Ann. Soc. belge Méd. trop.
1981, **61**, 433-440

Revue d'Actualité — Overzichtsartikel - Review Article

CURRENT TRENDS IN VECTOR CONTROL. A REVIEW (*)

by

A. FAIN

Prince Leopold Institute of Tropical Medicine,
Nationalestraat 155, B-2000 Antwerpen, Belgium

Introduction

During the last few decades synthetic insecticides have been extensively used in the world, generally with great benefit, for the control of important pests or vectors of diseases.

The discovery of DDT opened a new era in pest control. Being extremely effective at low rates, this insecticide provided a prolonged effect maintaining its lethal properties for months after application. DDT was followed by various other organochlorines, then by organophosphorous compounds, carbamates and synthetic pyrethroids.

The success of these chemical insecticides was gradually eroded by two unexpected and undesirable consequences : the emergence of resistant strains in most of the vectors and the toxic effect for the non-target animals leading to contamination of the environment.

Resistant strains of pests were very rare before the Second World War. They increased in number with the introduction of synthetic insecticides. Gradually resistance extended to more and more pests and at present about 400 species of arthropods have become resistant of synthetic insecticides. Among these about one third are of Public Health importance. Resistance involves all arthropod genera of medical importance except so far tsetse flies and sandflies.

Until now, it has not been possible to restore susceptibility to an insect population which has become resistant. The only way to prevent this trouble is to avoid excessive use of insecticides and to try to detect emergence of resistant strains as early as possible. As soon as resistance appears an alternative insecticide or another method of control should be used. Very often resistance in insects of Public Health importance is a consequence of extensive uses of insecticides in agriculture and it might be difficult for medical officers to prevent this kind of pollution.

(*) Paper presented at the II Conferencia Mediterranea de Parasitologia, Granada, Spain, 29 September — 2 October 1981.

Synthetic insecticides

Current vector control is still based largely on chemical compounds but there is a tendency to limit and supervise more carefully their application, thus preventing as far as possible emergence of resistance and pollution of environment.

A number of insecticides are still commonly used in vector control.

DDT has been restricted for Public Health use by numerous national governments in the world, however in many tropical countries it is still widely employed, especially to control tsetse flies and sandflies and occasionally against anophelines, lice, fleas, bed bugs, at least in the areas not yet affected by resistance.

Another widely used organochlorine is Gamma HCH (Lindane). It is active against lice, fleas, chiggers, *Sarcoptes scabiei*, Triatominae, ticks etc... Dieldrine, another compound of this group is effective against a wide range of arthropods but it is toxic for vertebrates. Endosulfan, another cyclodiene closely related to Dieldrine is used with success against tsetse flies.

Among the organophosphorous compounds, Malathion is probably the most widely used. It has a low toxicity for mammals and can be used in domiciliary applications to control domestic vectors or parasites (mosquitoes, lice, fleas etc...). Fenitrothion resembles Malathion by its low toxicity and it can replace the latter for imagocide applications in antimalaria campaigns. Dichlorvos (Vapona) has a fumigant action and its vapor kills domiciliar mosquitoes. Temephos (Abate) is a very useful insecticide. It is not toxic for mammals and is widely used against larvae of Diptera, mainly mosquitoes and black flies, however, recently resistance has been observed in some strains of *Simulium damnosum*. Diazinon and Trichlorfon are used to control flies and cattle ticks. Several other compounds are active against ticks, especially Coumaphos, Diethion, Crotoxyphos and Chlorfenvinhos (Mouchet, 1979).

Two carbamate compounds are commonly used : Propoxur in domiciliar applications against anophelines and Triatominae and Carbaryl against ticks and fleas.

Synthetic pyrethroids were available since 1949 but it is only after 1965 that compounds with activity higher than natural pyrethrins, such as Permethrin and Decamethrin, were produced. Decamethrin is particularly interesting because it has a very high insectidial activity and a prolonged residual action. It has been used with success in field tests against Triatominae, tsetse flies, ticks etc...

Biological agents to control vectors

During these last years many researches have been performed in order to find efficient biological agents that could destroy the vectors without killing their natural ennemies.

Among the new tools which are available at present, probably the most promising are the insecticides produced by some bacteria, especially *Bacillus thuringiensis* var. *israelensis* serotype H-14 or BTI. This strain produces a substance highly toxic for larvae of mosquitoes, *Simulium* and phlebotomes and harmless for mammals and non-target organisms (Goldberg & Margalit, 1977; de Barjac, 1978; Larget & de Barjac, 1981). The toxic agent is a crystal of protein elaborated in the spore of the bacterium. BTI is active at very small doses. It acts primarly as a stomach poison destroying the cells of the midgut. It has not contact effect. The production of this bacterium is fairly easy. In laboratory high larvicidal activity is obtained with soy broth substrate, but this bacterium can also be produced in « Cottage industry » with an unsophisticated equipment using various « media » sterilized by heath, such as agricultural or animal waste extracts, dung extracts and sewage (Hertlein *et al.*, 1980). The formulation of the sporulated culture is still in the experimental stage but one may expect that this biological insecticide will gradually replace the synthetic insecticides for the control of mosquitoes and black flies.

Another bacterium with insecticide activity is *Bacillus sphaericus* particularly the strain 1953. It produces a larvicide factor which is very potent against larvae of various mosquitoes.

Several fungi cause fatal disease in mosquito larvae or adults and they have already been used in the field with some success. The most promising are *Culicinomyces clavosporus*, *Coelomomyces* spp., *Lagenidium giganteum*, *Leptolegnia* spp. and *Typhlocladium cylindrosporum*.

Microsporidia of the genera *Nosema*, *Thelohania* and *Vavraia* and several viruses have also been used mainly against mosquitoes but new research is necessary before their activity can be established with certainty.

Nematodes are very interesting tools in the control of mosquitoes (Poinar, 1979; WHO, 1980c). The most promising species is *Romanomermis culicivorax* of the family Mermithidae. It is an obligatory endoparasite. Its larvae kill the larval mosquitoes, and are safe to mammals and other non-target organisms. This nematode has been extensively studied during the last ten years. It can be easily mass produced and is effective against many species of *Culicidae*, including *Anopheles stephensi*, *A. albimanus*, *A. gambiae* and many other vector species. Experiments to infect *Simulium* larvae with this nematod have failed. Several *Simulium* spp. including *S. damnosum* s.s. and *S. sirbanum* have been found naturally infected in W. Africa with another mermithid, *Isomermis lairdi*. However, it has not been possible, so far, to rear this nematod either *in vitro* or *in vivo* (Mondet, 1978; WHO, 1980d).

Predators have an important role to play as biological control agents. Larvivorous fish has been used in the past to control larvae of mosquitoes. With the introduction of synthetic insecticides this method was abandoned in mosquito control programme, but now that resistance against chemical insecticides is widespread a renewed interest is given in this biological mode of control. The most interesting species is *Gambusia affinis*, native of the Mississipi Valley, U. S. A. It is a small species which adapts to a wide range of environments, such as fresh water, brackish water and salt marshes with high salinity. It can also withstand a wide range of temperature. This fish feeds on aquatic insects and insect larvae and it is an efficient predator of mosquito larvae. It has been introduced in Europe in 1920. Since 1966, it is extensively used in Iran in the antimalaria compaign with good results.

For mosquitoes breeding in highly polluted waters, such as *Culex quinquefasciatus* another fish, *Paecilia reticulata*, also called « guppy » and originating from Thailand can succeed where *Gambusia* has failed.

Larvivorous fishes can provide a good help in the control of mosquito larvae, however they are inefficient against some important vectors, such as *Anopheles gambiae* and *Aedes aegypti* or against *Aedes caspius*, an important nuisance in the Mediterranean area, because these mosquitoes breed in very small and temporary ponds which are not accessible to the fish.

Mosquitoes of the cosmopolitan genus *Toxorhynchites* do not bite at all but their larvae are predacious on larvae of harmful mosquitoes and they can be used to control the latter.

Mites have also been used in the control of vectors. The best known is *Macrocheles muscadomesticae* which preys on eggs of the house-fly and thus could have a place in an integrated fly control programme.

Various kinds of predators have been used against the snails vectors of Schistosomiasis. The best known is an ampullarid snail *Marisa cornuarietis* which has been used with success in Puerto-Rico to control *Biomphalaria glabrata* (Jobin *et al.*, 1977). This predator feeds on the eggs and the offspring of the vector. The same predator was later used successfully in Egypt against the local vectors of *Schistosoma mansoni* and *S. haematobium.*

Some species of fishes are malacophagous and have been used with some success to control the vectors of schistosomiasis in Central Africa (Macmahon *et al.*, 1977).

In its fourth meeting held in Geneva, in October 1980 the Scientific Working Group of Biological Control of Vectors has defined the four ways in which biological agents could be used in the future for the control of vectors (WHO, 1980a).

The mode of release of these agents depends mainly of their behaviour in the environment :

1. Periodic inundative releases are necessary when little or not residual action is expected.
2. Periodic complementary releases are recommended for agents that recycle in the environment.
3. For agents that do not overwinter (or estivate) the releases should be done early in the vector breeding season to ensure a maximum effect during the breeding period.
4. It may also be indicated to make introductory releases into new environments with biological agents that are able to recycle and establish themselves at an effective level.

The Working Group also recommends to give more attention to agents easy to produce and to store than to agents which are easy to produce but difficult to store. The agents that are producible only in living hosts should only be retained when and where they self-reproduce after release.

According to these basic principles the research priorities recommended by the Working Group are the following :

Priority one should be given to agents that will probably be used in the near future, like *Bacillus thuringiensis*, serotype H-14 and *Gambusia affinis*.

Priority two concerns agents with are already available for field evaluation. This group is constituted by the fishes *Poecilia reticulata* and *Aplo-*

cheilus spp.; by a bacterium, *Bacillus sphaericus*; by a fungus *Culicinomyces clavosporus*; by a nematode of the family Mermithidae, *Romanomermis culicivorax*; by mosquitos of the genus *Toxorhynchites*.

Priority three is given to agents that need more research before extensive field evaluation. In this group we find the fishes *Aphanius dispar* and *Nothobranchius* spp., the fungi *Coelomomyces* spp., *Lagenidium giganteum*, *Leptolegnia* spp., and *Tolypocladium cylindrosporum*; a snail, *Marisa cornuarietis*; a nematode *Romanomermis iyengari* and the flies *Exhyalanthrax* spp. parasitic of tsetse flies.

Priority four is given to agents needing more information in order to evaluate control potential or with a limited control potential.

Priority five to agents unlikely to be used in biological control programme.

Biological control using substances secreted by insects : pheromones and hormones

Arthropods secrete several substances which can be used for their control.

One of these is the sexual pheromone produced by the female. It is an odor attractant for the males and is active at very low concentrations. Some of these sex attractants have been obtained by synthesis and are used in the control of insects of economic importance especially harmful lepidopteres. For insects of medical importance the only sexual pheromone available is muscalure secreted by the house-fly.

Insects produce a complex of hormones which regulate the growth, the metamorphosis and the reproduction. Three hormones are particularly important in the postembryonic development : The brain hormone produced by neurosecretory cells in the insect brain, the moulting hormone or *ecdysone* secreted by the thoracic glands and the « juvenile hormone » secreted by the corpora allata (Novak, 1966).

The brain hormone is also called activation hormone, because it regulates the production of the two other hormones. The moulting hormone induces the moult and the development of adult tissues. The juvenile hormone induces the production of larval or nymphal tissues. Ecdysone and juvenile hormone are mutually interdependant in both production and function. As long as the juvenile hormone is abundant only the juvenile tissues are reduplicated, but when its secretion gradually decreases the action of ecdysone becomes prevalent and induces the moulting processus.

Chemical compounds that mimic these hormones have now been obtained naturally or synthetically and may be used for the control of vectors. The most efficient are the « Juvenile hormone » mimics (or juvenoids) which block the metamorphosis causing stagnation of the insect in its immature stages, and finally its death.

Insect growth regulators (IGR) have given promising results in field experiments and they are safe to man and non-target organisms. Methoprene (Altocid), is one of these substances and it has been used with success against *Aedes aegypti*. Unfortunately it has been observed that some insects become resistant to these hormones.

Genetic control

Genetic control is potentially a very efficient tool for the control of arthropod vectors of diseases. It is a highly selective method that causes elimination of a target species without affecting other organisms living in the same area. The main procedures used for obtaining reproductive failure are the release of sterilized males and the release of insects carrying harmful genes.

Males may be sterilized by exposure to Gamma irradiation or by using various chemicals, such as antimetabolites or alkylating agents (e.g. tepa, thiotepa, apholate etc...) (Moreau *et al.*, 1978).

When using radiosterilisation it is necessary to find a dose of radiation that will sterilize virtually all the males without affecting their longevity or their competitivity in mating with wild females.

In Curaçao and in the southern United Sates (1954 to 1962) the sterile-male technique obtained a remarkable success in the eradication of the screw-worm fly (*Cochliomyia hominivorax*). In Florida the operation needed the release of more than 3.000 million flies over 17 months. It was achieved at a cost of $ 10.600.000 and was estimated to save an annual cost in death and damage of $ 20.000.000 (Knipling, 1959; Linquist, 1963, *in* Davidson, 1974). However, the eradication was only temporary and in 1972 extensive reinfestations occured in the Southwestern states of the U. S. A. (Bushland, 1975; Harwood *et al.*, 1979).

Limited field experiments with the sterile-male technique have also been conducted with mosquitoes (Morlan *et al.*, 1962), blowflies (Macleod *et al.*, 1961), houseflies (Rivosecchi, 1962) and tsetse flies (Clair *et al.*, 1979). The results were not very encouraging. In the experiments with tsetse flies the final decline of the fly population was significantly much more important when the release of the sterile males was preceded by an application of a non residual insecticide (e.g. Thiodan). The synergy obtained by the combination of both chemical and biological methods can be explained by the fact that the insecticide had killed most of the native male population so that the sterile males introduced later had to compete only with a very few newly emerging males (Hocking, 1972).

Another method of genetic control is to exploit the cytoplasmic incompatibility existing between certain strains of the same species. Such incompatibility has been observed in the *Culex quinquefasciatus* complex. The males of the incompatible strains are naturally sterile for females of the other strains and their release into a local population will reduce the insect population.

Sterile males can also be obtained by using hybrids resulting from the crossing between closely related species. This has been done with *Anopheles gambiae* which is a complex of several closely related species.

Chromosomic alterations such as translocations can be induced in insects either by radiation or by some chemical compounds, also called chemosterilants. By using translocated insects it is possible to introduce into a native population some inheritable characters leading to partial sterility. This autocidal method has been used in the control of house-fly and mosquitoes.

Genetic manipulation appears to be a very promising tool in the control of vectors however much more study and experimental work are still necessary before this method can become operational.

Besides, it is necessary to draw attention to the fact that some of the compounds used for sterilizing insects, specially the alkylating agents, are highly toxic and mutagenic for mammals. They should therefore be used very cautiously and great care should be taken to ensure that they do not contaminate the environment (Pal and Whitten, 1974).

Conclusions

During more than 30 years spectacular success has been achieved by the use of synthetic insecticides especially DDT. These chemicals still remain the principal weapon against the vectors of Public Health importance. However, owing to the emergence of resistance of the insects to these compounds and their toxicity for non-target animals it has become necessary to give increasing consideration to alternative methods based on biological and genetic control. It has also become clear that only integrated control using a combination of physical, biological and chemical measures will achieve a satisfactory control of pests and vectors of diseases.

Acknowledgements — *I wish to thank Dr N. G. Gratz, director of the Division Vector Biology and Control, for granting permission to quote from some unpublished documents of W. H. O.*

REFERENCES

Bushland, R. C. (1975) : Screwworm research and eradication. Bull. Entomol. Soc. Amer., **21**, 23-26.

Busvine, J. R. (1980) : Insects and hygiene. London, Chapman and Hall, 568 pp.

Claire, M., Cuisance, D., Politzar, H., Taze, Y. & Sellin, E. (1979) : Etat actuel de l'expérimentation de la lutte génétique par lachers de mâles stériles contre *Glossina palpalis gambiensis* en Haute-Volta. *in* Congrès sur la Lutte contre les Insectes en Milieu tropical, 2e partie. Marseille, pp. 1047-1054.

Craig, G. B. (1963) : Prospects of vector control through genetic manipulation of populations. Bull. Wrld Hlth Org., (Suppl.) **29**, 89-97.

Davidson, G. (1974) : Genetic control of insect pests. London, Academic Press, 158 pp.

Davidson, G. & Mason, G. F. (1963) : Genetics of mosquitoes. Ann. Rev. Ent., **8**, 177-196.

de Barjac, H. (1978) : Une nouvelle variété de *Bacillus thuringiensis* très toxique pour les moustiques : *B. thuringiensis* var. *israelensis* serotype 14. C. R. Acad. Sci. (Paris) Sér. D, **286**, 797-800.

Goldberg, L. J. & Margalit, J. (1977) : A bacterial spore demonstrating rapid larvicidal activity against *Anopheles sergentii, Uranotaenia unguiculata, Culex univittatus univittatis, Aedes aegypti* and *Culex pipiens.* Mosquito News, **37**, 355-358.

Hertlein, B. C., Hornby, J., Levy, R. & Miller, T. W. (1980) : Prospects of spore-forming bacteria for vector control with special emphasis on their local production potential. W. H. O./VBC/80.791.

Hocking, K. (1972) : Tsetseflies. *in* R. Pal & R. W. Wharton : Control of Arthropods of Medical and Veterinary Importance. New York, Plenum, pp. 95-103.

International Atomic Energy Agency (1968) : Control of livestock insect pests by the sterile-male technique. Vienna, 102 pp.

Jobin, W. R., Brown, R. A., Velez, S. P. & Ferguson, F. F. (1977) : Biological control of *Biomphalaria glabrata* in major reservoirs of Puerto Rico. Amer. J. trop. Med. Hyg., **26**, 1018-1024.

Knipling, E. F. (1959) : Sterile male method of population control. Science, **130**, 902.

Larget, I. & de Barjac, H. (1981) : Spécificité et principe actif de *Bacillus thuringiensis var. israelensis.* Bull. Soc. Path. exot., **74**, 216-227.

Lindquist, A. W. (1963) : Intern. Atomic Energy Agency Publication : Technical Report Series, 21. Vienna, 59 pp.

MacLeod, J. & Donnelly, J. (1961) : Failure to reduce an isolated blowfly population by the sterile males method. Ent. exp. appl., **4**, 101-118.

MacMahon, J. P., Highton, R. B. & Marshall, T. F. (1977) : Studies on biological control of intermediate hosts of schistosomiasis in Western Kenya. Environ. Conserv., **4**, 285-289.

Mondet, B. (1978) : Les Mermithidae parasites de Simulies comme agent de lutte biologique en Afrique de l'Ouest. Int. Congr. Parasit. ICOPA IV, Warsaw, Poland, 19-26. August 1978.

Moreau, C. M. & Stiles, A. R. (1978) : Insects sterilants. Document W. H. O./VBC/78.695.

Morlan, H. B., McCray, E. M. & Kilpatrick, J. W. (1962) : Field tests with sexually sterile males for control of *Aedes aegypti*. Mosquito News, **22**, 295-300.

Mouchet, J. (1979) : Les vecteurs de nuisance en santé humaine et animale. *in* Congrès sur la Lutte contre les Insectes en Milieu tropical; 2e partie. Marseille, pp. 937-954.

Novak, W. J. A. (1966) : Insect hormones. London, Methuen, 478 pp.

P. A. H. O. (1972) : Vector control and the recrudescence of vector-borne diseases. Washington, Scientific publication, 238, 85 pp.

Pal, R. & Wharton, R. H. (1972) : Control of Arthropods of Medical and Veterinary Importance. New York, Plenum, 138 pp.

Pal, R. & Whitten, M. J. (1974) : The use of genetics in insect control. Amsterdam, Elsevier, 241 pp.

Phanthumachinda, B. & Wattanachai, P. (1978) : Effectiveness of Methoprene (Altosid) in water jars in Bangkok, Thailand for the control of *Aedes aegypti* (L.) Document W. H. O./VBC/78.699.

Poinar, G. O. Jr. (1979) : Nematodes for the biological control of insects. Boca Raton, CRC Press, 277 pp.

Rivosecchi, L. (1962) : Un esperimento sul campo con mashi irradiati di mosca domestica in una zona rurale della provincia di Latina. Riv. Parassit., **23**, 71-74.

W. H. O. (1980a) : Fourth Meeting of the Scientific Working Group on Biological Control of Insect Vectors of Diseases, 6-10 October 1980. Document TDR/BVG.SWG (4) 80.3.

W. H. O.(1980b) : Bibliography of Pathogens of medically important Arthropods. Bull. Wrld Hlth Org. (Suppl.), **58**, 1-197.

W. H. O. (1980c) : Data sheet on the biological control agent : *Romanomermis culicivorax* (Ross and Smith, 1976). W. H. O./VBC/80.766.

W. H. O. (1980d) : Data sheet on the biological control agent : *Isomermis lairdi* Mondet, Poinar & Bernadou, 1977. W. H. O./VBC/80.785.