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RECENT ADVANCES IN CHEMICAL CONTROL OF MEDICALLY IMPORTANT INSECTS

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Despite the continued emphasis upon the basic principles of the successful control of arthropods (*i.e.* source reduction, improvement of environmental sanitation, and other means of decreasing or eliminating their breeding potential), chemical measures remain a significant phase in the methodology of insect abatement. Fifteen years ago, the appearance of DDT opened a new era in the war against flies and mosquitoes, an era in which the early hopes of eliminating such pests soon dissipated when the house fly and the *Culex* mosquito in certain areas showed the ability to cope with this new threat to their survival. To replace DDT, industry developed other chlorinated hydrocarbon insecticides such as dieldrin, BHC, and chlordane, but in time these too failed to give adequate control in many areas. Thus, in the early part of the past decade, the picture of chemical control of medically important insects was viewed with decided pessimism by vector control personnel. Fortunately industrial research did not share this pessimism, and through its efforts new insecticides—including that important class of compounds, the organophosphorus toxicants—were developed.

Consequently, as we review the past 15 years, it is obvious that there has been a continuing race between the insect's ability to cope with chemical agents and man's efforts to develop new toxicants or to improve the formulation of existing insecticides. Therefore, before discussing current advances in insecticidal research, consideration first must be given to the major problem which today faces the vector control operator: *resistance.*

Although resistance in insects can be of several types, the type which has been most detrimental to control campaigns is physiological resistance, *i.e.*, the ability of an insect to survive continued exposure to a toxicant to which it formerly succumbed. How this is accomplished by the insect varies with the species and with the pesticide In resistant houseflies, DDT is degraded into a nontoxic substance DDE, whereas dieldrin is stored unchanged in the body but removed from the site of lethal action. In contrast, the DDT-resistant human body louse degrades DDT to an unknown metabolite, but uses for that reaction an enzyme different from that found in the housefly (Perry and Buckner, 1958). Obviously, the mechanism of resistance embraces several interrelated processes, the nature of which still is a mystery despite the great amount of effort expended and the substantial progress which has occurred in that area of basic research.

During the period 1947 to 1960, the resistance problem was augmented in its severity by involving a greater number of species, and by extending to several insecticides and to various geographical areas. At the same time, it must be emphasized that many species continue to be susceptible to the chlorinated hydrocarbon pesticides despite the extensive use of the compounds in their control. In addition, resistance in a species may be "spotty" in its distribution by occurring in one state and not in another; housefly populations at one or two dairies in a county may be resistant to malathion, yet populations at similar dairies in the same county may remain susceptible. These facts are mentioned because all too often the discouraging aspects of chemical control are over-stressed to the extent that the continuing effectiveness of these measures in many areas is ignored.

Since 1947, the number of resistant species has increased until today more than 50 species are reported as being resistant to one or more chemicals. Of interest is the fact that this country leads all others in the number of resistant species present. Presumably this status is a reflection of the greater use of chemical measures in the United States.

Looking at the pesticide usage in general, it is apparent that during the past four years, principal attention has been given to the organophosphorus group of insecticides. The compounds of this type which were available initially (*e.g.* parathion) appeared to be too toxic for use against public health pests, but in time techniques were devised which permitted them to be used against houseflies and against mosquito larvae. Continued research in this field has led to the discovery of toxicants far less toxic to humans than is parathion. Comparative data on the toxicity of certain of the newer pesticides to female rats indicate that several are equivalent to or less toxic than DDT or dieldrin (Table I). Organophosphorus compounds now are being used or are under investigation for use against all of man's insect enemies (flies, lice, mosquitoes, bedbugs, cockroaches, ticks, and fleas).

TABLE I

LD-50 Oral and Dermal Dosages for Female Rats Expressed as mg/kg*

Toxicant	Oral	Dermal
DDT	118	2510
Dieldrin	46	60
Parathion	3.6	6.8
DDVP	56	75
Diazinon	76	455
Malathion	1000	4444+
Ronnel	2630	—

* Taken from Gaines, 1960.

In the field of fly control, parathion, Diazinon,[1] and ronnel serve as effective toxicants in the preparation of impregnated cords which in many areas provide season-long abatement with a single installation (Kilpatrick and Schoof, 1956). Various toxicants (Bayer L 13/59, Diazinon, DDVP, and malathion) serve in poison baits which provide excellent temporary abatement and may give extended control when employed at bait stations (Kilpatrick and Schoof, 1959). Residual applications of malathion, Diazinon, and ronnel are commonly employed for treatment of animal shelters, but the efficacy of such sprays is relatively short-lived as compared to DDT or dieldrin. In addition, the Bayer Compound 29493 has been shown in recent studies (Weinburgh *et al.* in press) to have much promise as a residual application. Both malathion and Diazinon also are of value against fly larvae, but neither compound shows an effectiveness greater than seven to fourteen days.

In the mosquito control field, both parathion and malathion have been in use as larvicides for more than nine years in the western United States, malathion also being the chief organophosphorus compound employed as a space treatment against the adult mosquito. However, the most recent development in the chemical control of mosquitoes relates to the possible use of the organophosphorus compounds against the vectors of malaria. The significance of this development is emphasized by the fact that during the past two years vectors in several countries (Schoof, 1959) have shown resistance to both DDT and dieldrin, the two compounds which are commonly employed as residual treatments. Prior to the initial work with organophosphorus compounds for this purpose, the outlook ap-

[1] Use of trade names is for identification purposes only and does not constitute endorsement by the Public Health Service.

peared bleak in view of the recognized absence of any prolonged residual action with such chemicals. However, laboratory and field tests readily established that of the organophosphorus toxicants commercially available in 1958, malathion had an extremely long-lasting quality on wood surfaces (Mathis and Schoof, 1958, 59). Recent studies in El Salvador with malathion and Bayer Compound 29493 indicate that either toxicant remains effective on wood, thatch, or mud for 2½ to 3 months (Schoof, *et al.*, in press).

The most promising lead in the search for better methods of mosquito control relates to the potential of DDVP vapor as a residual fumigant against adult mosquitoes. Mathis *et al.* (1959) have shown that the vapor of DDVP is highly toxic to adult mosquitoes, and that small quantities of this pesticide can produce complete mortalities of exposed mosquitoes even when used in ventilated huts. In 1959 (Mathis and Maddock, in press, complete kills of *A. quadrimaculatus* were obtained for seven weeks with a dosage of 34.2 grams of DDVP on Perlite while the same amount of DDVP plus 64.4 grams of malathion in a commercial bait produced similar kills for nine weeks (Table II). Concentrations of 0.01 microgram of DDVP per

TABLE II

Per Cent Kill of Caged Anopheles quadrimaculatus After Overnight Exposure in Huts (1000 cu ft)*

	Per Cent Mortality			
	Weeks			
Formulation	4	6	8	9
A	100	35	—	—
B	91	100	55	—
3 A	100	100	24	5
3 B	100	100	100	100

Dosage: 11.4 grams of DDVP on A(Perlite) on B(commercial bait)

* Taken from Mathis and Maddock, in press.

liter of air or higher produce kills of *A. quadrimaculatus* females at or above the 95 per cent level at four-hour exposure (Maddock and Sedlak, in press). Current investigations are designed to develop compact spontaneous vaporizers for providing uniform rates of emission, to evaluate the effect of temperature and ventilation on the efficacy of candidate vaporizers under field conditions and to assess the toxicological aspect of the technique. The successful application of this method in malarious areas should result in a significant saving of time, manpower, and equipment. Once this technique is perfected, there is little doubt that it will have widespread application against other arthropod pests (*e.g.* flies, fleas).

Another application of DDVP vapor lies in its use for aircraft disinsection. Recent studies with DDVP vapor (Maddock *et al.* in press) introduced into the ventilating system of intercontinental aircraft showed that 95 to 100 per cent kill of houseflies distributed through the passenger compartment could be obtained with an exposure period of 30 minutes and a concentration of 0.11-0.35 microgram of DDVP vapor per liter of air (Table III). The application of the insecticide in this manner offers considerable promise as a means of killing insects in aircraft, whether they are hidden beneath seats, in closets, or at other semiprotected sites. At the same time, it relegates the dispensing of the insecticide to a mechanical procedure in which crew participation could be limited to the pushing of a toggle switch.

Aside from their use against flies and mosquitoes, the organophosphorus pesticides assume a dominant role in arthropod abatement wherever the arthropod concerned has displayed marked resistance to control measures employing the chlorinated hydrocarbon insecticides. Currently, such toxicants are used extensively against certain species of roaches and fleas. Tests by Cole *et al.* (1960) have shown malathion to be highly effective against the resistant human body louse. The safety aspect of this compound was demonstrated by Hayes *et al.*

TABLE III

Average Per Cent Mortality of Caged Musca domestica Exposed to DDVP Vapor at 12 Sites in a DC-6B Aircraft for 30 Minutes*

Micrograms DDVP per liter of air	Average Per Cent Mortality
0.28†	96.4
0.28	100.0
0.25	99.3
0.11	99.8
0.35	99.2

* Taken from Maddock *et al.* in press.
† Vapor introduced into aircraft ventilating system.

1960, who dusted human volunteers with 1.0, 5.0, and 10.0 per cent malathion formulations five times per week for 8 to 16 weeks without causing any harmful effects. These and other toxicological studies on this group of insecticides are gradually getting the scientific and lay public to realize that the term "organophosphorus insecticides" does not necessarily mean a chemical which is highly inimical to man's well being.

Although the phosphorus insecticides are employed extensively to cope with resistant populations much effort is being devoted to finding chemicals to which the insects appear incapable of developing resistance. In some instances, this has meant reviving and using in a different manner pesticides which fell by the wayside when DDT was developed. The best example of such a development is the use of paris green pellets against salt marsh mosquitoes (Rogers *et al.*, 1958).

Another method which has been used successfully against an agricultural pest is the sterile male technique. The periodical release of sterilized male screwworm flies in Florida and South Georgia by the United States Department of Agriculture in 1958-59 resulted in the eradication of this serious pest in those areas. The possible use of the irradiation technique against insect vectors is now being explored by the Entomology Research Division, U. S. Department of Agriculture, against *A. quadrimaculatus*, the vector of malaria, and by the Communicable Disease Center against *Aedes aegypti*, the yellow fever mosquito. Whether the method will be successful against these species that are characterized by multiple rather than single mating habits (as is true of the screwworm fly), will depend largely on the results of field studies in progress or contemplated for 1960.

Still in the exploratory stage are numerous investigations on the potential of growth regulators and chemical sterilants for use against public health pests. Consideration also is being given to biological agents such as *B. thuringiensis* which are known to produce crystals highly toxic to certain agricultural insects.

The future of chemical control will simulate the past in that it will provoke many challenging problems both for industry and for science. As long as these problems are attacked with the same enthusiasm and optimism as has prevailed heretofore, man will continue to move forward in his effort to defeat his insect enemies.

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