PREVALENCE AND MAGNITUDE OF INSECTICIDE RESISTANCE IN THE GERMAN COCKROACH (DICTYOPTERA, BLATTELLIDAE)

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Abstract - Numerous studies have shown that German cockroaches, *Blattella germanica* (L.), are often resistant to insecticides in settings where insecticides have been used extensively in the past. We have now examined resistance in German cockroaches collected in homes in which insecticide usage has been minimal, and resident-initiated at best. Resistance to propoxur, chlorpyrifos, pyrethrins, permethrin, and cypermethrin was evaluated with a discriminating dose technique. Logit analysis was used to identify topical dosages of the insecticides expected to kill 99% of adult males in an insecticide-susceptible strain. These dosages, or slightly higher ones, were then used to screen for resistance in males of field-collected strains. All strains exhibited resistance to every insecticide, but the degree of resistance varied. Propoxur was the only insecticide to kill, with great frequency, more than 10% of insects, whereas the other insecticides usually killed less than 5%. The magnitude of resistance was assessed by treating insects with 25-fold more insecticide than the discriminating dosage. This amount of chlorpyrifos and propoxur killed almost all insects, but large numbers of males from most colonies survived being treated with high dosages of pyrethrins, permethrin, and cypermethrin. We conclude that insecticide resistance is a ubiquitous phenomenon in the German cockroach.
Key words - *Blattella germanica*, resistance detection, discriminating dose

INTRODUCTION

The German cockroach, *Blattella germanica* (L.), is by far the most important cockroach pest in the United States. Through the middle of this century, cockroach control efforts most often involved the use of baits that contained toxic compounds, such as boric acid, sodium fluoride, and white arsenic (Reierson, 1995). Since the Second World War, however, organic insecticides, particularly organochlorines, organophosphates, carbamates, and pyrethroids, have figured prominently in cockroach control programs. An unfortunate and inevitable result of the heavy use of these compounds has been the evolution of insecticide resistance. As early as 1952, German cockroaches were reported resistant to the organochlorine chlordane (Heal *et al.*, 1953), which had been on the market for only a few years. Since then, substantial resistance has been detected in *B. germanica* to almost all insecticides used for its control.

Many studies have addressed insecticide resistance in the German cockroach, and in recent years, investigators have mainly examined the mechanisms and genetics of resistance (Siegfried and Scott, 1992; Cochran, 1995). However, many fundamental issues remain to be studied. One such issue, the subject of our current investigation, is the prevalence of resistance in feral cockroach populations. A meta-analytic approach to the interpretation of previous studies would lead one to conclude that resistance is widespread. Nevertheless, the majority of these studies have been somewhat biased because cockroaches that were analyzed for resistance were, in most cases, already suspected to have this trait (Bennett and Spink, 1968; Rust and Reierson, 1991). This bias may have led to an overestimation of the prevalence of resistance in the German cockroach.

In our current study, we have examined insecticide resistance in cockroaches collected in homes in which past insecticide use has been limited and resident-initiated at best. Our initial hypothesis was that resistance would be uncommon in these settings, a hypothesis that we have now rejected.

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MATERIALS AND METHODS

Cockroach collecting and rearing

Cockroach-infested homes, primarily single-family dwellings, were located in several counties in North Carolina with the aid of county extension agents, public health officers, social workers, and housing inspectors. The current occupants of each home were questioned at length about past insecticide use in their home. In the present study, we report on insecticide resistance in cockroaches collected in dwellings that had not been treated by a pest control company during the current occupants' residence in the dwelling. In many cases, residents had lived in a home for several years without making a serious attempt to eliminate the extant infestation.

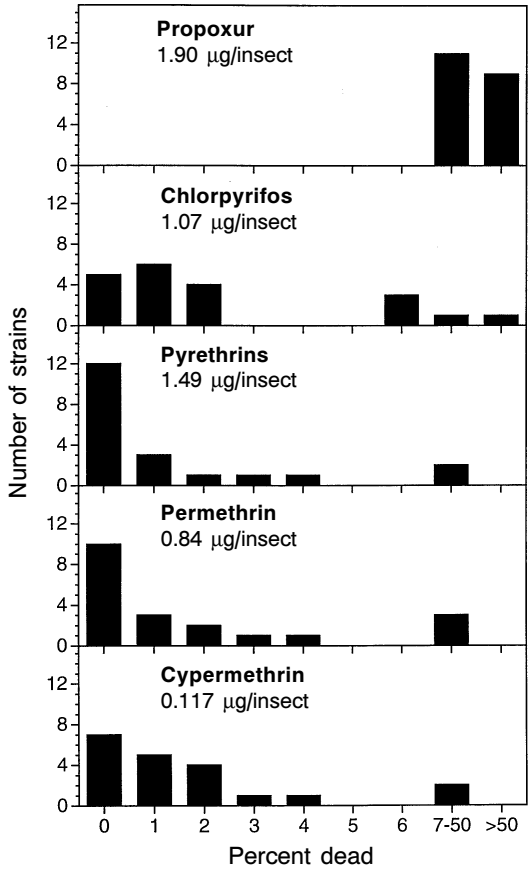

Figure 1. Mortality of adult males treated with the shown discriminating dosages of five insecticides. One hundred males from each of 20 strains were topically dosed with propoxur, chlorpyrifos, pyrethrins, permethrin, or cypermethrin. Mortality was recorded 48 hours later. The results were categorized according to the percentage of insects in a strain that were killed, the nine categories being shown on the X-axis. Each bar indicates the number of strains that fall into a mortality category. For instance, the discriminating dosage, 1.07 µg, of chlorpyrifos killed no males in five strains, 1% of males in six strains, 2% of males in 4 strains, and so on. Bars in each graph add up to 20.

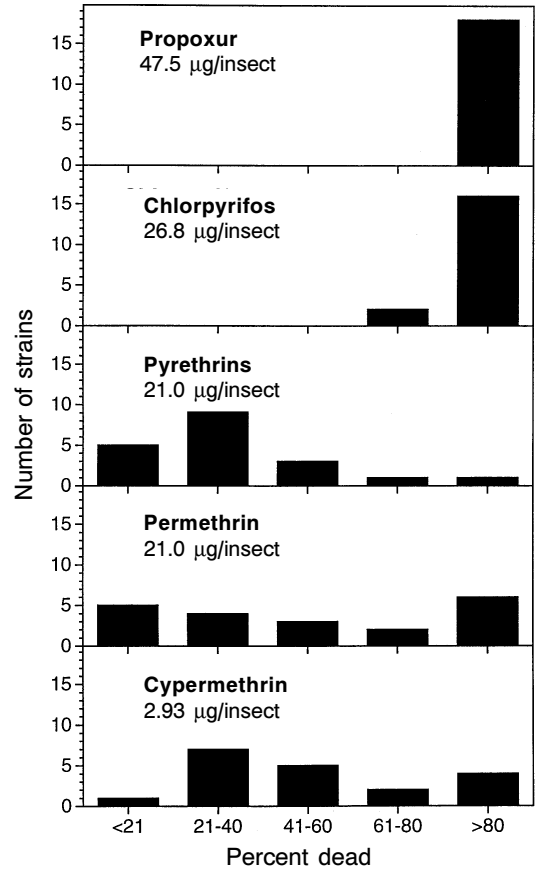

Figure 2. Mortality of adult males treated with the shown dosages of five insecticides. The dosages were 25-fold higher than the discriminating dosages in Figure 1. One hundred males from each of 18-20 strains were topically dosed with propoxur, chlorpyrifos, pyrethrins, permethrin, or cypermethrin. Mortality was recorded after 48 hours. The results were categorized according to the percentage of insects that died, the five categories being shown on the X-axis. Each bar shows the number of strains that fall into a mortality category. Bars in a graph add up to 18, 19, or 20.

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At least 50 cockroaches were collected in each home using a vacuum apparatus similar to the one designed by Wright (1966). Cockroaches were immediately brought into to the laboratory, where they were reared in plastic boxes (13.5 x 18.5 x 9.5 cm) at 27 ± 2° C and provided Purina rat chow (#5012; Purina Mills, St. Louis, Missouri) and water *ad libitum*. When colonies had reached a suitably large size, we began collecting from them newly emerged adult males. The males were then reared as described above but kept at 27 ± 0.5° C. All cockroaches were maintained under a 12:12 light:dark photoperiodic regime.

Discriminating dosages, topical applications, and resistance screening

A discriminating dose procedure was used to detect resistance (Roush and Miller, 1986; Cochran, 1995). This procedure calls for treating insects of indeterminate insecticide tolerance with an amount of insecticide known to cause a high level of mortality in a susceptible strain. In our current study, we used dosages of propoxur, chlorpyrifos, pyrethrins, permethrin, and cypermethrin that killed at least 99% of adult males of an insecticide-susceptible laboratory strain, which was obtained originally from American Cyanamid.

To determine discriminating dosages, or LC_{99}s, the relationship between insecticide dosage and mortality was established for each of the five insecticides with adult males of the laboratory strain. No fewer than eight dosages of each insecticide were used, and all insecticides were applied in 1 µl acetone to the mid-ventral thoracic surface of males that were 12-50 days old. All males were anesthetized with carbon dioxide before they were treated with insecticide. Three replicates of 10 insects were run at each dosage, and control insects, none of which died, were treated with acetone alone. Mortality was examined 48 hours after insects were treated, and LC_{99}s were determined with logit analysis. We tested empirically whether the LC_{99}s predicted in the logit models actually killed at least 99% of males. If not, dosages were increased incrementally until they were sufficiently high to kill 99%. The final dosages used to screen males of field strains were 1.90 µg propoxur, 1.07 µg chlorpyrifos, 1.49 µg pyrethrins, 0.84 µg permethrin, and 0.117 µg cypermethrin.

To evaluate the prevalence of resistance, one hundred 12-50 day-old adult males from each field-collected strain were treated on the ventral thorax with the aforementioned dosages of the five insecticides. If significantly fewer than 99% of treated males died (significantly more than 1% survived) in 48 hours, then a separate set of 50 males was treated with 25-fold greater insecticide. This latter procedure was carried out to determine the magnitude of resistance. All insecticides were obtained from S.C. Johnson Inc. (Racine, Wisconsin).

Data analysis

Logit analysis was carried out with SAS 6.12 (SAS Institute, 1990) for the personal computer. A one-sided *Z*-test, as described in Roush and Miller (1986, p. 295), was used to test whether insecticide treatments killed less than 50 or 99% of insects. Standard error of the mean is given with all means in the text.

RESULTS

The discriminating dosages of all insecticides killed at least 99% of insecticide-susceptible laboratory males in 48 hours; propoxur killed 99.0 ± 1.00%, chlorpyrifos 99.0 ± 0.58%, pyrethrins 99.3 ± 0.33%, permethrin 100.0 ± 0.00%, and cypermethrin 100.0 ± 0.00% ($N = 3$ for all). By contrast, an overwhelming majority of adult males from field-collected strains survived the treatments (Figure 1). Regardless of which insecticide was used, significantly more than 1% of treated males from all strains remained alive after 48 hours, or, stated differently, significantly less than 99% died (one-sided *Z*-test, $9.55 < Z < 99.00$, $P < 0.0001$). The discriminating dosage of propoxur killed from 10 to 89% of field-strain males (Figure 1), and 49.9 ± 4.72% on average. Chlorpyrifos, on the other hand, killed 8% or less of males in 19 of 20 strains and 77% in the remaining strain. The mean percent mortality with this compound was

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just 5.9 ± 3.78%. The remaining insecticides, the pyrethrins and two pyrethroids, killed at most 26% of males, and mean percent mortality was 1.5% ± 0.64%, 2.9 ± 1.22%, and 3.3 ± 1.54% for pyrethrins, permethrin, and cypermethrin, respectively.

The results obtained with the discriminating dosages indicated that resistance was common, but said little of its magnitude. We therefore treated insects with 25-fold greater insecticide. These dosages killed 100% of laboratory-strain males in 48 hours, but males of field-collected strains showed variable, and sometimes low, mortality (Figure 2). The increased dosages of propoxur and chlorpyrifos were highly lethal, killing more than 90% of males in most strains, although 20 and 24% of males from two strains survived the chlorpyrifos treatment. The pyrethrins and pyrethroids caused far less mortality than propoxur and chlorpyrifos (Figure 2). Significantly less than 50% of males died in 12 of 19 strains treated with pyrethrins ($2.40 < Z < 6.65$, $P = 0.0082$), 8 of 20 strains treated with permethrin ($1.84 < Z < 5.80$; $P = 0.0329$), and 7 of 18 strains treated with cypermethrin ($2.40 < Z < 4.38$; $P = 0.0082$). Therefore, there was high-level resistance to these three insecticides, but not to propoxur and chlorpyrifos.

DISCUSSION

All strains that we tested were resistant to the five insecticides, but they were least tolerant of propoxur. This compound and another carbamate, bendiocarb, were at one time used heavily for cockroach control, and as a consequence, resistance to them became prevalent and sometimes high (Cochran, 1995). In recent years, however, carbamates have been largely supplanted by the pyrethroids, and it is possible that the reduction in their use has resulted in a decline in carbamate resistance. If so, propoxur may currently be very effective for controlling cockroaches. Nevertheless, its application may soon be restricted in the United States under the Food Quality Protection Act (FQPA), and regular use of this compound might in any case bring about, in short order, high-level resistance.

With our current results, it is difficult to assess the magnitude of chlorpyrifos resistance, although it is indeed prevalent. Few insects died after treatment with the discriminating dosage of chlorpyrifos, but almost all did when dosed with 25-fold more insecticide. We have recently expanded our investigation into chlorpyrifos resistance and have treated insects with dosages intermediate to the ones used in this study. Our preliminary results agree with those of Cochran (1989) and show that chlorpyrifos resistance is low to moderate, despite the past heavy use of this insecticide. This compound may therefore continue to be useful in cockroach control programs, although, as with propoxur, its use may be restricted under the FQPA.

Our results indicate that insecticide resistance, particularly to pyrethrins and pyrethroids, prevails in German cockroach populations, even in settings where resistance might not be expected. None of the homes in our current study had been serviced by a pest control company, and the occupants of the homes used insecticides sparingly, inconsistently, and infrequently. It therefore seems implausible that sufficient selective pressure was exerted on the cockroach populations in these homes to bring about the high levels of resistance we detected. It is more probable that the insects were resistant before they were introduced into the homes. The limited efforts of residents to control the cockroaches probably killed some, but more importantly, helped to maintain resistance. Moreover, some forms of resistance, in particular to pyrethrins (Cochran, 1994), are quite stable, so the alleles responsible for resistance can be retained at high frequencies even in the absence of significant selective pressure. Greater research is needed on cockroach movement, gene flow, and resistance stability to better understand reasons underlying the ubiquity of insecticide resistance in the German cockroach.

In conclusion, it is very likely that the German cockroach is resistant to insecticides in all settings in which it is found. Previous investigations have shown cockroaches to be highly tolerant of carbamates, organophosphates, and pyrethroids in places where these insecticides have been used in abundance (Bennett and Spinks, 1968; Cochran, 1989; Rust and Reierson, 1991). We have extended on these observations by examining insecticide resistance in cockroaches obtained from homes in which rela-

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tively little insecticide has been used. We find nonetheless high levels of resistance even in these homes. Our findings have practical implications, the most important of which is that control failures can probably occur in almost any setting as a result of insecticide resistance.

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