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Further Studies on Cross-Resistance in the German Cockroach

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Four strains of German cockroaches have been exposed to a variety of insecticides in an effort to obtain more information on the cross-resistance phenomenon in this species. The insecticides chlordane, aldrin, and lindane were each tested against chlordane-resistant, lindane-resistant, and non-resistant strains. The insecticides diazinon and Sevin were each tested against DDT-resistant, chlordane-resistant, and non-resistant strains. Adult females were used exclusively in these tests. The data are presented in the form of regression lines.

The results show that the DDT-resistant strain is highly resistant to Sevin but is susceptible to diazinon, while the chlordane-resistant strain is susceptible to both of these compounds. Furthermore, the chlordane- and the lindane-resistant strains are both highly resistant to chlordane and to aldrin, but show only low-level resistance to lindane.

The over-all picture of cross-resistance between insecticidal groups in the German cockroach is still one of relative simplicity. At the present time the only real exception is that reported in this paper: the DDT-resistant strain was found to be resistant to the carbamate insecticide Sevin.

The problem of cross-resistance in insecticide-resistant strains of insects has received considerable study during the past several years. Such attention seems to be entirely justified because the already difficult task of controlling resistant forms is greatly compounded by this additional factor. Generally, these studies have consisted of determining the extent to which the phenomenon exists within a given species. This may seem a rather utilitarian task, but it is an essential part of the over-all attack on the problem. Unfortunately, the biochemical and genetical aspects of cross-resistance are largely unelucidated. Brown (1958) has recently published a rather extensive review in which this subject is discussed.

Cross-resistance in the German cockroach, *Blattella germanica* (L.), has been studied by several investigators. The most recently published work is that of Clarke & Cochran (1959), who reviewed and extended the information available for this species. The present paper is a continuation of that work. Additional information is presented on Group II chlorinated-hydrocarbon insecticides (after Metcalf, 1955), the organophosphorus insecticide diazinon (Group IV), and the carbamate insecticide Sevin (Group VII).

MATERIALS AND METHODS

The cockroaches used in these experiments were derived from stock cultures of DDT-resistant, chlordane-resistant, lindane-resistant and non-resistant strains of the German cockroach which are continuously available in the author's laboratory. The details of rearing and testing these insects have previously been described (Clarke & Cochran, 1959), but for the reader's convenience it may be well to quote the following paragraph from that description:

"For purposes of insecticide treatment, adult females were placed in small screen cages, usually 25 to 30 per cage, and dipped in the insecticidal preparations at 30°C. They were held in the insecticide suspensions for 20 seconds and then kept in the treated cages for 60 minutes before removal to recovery jars. Food and water were provided during the subsequent period of observation. Mortality counts were made six days following treatment. Dead and moribund cockroaches were combined in the mortality counts. The criterion for regarding a cockroach as moribund was inability to exhibit active locomotion." (Clarke & Cochran, 1959, p. 825.)

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Adult females between five and 15 days of age were used exclusively in these experiments.

The insecticides tested were as follows: chlordane, aldrin, lindane (γ-BHC), diazinon, and Sevin. Chlordane, lindane, and diazinon were formulated from technical-grade material, whereas chemically pure aldrin and an 85% wettable powder of Sevin were used. With Sevin water suspensions were prepared directly from the wettable powder. In all other cases the insecticides were dissolved in acetone to form stock solutions, from which the desired amounts were volumetrically measured in the preparation of water suspensions. It was necessary to add a suspending agent to chlordane in order to obtain satisfactory suspensions. No difficulties of this nature were experienced with any of the other toxicants at the concentrations used.

Dosage-mortality data were obtained with the appropriate strains of cockroaches for each of the insecticides listed above. These data were plotted on logarithmic-probability paper, and regression lines were fitted to the points by the methods of least squares (Bliss, 1935), From this procedure the " b " values or slopes of the regression lines were also determined. LC_{50} values were recorded directly from the regression lines.

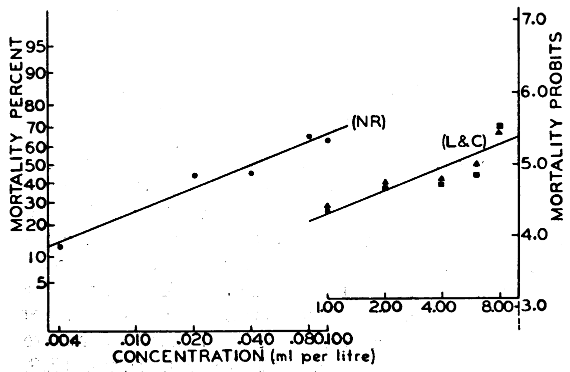
RESULTS

The results can be conveniently divided into two parts. The first part consists of three Group II chlorinated-hydrocarbon insecticides tested against chlordane-resistant, lindane-resistant, and normal (susceptible) strains of cockroaches. The second part consists of the insecticides diazinon and Sevin tested against DDT-resistant, chlordane-resistant, and susceptible strains of the same species. The results of the chlorinated-hydrocarbon tests are shown in Fig. 1-3, while Fig. 4 and 5 depict the situation with diazinon and Sevin, respectively.

The data show that the chlordane-resistant and lindane-resistant strains are virtually identical in their response to each of the three chlorinated-hydrocarbon insecticides tested (Fig. 1-3). Furthermore, the order of resistance exhibited by these two strains seems to depend upon the insecticide used. Based on the present data, the approximate orders of resistance at LC_{50} are chlordane 110×, aldrin 140×, and lindane 5×. These values were calcu-

FIG. 1

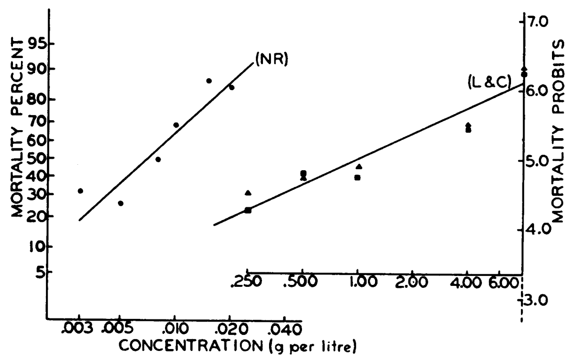
TOXICITY OF CHLORDANE TO FEMALES OF THREE STRAINS OF GERMAN COCKROACH



L = lindane-resistant strain. C = chlordane-resistant strain. NR = non-resistant strains.

FIG. 2

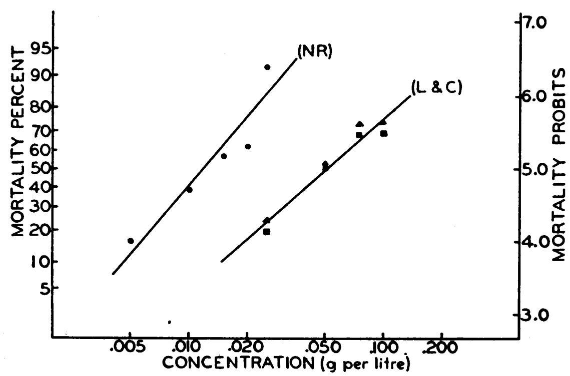
TOXICITY OF ALDRIN TO FEMALES OF THREE STRAINS OF GERMAN COCKROACH



For explanation see Fig. 1.

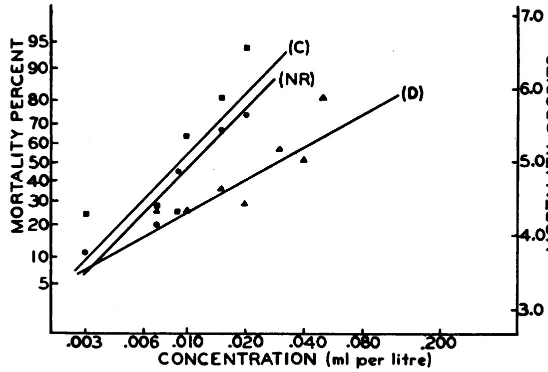
FIG. 3

TOXICITY OF LINDANE TO FEMALES OF THREE STRAINS OF GERMAN COCKROACH



For explanation see Fig. 1.

FIG. 4
TOXICITY OF DIAZINON TO FEMALES OF THREE STRAINS OF GERMAN COCKROACH



D = DDT-resistant strain. C = chlordane-resistant strain. NR = non-resistant strains.

lated by setting the LC_{50} value of the non-resistant strain equal to one.

The responses obtained from the tests involving diazinon (Fig. 4) are very similar to those previously reported for another organophosphorus insecticide, malathion (Clarke & Cochran, 1959). In both cases virtually no resistance is indicated in either of the resistant strains tested. However, in the DDT-resistant strain from two to three times as much of either diazinon or malathion is required to kill 50% of the cockroaches as is the case in the normal strain. This is probably of minor significance from the standpoint of true resistance.

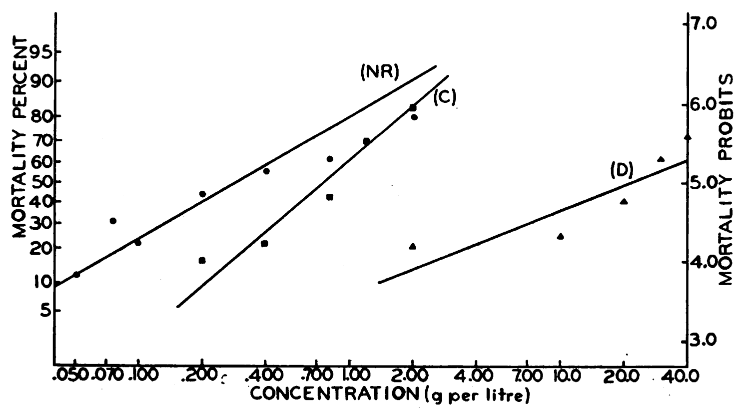
With the carbamate insecticide Sevin, a somewhat different situation prevails (Fig. 5). Here the chlordane-resistant strain shows a low-level resistance of nearly three times, but the DDT-resistant strain is about 75 times resistant at LC_{50}. Neither of these strains had previously been exposed to any carbamate insecticide.

The slopes and LC_{50} values of the various regression lines are recorded in the table. Of necessity, the slopes of the lines for the chlordane- and lindane-resistant strains are equal with respect to each of the three chlorinated-hydrocarbon insecticides tested. No other consistent pattern is evident. Variations in the slopes of the different lines do occur. As has previously been pointed out (Clarke & Cochran, 1959), this is probably what should be expected from experiments of this nature.

DISCUSSION

Perhaps the most significant findings reported in the present paper are the responses obtained with the carbamate insecticide Sevin. In the first place, it appears that this is not a very good insecticide for use in control of German cockroaches. As shown in the table, several times as much Sevin is required to give 50% mortality in the non-resistant strain as with any of the other insecticides tested in this study. Similar results were obtained by Eldefrawi et al. (1959) with houseflies. Furthermore, both the chlordane-resistant and the DDT-resistant strains of cockroaches show some degree of resistance to Sevin. In the case of the chlordane-resistant strain this resistance is of a very minor nature, probably well within the limits of " vigour tolerance " (Hoskins & Gordon, 1956). Along the same lines, Eldefrawi et al. (1959) found a DDT-resistant strain of houseflies to have a sevenfold resistance to Sevin, and

FIG. 5
TOXICITY OF SEVIN TO FEMALES OF THREE STRAINS OF GERMAN COCKROACH



For explanation see Fig. 4.

LC$_{50}$ VALUES [a] AND SLOPES OR "b" VALUES OF THE REGRESSION LINES OBTAINED BY EXPOSING FOUR STRAINS OF GERMAN COCKROACH TO VARIOUS INSECTICIDES

Toxicant	DDT-resistant strain		Chlordane-resistant strain		Lindane-resistant strain		Non-resistant strain	
	LC$_{50}$	Slope	LC$_{50}$	Slope	LC$_{50}$	Slope	LC$_{50}$	Slope
Chlordane	—	—	4.500	1.0	4.500	1.0	0.040	1.0
Aldrin	—	—	1.000	1.3	1.000	1.3	0.007	2.5
Lindane	—	—	0.052	2.2	0.052	2.2	0.012	3.2
Diazinon	0.030	1.4	0.009	2.6	—	—	0.011	2.6
Sevin	21.500	1.0	0.750	2.2	—	—	0.290	1.6

[a] LC$_{50}$ values are expressed as grams or millilitres of toxicant per litre of suspension.

this they also attributed to " vigour tolerance ". The findings of LaBreque, Wilson & Smith (1959), in which they reported an eightfold to tenfold resistance to Pyrolan and methyl carbamate in DDT-resistant houseflies, can probably be explained in the same way. On the other hand, the resistance to Sevin exhibited by the DDT-resistant strain of cockroaches is of a much higher order (approximately 75 times at LC$_{50}$), and is probably biochemical in nature, although no evidence is available on this point. In any case, it represents an example of aberrant cross-resistance in this species. As mentioned previously, none of the strains of cockroaches used in these experiments had ever been exposed to a carbamate insecticide. In our present state of knowledge on such instances of aberrant cross-resistance patterns, it can only be postulated that the detoxification mechanism operative against Group I chlorinated-hydrocarbon insecticides must, in this case, also detoxify Sevin and possibly other carbamates as well. The diverse chemical nature of these two groups of insecticides makes this a particularly interesting situation.

It is perhaps pertinent to point out the work of Forgash & Hansens (1959), who reported on a strain of diazinon-selected houseflies which are resistant not only to several other phosphate insecticides but also to DDT, chlordane, and a number of different toxicants including Sevin. This tendency of phosphate-resistant strains to be broadly resistant to diverse insecticides has been reported by a number of authors (Meltzer, 1956; March, 1959; LaBreque, Wilson, Bowman & Gahan, 1959). On the contrary, resistance to chlorinated-hydrocarbon insecticides is usually quite group-specific (Decker & Bruce, 1952; Busvine, 1953, 1954; March, 1959), thus emphasizing the aberrant nature of the present results with Sevin and certain other similar examples (Meltzer, 1958).

Several points seem worth comment regarding the information presented on Group II chlorinated-hydrocarbon insecticides. First, it is interesting to note that the lindane- and chlordane-resistant strains are virtually identical with respect to their resistance to lindane, chlordane or aldrin. This is in spite of the different and independent ways in which the two strains were developed; that is, one was selected with lindane and the other with chlordane. In this case it appears that development of resistance may be independent of the selecting agent as long as that agent is a Group II insecticide.

Secondly, it was previously reported by Grayson (1954) and Heal et al. (1953) that chlordane-resistant cockroaches are quite susceptible to lindane. This finding appeared to be an exception to the usual cross-resistance situation in Group II insecticides. It now appears that it was not an exception at all, but merely an expression of the fact that resistance to lindane does not attain very high levels in this insect. As mentioned earlier, in the present work both the lindane- and chlordane-resistant strains are only about 5 times more resistant to lindane than the non-resistant strain. At the same time both strains are highly resistant to aldrin (140×) and chlordane (110×).

Finally, based on the present work and that of Clarke & Cochran (1959), it is now possible to rank several of the Group II insecticides with respect to the order of resistance elicited by each in the German cockroach. That ranking in order of decreasing level of resistance is as follows: aldrin, chlordane, dieldrin, and lindane.

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RÉSUMÉ

L'auteur décrit dans cet article la suite de ses études sur la résistance croisée aux insecticides de divers groupes, présentée par la blatte *Blattella germanica.* Des femelles adultes de souches non résistantes et résistantes au lindane et au chlordane ont été mises en présence de chlordane, d'aldrine et de lindane, tandis que des souches non résistantes et résistantes au DDT et au chlordane étaient exposées au diazinon et au Sevin (carbamate). Les résultats ont montré que la souche résistante au DDT est fortement résistante au Sevin, mais sensible au diazinon, alors que la souche résistante au chlordane est sensible au diazinon et au Sevin. Les souches résistantes au chlordane et au lindane le sont très fortement au chlordane et à l'aldrine, et faiblement au lindane.

Dans l'ensemble, le schéma de la résistance croisée de *Blattella germanica* reste relativement simple. La seule anomalie signalée dans cette étude est la résistance au carbamate de la souche résistante au DDT. L'auteur souligne que le Sevin n'est pas un insecticide très prometteur pour détruire les blattes, car plusieurs souches, comme du reste d'autres espèces d'insectes, présentent une certaine résistance physiologique naturelle à ce produit (vigor tolerance).

Cette étude permet de compléter les résultats obtenus précédemment par l'auteur et ses collaborateurs, en établissant une échelle de résistance de la blatte aux insecticides du groupe II, qui se présente ainsi, par ordre décroissant de résistance: aldrine, chlordane, dieldrine, lindane.

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