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Mini-Review

Agriculture and Vector Resistance

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Abstract—Agricultural treatments mainly against cotton and rice pests put a considerable insecticide pressure on larvae and sometimes adults of several vector species. Resistances to compounds which had never been used for public health, but were currently employed in agriculture were observed among vectors. It was also noticed that resistance level in some vector species was linked to the quantity of the compound used in the same area against crop pests.

Resistance in *Anopheles gambiae* in Africa, in *An. albimanus* in Central America, in *An. culicifacies* and *An. aconitus* in South East Asia, in *An. sacharovi* in Turkey, in *Culex tritaeniorhynchus* in the Far East as well as the DDT resistance in *Simulium damnosum* in West Africa, seem to be associated with the agricultural practices.

On the other hand, resistance did not develop in species which, due to their ecology, were not in contact with agricultural insecticide even in areas where DDT was applied for more than 20 years in house spraying. This is the case of *An. dirus* and *An. minimus* in Thaïland and *An. darlingi* South America.

However several important factors like *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus*, have developed resistance for which agricultural treatments cannot be held responsible. It would be worth saying that the rise in malaria in certain countries, such as India, is only due to the increase of insecticide in agriculture after the "green revolution".

Key Words: Agriculture, insecticide, resistance, *Anopheles*, *Culex*, *Aedes*, malaria, Japanese encephalitis

Résumé—Les traitements agricoles destinés, en particulier, au coton et au riz ont provoqué une pression insecticide considérable sur les larves et quelquefois les adultes de plusieurs espèces de vecteurs. On a observé chez ces derniers le développement de résistances à des produits qui n'avaient jamais été utilisés en santé publique mais étaient d'emploi courant en agriculture. On a également noté que les niveaux de résistance des vecteurs à certains produits étaient étroitement correlés à l'utilisation de ces composés en agriculture dans la même région.

On a ainsi constaté que les résistances d'*Anopheles gambiae* en Afrique, d'*An. albimanus* en Amérique Centrale, d'*An. culicifacies* et d'*An. aconitus* en Asie, d'*An. sacharovi* en Turquie, de *Culex tritaeniorhynchus* en Extrême Orient étaient liées aux pratiques agricoles de même que la résistance au DDT de *Simulium damnosum* en Afrique de l'Ouest.

Inversement l'utilisation du DDT en traitement intradomiciliaire pendant plus de 20 ans n'a pas entrainé de résistance chez des espèces, comme *An. minimus* et *An. dirus* en Thaïlande et *An. darlingi* en Amérique du Sud, que leur écologie tient à l'écart des traitements agricoles.

Il existe cependant des vecteurs importants comme *An. stephensi*, *Culex quinquefasciatus* et *Ae. aegypti* qui ont développé des résistances dont les traitements agricoles ne peuvent être tenus pour responsables. Ces traitements ne sauraient d'ailleurs supporter la responsabilité totale de la reprise du paludisme dans certains pays comme l'Inde.

Mots Cléfs: Agriculture, insecticide, résistance, *Anopheles*, *Culex*, *Aedes*, Paludisme-Encéphalite japanaise

INTRODUCTION

When resistance to DDT and dieldrin appeared first in anophelines in Greece and Africa, the agricultural treatments of cotton and rice were said to be at least partly responsible for these phenomena (Hamon and Garrett-Jones, 1963). Later, agricultural practices were also involved in the development of multi-resistance (DDT, D1, organophosphates and carbamates) in anopheline populations in Turkey, Central America and India. In 1982, a workshop was held in Colombo, Sri Lanka, to review the situation and to propose countermeasures. Papers presented at this workshop have been largely taken into account in the present review.

INSECTICIDES IN AGRICULTURE

Globally, 95% of the insecticides produced are used in agriculture, and up to now consumption of pesticides is continuously increasing.

- Cotton crop consumes the largest share of the insecticides used in agriculture. Since the cotton pests became resistant to most of the classes of available compounds, it was necessary to increase both the

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dosages and the rhythm of the treatments in a spiralling system. In some places of Central America, during the six months' growing season, up to 30 treatments are applied, by air or from the ground (Georghiou, 1982a). More than 50% of the total insecticides used in developing countries are employed in cotton farming.

Rice crop became a major insecticide consumer when the traditional varieties were replaced by high-yielding ones following the "green revolution" by 1965. These new varieties are much more susceptible to pests and need to be protected by insecticide treatments (Sharma and Mehrotra, 1985). Generally, there is none or little restriction in the use of pesticides in agriculture in large estates as well as in small farms. In many countries, the only limiting factors are the foreign exchange laws (which relate to the importation) and the resources of the farm.

SELECTIVE PRESSURE OF AGRICULTURAL TREATMENTS ON VECTORS

Agricultural treatment can exert a selective pressure on both the larval and adult stages of vectors.

Some of the breeding sites created by agricultural practices (rice fields, irrigation schemes) are sprayed directly when the crops are treated. Insecticides sprayed in crop fields can also drift as a result of wind to nearby mosquito breeding sites. Finally, rains can wash pesticides applied on crops and drain them into ground pools or into rivers where mosquito and blackfly larvae breed. This last point is poorly documented.

Some species of mosquitoes have been observed resting on treated vegetation, e.g. *An. pharoensis* on cotton trees in the dry areas of the Nile Delta, Egypt. In Burundi, the malathion resistance of body lice followed the use of this compound for coffee treatment and its storage in houses (Davidson, 1982b).

When breeding sites are reached by agricultural treatments, all the mosquito larvae are subjected to selective pressure which is more likely to induce resistance than the house spraying which reaches only anthropophilic females, generally less than 25% of the total mosquito population for semi-exophilic species, such as *An. albimanus* (Georghiou, 1982b).

Residues could act at sublethal dosages for genetic selection of resistance (Muir, 1982). The selection of both larval and adult stages in certain agricultural areas will enhance the pressure for rapid development of resistance.

In contrast, some vector species are very unlikely to be submitted to agricultural insecticide pressure; for example, *An. dirus* is found in the forest areas in many parts of Southern Asia. Other species, such as *An. minimus* found in the edges of rivers out of the mainstream, are ecologically isolated from the insecticide carried by the river. It is remarkable that these species had not developed resistance until recently, even in areas of continuous house spraying for 20 years. But, it must be noted that many urban species have developed multiresistance, for which the agricultural use of insecticides cannot be held responsible.

EVIDENCE OF IMPLICATION OF AGRICULTURE IN VECTOR RESISTANCE

The problem has been discussed by Georghiou (1982b), who recognized the following relevant points to implicate agricultural practices in the development of vector resistance:

(a) Appearance of resistance in the vector species prior to the application of chemicals for public health for their specific control.

(b) Temporary decrease or suppression of vector populations in areas sprayed for agricultural purposes without any public health use of pesticides. Often these populations built up again when the vector species became resistant.

(c) Higher resistance in vectors in agricultural sprayed areas than in areas without such treatments.

(d) Correlation between intensity of insecticide use in agriculture and resistance level in vector.

(e) Seasonal fluctuations of resistance level following the use of insecticides in agriculture.

(f) Correspondence between resistance spectrum and the classes of compounds used in agriculture.

As these criteria are mainly circumstantial, and as public health and agricultural treatments are often both carried out in the same areas, it is sometimes difficult to reach conclusions with absolute certainty. The best documented cases on the development of insecticide resistance through agricultural use are to be found in malaria vectors, and some culicines and blackflies, and the implications are reviewed in the following pages.

It should be pointed out that resistance to pyrethroids was never observed following agricultural treatments. These insecticides, when reaching the ground, are strongly adsorbed on soil particles and are no longer active by contact.

CASE STUDIES—ANOPHELINES

Mediterranean region

In Greece, Belios (1961, in Hamon and Garrett-Jones, 1963) implicated cotton and rice treatments in the development of D1 and DDT resistance in *An. sacharovi*. In Turkey, Ramsdale (1975) pointed out that D1 resistance appeared in *An. sacharovi* in areas where this insecticide had only been applied on cotton and rice and never in public health. DDT resistance could also be due to agricultural use of this insecticide, but the role of house spraying cannot be entirely ruled out.

In the 1970s, organophosphate treatments of rice and cotton drastically decreased mosquito populations. But a few years later, they became resistant to OP (apart from malathion) and carbamates. The OP resistance appeared in exophilic species, such as *An. hyrcanus*, *An. maculipennis* and *An. melanoon subalpinus*, as well as in the endophilic *An. sacharovi*. It was concluded that house spraying could not be held responsible for the OP resistance, which also appeared in areas never sprayed for public health. In the few areas where malathion had been used only for house-spraying, the anophelines remained susceptible to it. In the same way, *An. superpictus*, an endophilic species which breeds in residual pools in river beds,

Table 1. Development of Dl resistance in *Anopheles funestus* and cotton production at Somousso*, Burkina Faso

	Percentage of *An. funestus* susceptible homozygotes at Somousso	Quantities of insecticides used in Bobo-Dioulasso area (in litres)	Cotton production in Somousso sector, Bobo-Dioulasso
1962		1,000	
1967	89%		5,500 kg
1972		120,000	63,000 kg
1975	5%	250,000	105,000 kg

*The Somousso sector is just a small part of the cotton production belt in Bobo-Dioulasso area and the data give the general trends of the production.

never developed any resistance even in areas where house spraying was done for several years (Ramsdale, 1975; Davidson, 1982a).

In Egypt, *An. pharoensis* became DDT-resistant in the Nile Delta, where house spraying was never carried out. It is thought that selection was made on adults resting on treated cotton plants in that very dry area (Davidson, 1982b).

Afrotropical region

Dl resistance in *An. gambiae* was recorded between 1955 and 1963 in several countries of West Africa, e.g. Mali and Ivory Coast, where this compound had never been used in public health. BHC and endrin had only been applied to cotton and coffee (Hamon and Garrett-Jones, 1963). In 1960, when DDT spraying in the pilot zone of Bobo-Dioulasso (Burkina Faso) was stopped, *An. gambiae* was susceptible to DDT. But in that area where no more house spraying was carried out, it became DDT-resistant in 1967 (Hamon *et al.*, 1968a, c) when cotton cultivation improved. In the same area *An. funestus*, which was susceptible to Dl in 1959, became resistant to this compound after 1963 (Hamon *et al.*, 1968a, b). The selective pressure was due to cotton treatments with a mixture of endrin and DDT. From 1967 to 1975, there is a correlation between the increase in cotton production, the intensive use of insecticide for controlling its pests, and the increase of resistance to Dl in *An. funestus* (Brun and Sales, 1975) (see Table 1). Double resistance in *An. gambiae* s.l. and Dl resistance in *An. funestus* and *An. rufipes* were also recorded in areas of Mali where no insecticide had ever been used for public health (Hamon and Ouedraogo, 1969).

In contrast, in the irrigation scheme of Gezira in the Sudan, malathion was used against *An. arabiensis* already resistant to DDT and Dl. But after one year of such house treatments, malathion resistance appeared. It is limited to adult mosquitoes, although larval stages are still susceptible. This strongly suggests that the selection of resistance was due to house spraying. Moreover, *An. arabiensis* is only resistant to malathion and not to other OP compounds used in agriculture (Davidson, 1982b).

Oriental region

In India, Wattal *et al.* (1981) observed that *An. culicifacies* had become Dl and OP resistant in areas where these insecticides had only been used in agriculture for controlling cotton and rice pests. Their usage increased greatly after 1960, when high-yielding varieties of rice were introduced in India. The authors concluded that the degree of resistance was proportional to the quantities of insecticides used in a given area.

In Sri Lanka, DDT resistance in *An. culicifacies* could have been selected by house spraying as well as by agricultural treatment (Herath, 1982). The author remarks that this species in irrigated areas does not breed directly in the rice fields. The true rice field breeders, *An. subpictus* and *An. nigerrimus*, have developed resistance to the five classes of insecticides. It is remarkable that the last species is completely exophilic, and thus has no contact with sprayed houses.

In Thailand, two species of irrigated areas, *An. culicifacies* and *An. vagus* are DDT-resistant. The first species enters the houses, but the other is largely exophilic. It was concluded that the resistance was induced by rice insecticidal treatments (Ismail and Phinichpongse, 1980). Fortunately, these anophelines are not important malaria vectors in Thailand and the main vectors, *An. minimus* and *An. dirus*, which have little contact with agricultural treatments (cf. supra), were not reported resistant up to now. The problems of malaria control were mainly due to mosquito and human behaviour and to drug resistance of *Plasmodium falciparum*.

In Indonesia, the rice field breeder, *An. aconitus*, was found Dl-resistant more than 20 years ago in areas where this insecticide had only been used for agriculture (Badawi in Ismail, 1982).

In China, the rice field breeding anopheline, *An. sinensis*, even though mainly exophilic and zoophilic, has developed resistance to DDT, Dl and OP following the use of these compounds for rice pest control. But it must be pointed out that in Asia, another rice field breeder, *An. philippinensis*, has not yet developed any OP resistance and only very limited resistance to organochlorines (Ismail, 1982).

In India, many malaria cases are due to the multiresistant *An. stephensi*. Agricultural treatments can hardly be involved in the development of resistance in this urban species.

American regions

Development of multiresistance in *An. albimanus* has been well documented in Central America, particularly in El Salvador, and these studies have served as models. An excellent summary was given by Georghiou (1982b).

Breeland *et al.* (1970) found malathion-resistant populations of *An. albimanus* on the Pacific coast of the El Salvador, where OP had never been used in public health. Hobbs (1973) showed that cotton treatments beginning in July were followed by a sharp decrease of the *An. albimanus* populations; in contrast, in non-agriculturally treated areas the populations of this species remained at high level up to December.

OP and carbamate resistance appeared in areas where these compounds had been intensively used for cotton (up to 30 OP treatments during the six months' growing season) and later for rice (carbaryl) mainly in La Paz district in El Salvador. In parts of this country where agriculture remained traditional and where these pesticides had not been used, *An. albimanus* populations remained susceptible like the ones of Haiti or the laboratory strains. There was a positive correlation between the quantities of insecticides used in agriculture and the level of resistance in *An. albimanus* (Georghiou, 1972; Georghiou *et al.*, 1971). OP resistance increased every year during the cotton growing period (June–December) and slightly decreased during the following dry season, but remained higher than at the same period of the previous year (Georghiou *et al.*, 1973). OP and carbamate resistances in *An. albimanus* in El Salvador could have been selected by parathion and methyl parathion for OP and carbaryl for carbamates. The high insecticide pressure led to the selection of a variant with acetylcholinesterase less sensitive to these chemicals. This would explain the high resistance to the two classes of insecticides (Ayad and Georghiou, 1975). In Nicaragua, in 1970, the strong relationship between DDT resistance in *An. albimanus* and cotton cropping was also observed (Georghiou, 1982b).

CASE STUDIES—OTHER VECTORS

Culex tritaeniorhynchus

In Korea, intensive use of OP against rice borers drastically reduced the populations of the rice field breeder, *Culex tritaeniorhynchus summorosus*. This was considered as a beneficial side-effect of agricultural treatment, since it was followed by a sharp decrease in the annual number of Japanese B encephalitis cases (Bang, 1970). In Taiwan, rice insecticidal treatment had not the same impact because the interval between the applications is much longer than the mosquito preimaginal cycle. During the 1970s, *C. tritaeniorhynchus* became resistant to DDT, D1 and OP in China, Korea and Japan (Anon, 1980). As no specific treatment had ever been undertaken against this exophilic species, agricultural practices should be considered the cause of these resistances.

Culex quinquefasciatus

Georghiou (1982b) involved agricultural treatments in the development of OP resistance in *C. quinquefasciatus* in California. But in most of the tropical cities, this mosquito has developed DDT, D1 and sometimes OP resistance without any pressure of agricultural insecticides. In Douala, Cameroon, it developed resistance to malathion very quickly after a very limited usage of OP in public health (Mouchet *et al.*, 1960).

Aedes aegypti

In Tahiti Island, French Polynesia Mouchet and Laigret (1967) suggested that D1 resistance in *Ae. aegypti* could be due to coconut-tree insecticidal treatments. But this statement needs to be supported by more evidence. So far, there is no evidence of the impact of agriculture in the development of resistance in this urban mosquito.

Simulium damnosum *s.l.*

It is generally considered that resistance in blackfly larvae is selected by specific insecticide applications for their control (Davidson, 1982b). But Guillet *et al.* (1977), in checking susceptibility in the Volta Basin region of blackflies in a pre-control survey in the Onchocerciasis Control Programme (OCP), found several DDT-resistant populations of *S. damnosum* s.l. in Ivory Coast, Mali and Benin in rivers which had never been treated for blackfly control. In Benin, the site was more than 600 km away from any treated river. Selective pressure could have resulted from the draining into rivers of the insecticides applied on cotton. An hypothesis which has yet to be proven is the possible selection of resistance on adult flies resting on the treated cotton trees. The question is important for the schedule of insecticide treatment sequences in the future developments of OCP activities.

Pediculus humanus

Body lice, apart from being DDT and D1 resistant in most of the world, have developed malathion resistance in Egypt, Ethiopia and Burundi (Anon, 1980). In Burundi, this phenomenon could be related to the contamination of workers treating coffee plantations and to the storage of insecticide in their houses (Davidson, 1982b).

AGRICULTURE AND PUBLIC HEALTH

For agricultural insecticidal treatments, vectors are non-target organisms just as many other species living in the treated ecosystem. At the beginning of the treatment, some vector species have been destroyed with a beneficial side-effect for public health. There is no doubt now that later these agricultural treatments produce a selective pressure leading to the development of resistance in several vector species like in other organisms of the contaminated ecosystems, e.g. fishes in the Mississippi River, mayflies in New Brunswick rivers (Grant and Brown, 1967; Brown and Pal, 1973).

The reciprocal impact of agricultural and public health treatments is poorly understood, partly due to the lack of information on the behaviour of insecticides in the environment, particularly of those washed from the crops by the rains. Collaboration with environmentalists and ecotoxicologists would be highly desirable. A great deal of work has been done on the DDT residues but much less is known on the short-term impact of biodegradable compounds repeatedly applied. OCP has built a very good aquatic monitoring programme, and opportunity could be taken to study the development of insecticide resistance in non-target organisms. Whenever resistance was selected by agriculture or public health activities, its impact on disease control is the same. The subject has been extensively discussed in several expert committees of WHO (Anon, 1980).

Chapin and Wasserstrom (1981; 1983) and Wasserstrom and Chapin (1981), taking examples of El

Salvador and India, claimed that there was a direct correlation between the quantities of insecticides used in agriculture and the number of cases of resurgent malaria, through the process of vector resistance development. Bruce-Chwatt (1981) maintained that vector resistance is not the only reason of malaria resurgence, and Curtis (1981) gave examples of lack of linkages between resistance and agriculture. One of the most comprehensive studies was made by Sharma and Mehrotra (1982a, b; 1983), who analysed the malaria resurgence phenomenon in India. They showed that the disease reappeared in areas where *An. culicifacies* was susceptible as well as in areas where it was resistant. The resurgence also took place in cities where the urban vector, *An. stephensi*, even if resistant, is not likely to be in contact with agricultural activities. Moreover, they noticed that malaria had never disappeared in certain areas due to the vector behaviour. The main causes of malaria resurgences were poor epidemiological surveillance, lack of qualified personnel supervising spraying, and shortage of DDT at a crucial time when the transmission started again. Cotton treatment had no or little impact. The Indian case gives a good idea of the complexity of the phenomena implied in malaria resurgence and every case must be judged on its own merit, avoiding generalizations.

Resistance problems are only a small part of relationships between public health and agricultural development. Land reclamations, dams and irrigation schemes are likely to create or to increase breeding places of a number of vectors of malaria, arboviruses, filariasis, onchocerciasis, schistosomiasis, etc. (Philipon and Mouchet, 1976; Sharma and Uprety, 1982). But the relationship between the number of vectors and the prevalence of the disease is not always clear; in an irrigated area of Burkina Faso it was shown that the malaria transmission was lower than in villages outside the irrigation scheme. In the latter, the *An. gambiae* population was three times higher but its sporozoite rate was seven times lower (Carnevale, pers. commun.). On the other hand, food production is the key point for solving nutritional problems and the recovery of new lands for cultivation often needs preliminary vector control as in the Onchocerciasis Control Programme in West Africa. The need for intersectoral co-operation between health and agriculture has been underlined in many WHO meetings. It should be supported by actual joint field programmes. Studies on resistance development should be included in such activities.

Dealing with the pesticide management, some countries have banned some insecticides in agriculture, e.g. malathion in Sri Lanka and DDT in China. Such measures have to be encouraged, wherever they can be applied and are desirable, and where it is not too late. Integrated control has been recommended, but up to now it has severe limitations which have been highlighted by the WHO Expert Committee in 1982 (Anon, 1982).

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