(t)$ , that contained information on the age distribution of the population to be evaluated was multiplied against

the primary matrix resulting in a secondary vector,  $n(t+1)$ , that was then multiplied against the matrix and so on, thus projecting population growth by the time step of the matrix (one day for *D. rapae*). The simulation was run twice, once with a starting vector,  $n(t)$ , consisting of all adults and once with a starting vector consisting of the stable age distribution. The stable age distribution for *D. rapae* is reached when life stages occur in the following proportions: eggs (0.51), first instars (0.19), second instars (0.07), third instars (0.05), fourth instars (0.04), pupae (0.11), and adults (0.03).

The model parameters (i.e., survival and fecundity) were obtained from life tables developed for this study in which daily measurements of survival and fecundity were recorded over the life span of the population. As such, each subsequent time-step calculated by the model corresponded to a one-day projection of the population, and the string of matrices represented  $t$  days of population change. Because each time-step represents a 1-day change in the population size, it was possible to calculate the population size at each time step. In addition, the model was designed so that changes in the levels of mortality by life stage could be manually assigned to evaluate the effect of differential susceptibility among life stages.

## RESULTS

Differential susceptibility between two life stages of *D. rapae* was found after exposure to imidacloprid. Applications at the recommended field rate killed 100% of adult *D. rapae* but only 50% of larvae in the mummy stage. Results of the simulation model indicated that *D. rapae* population growth was dependent upon population structure at the time of pesticide application. If the population was primarily in the adult stage at the time the pesticide was applied, imidacloprid drove *D. rapae* populations to extinction, but if the *D. rapae* population had a stable age distribution when the insecticide was applied, then the *D. rapae* population was reduced by only 32%.

## DISCUSSION

Differential susceptibility among life stages to pesticides is fairly common (Green *et al.*, 1986; Williams *et al.*, 1986; O'Brien *et al.*, 1988; Collyard *et al.*, 1994). However, what this might mean to population survival has not been thoroughly addressed. Stark and Wennergren (1995) evaluated the effects of a neem insecticide on two life stages of the pea aphid, *Acyrtosiphon pisum* (Harris) using a life table approach. Populations exposed as neonates were much more susceptible than were populations exposed as adults. Stark and Wennergren (1995) suggested that in order to obtain a complete picture of the impact a pesticide might have on a population, evaluation of more than one life stage was necessary.

Stark and Banken (1999) explored the effects of pesticides on differently structured starting populations of the two spotted spider mite, *Tetranychus urticae* Koch, and the pea aphid, *A. pisum*. Three differently structured populations were tested. The first consisted of neonates for the pea aphid and eggs for *T. urticae*. The second consisted of the stable age distribution for each species, and the third consisted of young adult females only. The starting population structure was found to have a significant influence on population growth rate for both species.

Results of the study on *D. rapae* presented here also indicate that differential susceptibility and population structure are important components of population susceptibility that have been largely ignored in the past. Because different stages or ages of organisms might have different susceptibilities to toxicants, it is essential that these factors be considered when estimating population susceptibility.

## CONCLUSIONS

Some insecticides are more toxic to one life stage of an organism than to another. The life stages present and the proportion of the population in each life stage in the field at the time of pesticide application are very important in determining the level of population susceptibility. Thus, timing of pesticide application can be critical for protecting biological control agents. Even though imidacloprid is not very selective to adult *D. rapae*, it can be used if applied after *D. rapae* have laid eggs because the majority of the population will then be inside hosts and less susceptible to the insecticide. Therefore, a population modeling approach that incorporates differential susceptibility and stage structure can be used to obtain a better estimate of the effects of pesticides on biological control agents compared with lethal concentration estimates. However, timing pesticide applications to coincide with biological control agents may be a difficult task for farmers to accomplish. Thus, the practicality of pesticide timing needs to be considered in future studies.

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