Pyrethroid Resistance in the Bollworm Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae) in West Africa

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ABSTRACT

The sensitivity of bollworm, Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae) to pyrethroids has been monitored in co-operation with CIRAD-CA in research laboratories of National Research Institutes in West and Central Africa for more that ten years. This survey over the last three years, enabled observations of a tendency for resistance to pyrethroids to develop in bollworm. At the same time, loss of efficacy of pyrethroid based sprays has been observed in farmers' fields in Benin, Burkina Faso, Côte d'Ivoire and Mali. The LD_{50} recorded in the laboratory on different strains of H. armigera in 1997 and 1998 leads to the factors of resistance varying from 10 to 100 for cypermethrin and deltamethrin. Short term proposals are 1) the implementation of a field survey using the vial test method to learn more about spatial re-partition of the resistant population; b) calendar based spraying programmes with reduced use of pyrethroids; and c) threshold based interventions to control bollworm.

Introduction

The noctuid *Helicoverpa armigera* (Hübner) is today the main pest of cotton in the Old World. This has not always been the case, especially in sub-Saharan Africa where it was not even observed in the early studies (Vayssière and Mimeur, 1926). Since then, the intensification of cropping, the presence of host plants in the agrosystem and the use of insecticides have enabled it to gradually become the leading pest.

For many years, *H. armigera* was controlled by applications of DDT or DDT-based combinations. The systematic use of this active ingredient led to the first cases of resistance (Goodyer and Greenup, 1980). Numerous biological control operations using entomophagous organisms (Trichogrammatidae) or entomopathogens (nuclear polyhedrosis viruses) were initiated and are still running in some areas (Uzbekistan and Vietnam). The introduction of pyrethroids in 1975 and the degree of control achieved, together with the lower costs of protection, resulted in biological methods playing a minor role. Cotton growing became strongly dependent on chemical control in general and on pyrethroids in particular.

Resistance of Helicoverpa armigera to pyrethroids in the world

Launched in the mid-1970s, pyrethroids were a spectacular success and were very widely used to control bollworms in the Old World. Cases of resistance were reported in *H. armigera* in Australia (Gunning *et al.* ,1984), Thailand (Collins, 1986), India (McCaffery *et al.*, 1989), Turkey (Riley, 1990), Indonesia (McCaffery and Walker, 1991) and China (Shen *et al.*, 1992). Few cotton areas are free of the problem, although West Africa has been an exception for over 10 years (Alaux *et al.*, 1997).

The mechanisms involved in resistance to pyrethroids

The two most frequently encountered mechanisms are nerve insensitivity (related to the *kdr* gene) and metabolic detoxification involving oxidases (Gunning *et al.*, 1993; McCaffery, 1994). Resistance to the knock down effect results usually in a moderate loss of susceptibility. Metabolic resistance can be demonstrated by the use of synergists (piperonyl butoxide for oxidases and DEF for esterases) and esterases in Australia (Gunning, 1994), India (Armes *et al.*, 1994) and China (Tan *et al.*, 1997) and generally leads to much higher levels of resistance. Dubbeldam and McCaffery (1996) showed that resistance, at least the type associated with modification of the target sites, has a high cost. This lack of competitiveness of *kdr* individuals may explain why their frequency has decreased in Australia.

Results of laboratory monitoring in West Africa

Following the first bioassays in Chad (Renou and Vaissayre, 1978), CIRAD proposed in 1984 that a network be set up in West and Central Africa to monitor the susceptibility to pyrethroids of the main cotton pests, with *H. armigera* among the leading species. Several countries have participated in the network in a more or less sustained manner. This monitoring is a basic component of any programme for the prevention of resistance (Roush, 1990).

The topical application method is used, in which the active substances are diluted in acetone and 1 µl of the product per 50 mg larva is applied. Statistical analysis of the results is performed using the log-probit method

(Finney, 1971). The CIRAD Montpellier laboratory maintains a strain of *H. armigera* from Côte d'Ivoire collected in 1977. This strain has never been exposed to pyrethroids and is considered here as the reference strain. The results shown in Table 1 were obtained in Benin, Burkina Faso, Côte d'Ivoire and Chad. Values of LD_{50} (in µg/g) and corresponding regression lines are shown.

The figures indicate that the populations subjected to successive tests, are at first increasingly heterogeneous, with an increasing fraction of the *H. armigera* population escaping the effect of pyrethroids. When the resistance mechanism is established in the entire population, the slope of the regression becomes steeper. LD_{50} values as high as those obtained this year for the population at Angaradébou (Benin) could lead to control failure in the fields.

Field observations

Cases of the ineffectiveness of the *H. armigera* control programme have been reported in Burkina Faso, where the infestation in 1996 was particularly spectacular, in Mali (Koutiala region), in Benin and in northern Côte d'Ivoire.

During exceptional pest outbreaks, farmers have complained about the formulations distributed to them. However, other possible factors may be questionable application, the rain that may have followed spraying or under-dosage—a practice that has become widespread in farmers' calendar programmes. The presence of brokers during bidding for supplies and the subsequent decrease in product quality (with regard to both the active substance and the formulation) contribute to the negative image of pesticides among African cotton growers.

This is partly the after-effect of an excessively strict official policy with regard to inputs, putting the cost of cotton crop protection at less than the equivalent of 100 kg seed cotton per hectare, which is much less than the figures observed outside francophone Africa. The demonstration of loss of susceptibility or of real resistance of *H. armigera* to pyrethroids would make this policy of cost minimization obsolete.

Laboratory studies

Two types of study were undertaken in Côte d'Ivoire :
- monitoring of the LD_{50} of *H. armigera* during the season,
- study of the addition of synergists with regard to pyrethroid toxicity.

Monitoring of the susceptibility of the successive generations

The first study was performed by Alaux (1994) on deltamethrin, applied to *H. armigera* populations collected on cotton at Bouaké from September to December 1992. No significant changes in LD_{50} were detected. A similar study was performed from September to November 1997. The results are shown in Table 2. No significant change was observed in the LD_{50} but the successive slopes indicated selection within the population, probably by the elimination of susceptible individuals.

The effect of different synergists

In order to identify the mechanism/s involved in resistance, two synergists were combined with pyrethroids. These were piperonyl butoxide (Pbo), an oxidase inhibitor, and S,S,S-tributylphosphorotrithioate (DEF), an inhibitor of a number of esterase resistance mechanisms. They were used at a concentration of 0.02 g/l and applied at 1 µl per larva before the insecticide.

Several *H. armigera* strains were tested with and without synergists. A coefficient of synergism (CS) was calculated as the ratio LD_{50} without inhibitor to LD_{50} with inhibitor. The following insect strains were used:

- Bk 77: control strain from Bouaké kept in the CIRAD laboratory in Montpellier.
- Bk 96: a strain collected at the IDESSA station at Bouaké in October 1996, and subjected to selection pressure (deltamethrin) for 4 successive generations.
- Bk 97: a strain collected at the IDESSA station at Bouaké in October 1997.
- Nb 97: a strain collected under on-farm conditions some 250 km north of Bouaké in September 1997.

The main results with deltamethrin, Pbo or DEF show three kinds of situation (Tables 3 and 4):

- in the strain collected under on-farm conditions (Nb 97), the Pbo reduced the LD_{50} compared to that of the control. An MFO mechanism, rather than target modification (kdr type), is probably responsible for the loss of susceptibility under on-farm conditions. This result is in agreement with that obtained at the CIRAD laboratory in Montpellier on a strain collected in Benin, considered to be resistant to pyrethroids and in which there was no detectable resistance to DDT.

- in the strain collected in Bouaké in 1997, DEF had a minimal effect and the LD_{50} remained 20 times as high as that of the control. In contrast, Pbo reduced the LD_{50} at a ratio of 1:3 but it was still 10 times higher than that of the control. This strain would therefore seem to display both a *kdr* mechanism responsible for a first level of loss of susceptibility (with a factor of 10 for deltamethrin) and an oxidase system responsible for a further factor of 3.

- in the strain collected in Bouaké in 1996, on which selection pressure was continued in the laboratory, both the synergists had a much more marked

effect (with a CS of 7 to 10); this was added to the *kdr* mechanism.

Discussion

Protection of cotton in francophone Africa, as in the rest of the world, is based on pesticide application. However, in Africa, perhaps more than elsewhere, protection includes numerous non-chemical components (cultural practices and varietal characters of resistance) and the use of pesticides is moderate and above all controlled by the cotton companies. One might think that Africa is sheltered from problems of resistance to pyrethroids of the types experienced by large cotton-producing countries like Australia, India and China. Laboratory results and the repeated failures observed in some production zones show that the populations are evolving resistance. The establishment of improved preventive methods is necessary. This should include the exclusion of pyrethroids used alone, the use of the windows and spraying only when threshold levels are exceeded. The effect of these measures will depend on the results of the studies undertaken to determine the geographical extent of pyrethroid-resistant *H. armigera* populations and the scale of gene exchange between separate populations.

It is clear that as the pest concerned is polyphagous, measures taken in cotton alone cannot control all the problem. Preventive measures taken by cotton growers should be applied to other crops, especially vegetable crops, where large amounts of pesticides are used. This falls within the orbit of the National Plant Protection Services, commissioned to work together to define the registration and control measures needed for rationalized management of pesticides in West Africa.

Alternatives to chemical control, and especially varietal resistance characters, are now increasing in importance. However, they currently feature more in publications than in the field. It is important that the research sector should reactivate programmes on the subject.

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Table 1. LD50 and slopes obtained for *H. armigera.*

Active Ingredient	Country/year	LD_{50}	Slope
deltamethrin	France		
	1992	0.07	1.7
	Chad		
	1978	0.06	
	1991	0.07	1.2
	Burkina		
	1991	2.77	1.4
	1992	6.56	2.2
	Côte d'Ivoire		
	1986	0.14	1.1
	1994	0.09	0.7
	1995	0.13	0.7
	1996	0.92	1.3
	1997	1.33	1.2
cypermethrin	France		
	1992	0.47	3.0
	Côte d'Ivoire		
	1989	0.55	1.6
	1994	0.76	1.1
	1995	2.59	0.7
	1996	5.05	1.5
	1997	2.73	1.1
	Bénin		
	1997		
		25.6	3.0
fenvalerate	France		
	1992	0.14	3.2
	Tchad		
	1978	0.54	1.7
	Côte d'Ivoire		
	1992	0.28	0.9
	1996	10.41	1.3

Table 2 . DL50 observed with deltamethrin on successive generations.

Generations	LD_{50}	confidence interval	slope
September	0.92	0.54_1.55	0.91
October	1.33	0.89_1.99	1.10
November	1.34	0.89_2.02	1.39

Table 3 . Bioassays with Pbo.

Strains	LD_{50} deltamethrin	LD_{50} with Pbo	Synerg. Coeff.
control (Bk 77)	0.049	0.045	1.1
Bk 96 lab. Strain	2.26	0.229	10
Bk 97 field strain	1.33	0.430	3
Nb 97 field strain	0.89	0.047	19

Table 4 . Bioassays with DEF.

Strains	LD_{50} deltamethrin	LD_{50} with Def	Synerg. Coeff.
control (Bk 77)	0.049	0.045	1.1
Bk 96 lab. Strain	2.26	0.320	7
Bk 97 field strain	1.66	0.860	1.5
Nb 97 field strain	*	*	

*Insufficient number of insects for testing Def on Nb 97 strain.