Why is a study of the genetics of *Heliothis* important in pesticide resistance?

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The term 'genetics' encompasses a group of disciplines which study aspects of evolution. The first of these, molecular genetics, examines DNA, the raw material of evolution, and its organization into genes. Genes code for information which, when expressed, gives rise to the characteristics of the organism. It is changes at this level which yield the variation necessary for evolution to occur.

Genes are organised along the length of chromosomes like beads on a string. The size and number of chromosomes varies from species to species and the study of the role of this variation in evolution is included in the field of cytogenetics. Population genetics is concerned with changes in gene frequencies in populations due to natural selection or to chance events. The inter-relationship between the genetic structure of a population and its ecology are examined in ecological genetics. Factors such as the size of populations, the sex ratio, the mating system and the amount of dispersal are important here.

Evolution occurs when there is a change in the total genetic information of the population (i.e. the gene pool) which persists in time. Pesticide resistance is an example of such an evolutionary change because a population which is resistant to an insecticide is genetically different from one which is not, although the difference may be limited to a single gene. In the simplest situation, resistance arises from a single, random mutation within one gene of an individual. The different mutant forms of a gene are called alleles. Because individuals with this new allele are more able to survive and reproduce in the presence of insecticide it increases in frequency in subsequent generations, eventually leading to the ineffectiveness of the insecticide. Through an understanding of the evolution of resistance, we can devise strategies of pesticide usage, which when coupled with pest management practices, can retard the evolution of resistance to new insecticides and enable the continued effective use of insecticides, such as pyrethroids, even after resistance has been detected.

Strategies of insecticide usage, such as the one developed for Heliothis in Australia, are an attempt to modify the rate of evolution of resistance, yet these strategies are developed from very incomplete information about the genetics of the species concerned, and indeed, about the evolution of pesticide resistance in general. Solutions appropriate to H. armiger can only come from an understanding of the genetics of this species but, as it is difficult to study organisms in their natural habitat, we are forced to build strategies based on naive genetic models developed from a combination of mathematical theory and laboratory experimentation in organisms such as house flies. It is important to remember that the genetical assumptions underlying these strategies remain, by and large, untested. Until we can test them, any strategy that we implement will, at the best, remain an approximate solution to be honed by trial and error. Clearly, when we are dealing with an industry such as cotton production, trial and error can be expensive.

We can illustrate the value of genetics to an understanding of pesticide resistance by the following five examples.

1. Interpretation of the data collected on resistance

At present, resistance in a population is measured by the proportion of individuals which survive a discriminating dose of the insecticide, that is, a dose that will kill more than 99 percent of susceptible individuals. Resistance is further characterised in a bioassay which measures the response of a population to different doses of the insecticide. The next important step is to define the results of these experiments in genetic terms.

Most living organisms carry two complete sets of genes (one set derived from the egg and one set from the sperm). Thus, using the simplest genetic model, individuals in a population in which resistance is present, can be divided into three categories: those which carry two copies of the allele which gives rise to susceptibility (individuals are referred to as 'homozygous susceptible'), those which carry two copies of the allele giving rise to resistance ('homozygous resistant') and those that carry one copy of each allele ('heterozygous resistant'). The last two categories are usually both resistant to the insecticide but the homozygous resistant individuals can survive a higher dose than the heterozygous resistant ones (Figure). The rate of evolution of resistance depends on the relative survival of heterozygous to susceptible individuals because homozygous individuals are very rare in the population until the resistant allele is common. This normally occurs when when resistance is at detectable levels in the population. Thus, a proper understanding of the evolution of resistance requires discrimination between heterozygous and homozygous resistant individuals.

2. Defining the genetic basis of the strategy

The strategy designed to control insecticide usage against Heliothis contains a number of implicit assumptions about the genetics of resistance. For example, it is assumed that resistant individuals do not survive and reproduce as well as susceptible ones when insecticide is not present, that is, the resistant individuals are less fit. In 1983/84, pyrethroid use for Heliothis control was restricted to only one generation in the possible four generations observed in a season. Thus, resistant individuals should only increase in frequency in the population in that generation. In the other three generations, the frequency should decrease so that when averaged over the entire year, the frequency of resistance should not increase.

We simply do not know if the assumption regarding the lower fitness of resistant individuals is true. Certainly, from experience with other insects, the assumption seems to be reasonable, at least in the early stages just after resistance appears. However, once such alleles are present at a sufficient frequency for a number of generations, the genetic background of the population also becomes selected so that resistant individuals can become as fit as susceptible ones.

3. Population Structure

All models of evolution contain assumptions about the structure of populations. Simplistic models assume that populations are infinitely large and individuals are randomly distributed with respect to genetic makeup. This infers that mating is at random and relatives are not clumped in their distribution. In addition, it is assumed that the amount exchanged between populations is sufficient to minimize differentiation between them. Natural populations often do not conform to such simple models.

Models of population structure have been used to explain why insecticide resistance has evolved in one pest species of Heliothis (H. armiger) and not in the other (H. punctiger). The two species differ in their distribution between habitats which are exposed to insecticides. Further, it is often suggested that H. punctiger is a migratory species whereas H. armiger is more sedentary (Wardhaugh et al 1980). However, the importance of these factors in the evolution of resistance in Heliothis must remain conjecture until this can be demonstrated.

4. Sampling programmes

The distribution of species in space also has important implications regarding the method of sampling for resistance testing. Genetic models of resistance assume that all individuals collected in the field, in this case, larvae, are a random sample of the population. Thus, a small sample from a large population should not contain a high proportion of individuals which are related. Little is known about how female Heliothis distribute their eggs but one possibility is that a female lays many eggs in one part of a field before she moves elsewhere. If larvae collected for testing are taken from a restricted region, say a small part of a field, instead of throughout the locally available habitat, such as a group of fields, then interpretation of the data using such models would be invalid. A study of the genetic structure of the population within and between localities such as one undertaken last year (Daly and Gregg, in prep) can examine some of these issues.

5. Hybrid Sterility Programmes

The U.S. Department of Agriculture is currently investigating the possibility of using genetic manipulation for the control of populations of American pest species of Heliothis. In such a programme, sterile males are obtained through selective breeding. These males are released into the habitat as adults at a sufficiently high density that they outnumber the wild, fertile males. If these sterile males mate successfully with females, few fertile eggs are laid and the population of larvae is kept at low numbers. Such a programme requires a thorough knowledge of the genetics of Heliothis before its implementation.

Conclusions

These five examples represent just some of the practical problems whose solution uses information from the field of genetics, either implicitly or explicitly. Knowledge of genetic mechanisms are also implicit in discussions of cross-resistance between different pesticides and in our interpretation of the mechanisms of resistance, as well as in the information that is used in the development of an insecticide strategy. Without a knowledge of the pecularities of the genetical structure of Heliothis populations, we can only make guesses about the important parameters which determine the rate of evolution of pesticide resistance.

References and Background Reading

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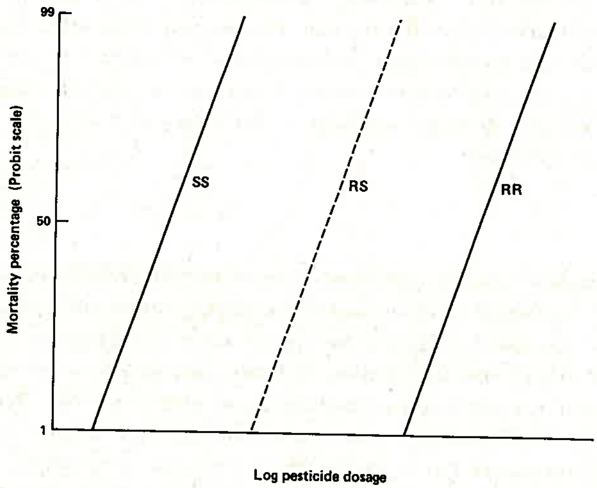

Figure Idealised dose-mortality relationship between pure strains of homozygous susceptible (SS), heterozygous resistant (RS) and homozygous resistant (RR) individuals.