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Pesticide resistance of Tetranychus cinnabarinus (Acari: Tetranychidae) in China: a review

FENGYING GUO[1], ZHI-QIANG ZHANG[2] & ZHIMO ZHAO[1]
[1] *Department of Plant Protection, Southwest Agricultural University, Chongqing 400716, China*
[2] *CABI BIOSCIENCE, UK Centre (Silwood Park), Ascot, Berkshire SL5 7TA, UK*

Abstract

This paper reviews the development of pesticide resistance in *Tetranychus cinnabarinus* (Boisduval) and studies on the genetics and management of pesticide resistance in China. This mite has developed resistance to at least 25 pesticides in China. It first developed resistance to parathion and demeton. As early as 1962, the level of resistance to demeton in *T. cinnabarinus* reached 62 times, which resulted in control failure of this mite on cotton in most cotton growing areas in China. The genetics of omethoate-resistance and monocrotophos-resistance in *T. cinnabarinus* is each controlled by an incompletely dominant gene and the development of resistance is therefore rapid. The developmental time and other life table parameters of *T. cinnabarinus* are altered when the mite becomes pesticide-resistant: life cycle becomes shorter and reproductive rate becomes greater. This is another reason for the rapid development of pesticide resistance in *T. cinnabarinus*. Pesticide resistance may be managed by rotational use of pesticides, biological control and other methods.

Key words: *Tetranychus cinnabarinus*, pesticide resistance, China

Introduction

Of more than 130 species of spider mites known in China, *Tetranychus cinnabarinus* (Boisduval) is the major pest species on agricultural crops. For many years, the control of this mite in China has traditionally replied on sprays of pesticides. Since the 1980s, pesticide resistance level in *T. cinnabarinus* has increased rapidly (Wu *et al*. 1990). As a result, the efficacy of many pesticides has been reduced and the cost of chemical control has increased. Farmers responded to this by increasing the dosage and frequency of sprays, but this irrational use of pesticides only speeded up the development of pesticide resistance in *T. cinnabarinus*. During the 1980s and 1990s, scientists in China became aware of this problem and have done some research on the management of pesticide resistance in this species. The concerned departments (*e.g*. Plant Protection) of each province also began to work on monitoring and management of pesticide resistance in major pests. As a result, the development of pesticide resistance in *T. cinnabarinus* and other pests has been slowed and brought under control to some extent.

History of pesticide resistance

Before the 1950s, pest control in China was not strongly dependent on chemical pesticides. Many pesticides were very effective during this period. From 1957, parathion and demeton were used for cotton pest control in China. By 1962, *T. cinnabarinus* resistance to demeton had increased 62 times in Hubei (Cao *et al*. 1993). During the mid-1960s, parathion and demeton were continuously used to control cotton pests in Shandong, Hunan, Hubei, Liaoning and other provinces and pesticide resistance developed there. In Hubei, for example, sprays of diluted solution at 10000 times of parathion and demeton achieved 100% mortality of *T. cinnabarinus* on cotton in 1957, but sprays of diluted solution at 500 times of marathion killed only 66.2% of spider mites in 1963 (Zhang & Wang 1964). During this period, the seriousness of pesticide resistance was not fully appreciated; there was no management of pesticide resistance and *T. cinnabarinus* developed resistance to organophosphorous pesticides. During the 1960s and 1970s, organochlorine pesticides remained effective, although organophosphorous pesticides were no longer effective (Zhang & Wang 1964). In the 1980s, *T. cinnabarinus* developed resistance to many organophosphorus pesticides such as parathion-methyl, monocrotophos, parathion, phosphamidon and omethoate; resistance to parathion, for example, increased 466.8-fold (Wu *et al*. 1990). During this period, *T. cinnabarinus* also developed resistance to organochlorine pesticides and levels of resistance were on the increase. In 1986, the level of dicofol resistance was 6.7-fold for spider mites on cotton in Henan province, but cyhexalin and hexythiazox were still effective against spider mites. Since the 1990s, pesticide resistance in spider mites and other pests has been under control because the problem has received adequate attention from state and provincial governments and programmes of monitoring and management of pesticide resistance have been implemented. For example, from 1986 to 1992, mite resistance to dicofol increased from 5.3~6.7 to 8.6~15.8-fold and that to omethoate changed from 9.2~11.3 to 19.2~28.5-fold (Wu & Liu 1995).

Pesticides to which T. cinnabarinus has developed resistance

Tetranychus cinnabarinus infests over 100 host plants, among which are crops such as cotton, tobacco, maize and legumes. Cotton is sprayed more often than other crops and this increases the exposure of spider mites on cotton to pesticides. Because of their short life cycle and high reproductive rates, spider mites develop resistance faster than most insects. Spider mites therefore could become resistant to many pesticides soon after they were used. Based on a survey of published reports in China, *T. cinnabarinus* has developed at least some levels of resistance to 18 different pesticides in China. Because of the variation in the methods of cultivation in different regions of China, the degree of pest occurrence and level of pest control also vary greatly, so is variation in the level of resistance of *T. cinnabarinus* to various pesticides. Table 1 lists the toxicity of 16 pesticides to resistant and susceptible *T. cinnabarinus* and levels of mite resistance to these pesticides.

Like many other insect and mite pests, *T. cinnabarinus* can develop cross-resistance to other pesticides when it has developed resistance to one pesticide. Wu and Liu (1994a) tested the susceptibility of monocrotophos-resistant *T. cinnabarinus* (index of resistance = 161.5 times) to 15 pesticides during 1991-1992. They showed that the toxicity of isofenphos-methyl, malathion, hexithiazox and dicofol was low, that of parathion-methyl, methamedophos, phoxim and others medium and that of dichlorvos, fenpropathrin and cyhalothrin high, indicating that these monocrotophos-resistant mites developed cross-resistance to isofenphos-methyl, malathion, hexithiazox and dicofol.

Genetics of pesticide resistance

Genetics of omethoate-resistance (index of resistance 161.5 times) and monocrotophos-resistance (index 369) in *T. cinnabarinus* was analyzed by Wu and Liu (1994a, b), who showed that both were controlled by an incomplete dominant gene with a lack of notable maternal effects. LC_{50} of F_1 from SR-cross and RS-cross were 164.1 and 163.5 ppm, respectively, for omethoate-resistant mites, and 621.0 ppm and 617.7 ppm, respectively, for monocrotophos-resistant mites. These values were intermediate between LC_{50} values of resistant strains (omethoate-resistant strain: 357.8 ppm; monocrotophos-resistant strain: 1884.6 ppm) and susceptible strains (omethoate-resistant strain: 9.7 ppm; monocrotophos-resistant strain: 11.7 ppm) and skewed toward LC_{50} values of resistant strains. Dominant indices of heterozygote F_1: D_{SR} = 0.5679 and D_{RS} = 0.5659 for omethoate-resistant strain and D_{SR} = 0.5634 and D_{RS} = 0.510 for monocrotophos-resistant strain. Wu and Liu (1994a,b) further showed via tests on F_2 from crosses between heterozygote F_1 and parents that resistance to the two pesticides was monogenic in *T. cinnabarinus*.

TABLE 1. Toxicity of 16 pesticides to *Tetranychus cinnabarinus* and levels of resistance in China.

Pesticides	LC_{50} (ppm) S*	LC_{50} (ppm) R*	Index of resistance to pesticides**	Year	Locality
Demeton	1.1	65.6	62.5	1962	Mianyang, Hebei
Parathion	5.2	2427.2	466.8	1986	Xinxiang, Henan
Phosphamidon	28.6	1213.1	42.2	1986	Xinxiang, Henan
Monocrotophos	16.8	338.8	20.2	1986	Xinxiang, Henan
Malathion	168.1	2740.9	16.3	1986	Xinxiang, Henan
Isocarbophos	42.9	369.9	8.6	1986	Xinxiang, Henan
Phosmet	143.7	764.7	5.3	1986	Xinxiang, Henan
Dichlorvos	3.7	10.8	2.9	1986	Xinxiang, Henan
Omethoate	6.7	109.1	11.3	1986	Xinxiang, Henan
		129.3	13.3	1987	Xinxiang, Henan
		134.7	13.9	1987	Xinxiang, Henan
		225.2	23.2	1988	Xinxiang, Henan
		247.3	25.5	1989	Xinxiang, Henan
		262.6	27.1	1990	Xinxiang, Henan
		265.6	27.4	1990	Zhengzhou, Henan
		224.2	23.1	1991	Zhengzhou, Henan
		328.6	33.9	1992	Zhengzhou, Henan
Cypermethrin	58.3	557.2	9.6	1986	Xinxiang, Henan
Fenvalerate	94.4	557.0	6.1	1986	Xinxiang, Henan
Deltamelthrin	25.2	117.0	4.7	1986	Xinxiang, Henan
Cyfluthrin	15.8	35.7	2.3	1986	Xinxiang, Henan
Fenpropathrin	81.9	106.7	1.3	1986	Xinxiang, Henan
Cyhexatin	130.6	185.6	1.4	1986	Xinxiang, Henan
Dicofol	18.2	120.9	6.6	1986	Xinxiang, Henan
		152.7	8.4	1986	Xinxiang, Henan
		100.7	5.5	1987	Zhengzhou, Henan
		144.2	7.9	1988	Zhengzhou, Henan
		220.6	12.1	1989	Zhengzhou, Henan
		247.4	13.6	1990	Zhengzhou, Henan
		243.8	18.9	1996	Zhengzhou, Henan
		328.2	18.0	1992	Zhengzhou, Henan

* S = susceptible strain of *T. cinnabarinus*; R = resistant strain of *T. cinnabarinus*.
** LC_{50} of R / LC_{50} of S.

Biology of pesticide-resistant mites

Developmental time and other life table parameters might be altered when *T. cinnabarinus* developed resistance to some pesticides (Gao *et al.* 1991). Three sprays of deltamethrin, omethoate, chlodimeform and dicofol resulted in 6.2, 1.2, 1.2 and 2.3-fold increases in the resistance of *T. cinnabarinus* to these pesticides respectively and accelerated the development of all immature stages of selected mites. At the extreme, the life cycle of deltamethrin-sprayed mites was reduced by 4.3-9.4 days. Deltamethrin-selected and omethoate-selected mites both had higher net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ) and general reproductive rate (GRR) than control mites. These parameters of chlodimeform-selected mites were, however, lower than those of control. Main parameters (r_m and λ) of dicofol-selected mites were not different from those of the control.

Biochemical mechanism of pesticide resistance

The change in the activity of esterase and a drop in target site susceptibility are key biochemical mechanisms of development of pesticide resistance in the Tetranychidae. For example, after *T. urticae* (Koch) developed resistance to organophosphrus pesticide, its activity of carboxylesterae was 20% lower than that of susceptible mites, so was the activity of acetylcholinesterase (Anonymous 1990). Guo *et al.* (1996, 1997a, b) studied the optimal conditions for assaying the activities of carboxylesterase, phosphatases (acid and alkaline) and glutathione-s-aromatic groups transferase, and the role of these enzymes in pesticide resistance in *T. cinnabarinus*. These studies laid a solid foundation for further studies on the biochemical mechanisms of pesticide resistance in *T. cinnabarinus* and other spider mites.

Management of pesticide resistance

Resistance to one or more pesticides has been reported for 27 insect and mites pests in China (Wang & Han 1991). The problem of pesticide resistance in *T. cinnabarinus* is of intermediate seriousness among these 27 pests. In China, the following measures have been taken to manage the pesticide resistance in *T. cinnabarinus*: (1) the use of highly effective pesticides at an early stage to control mite populations at isolated loci, (2) the use of selective pesticides to conserve natural enemies and to maximize their role in natural pest control, and (3) the rotational use of different pesticides. The rotation of different highly effective acaricides was an effective method for postponing the development of pesticide resistance in *T. cinnabarinus*. Gao *et al.* (1991) showed that the susceptibility of F_2 deltamethrin-resistant mites was doubled when they were sprayed by rotating omethoate, dicofol and deltamethrin, as compared with continuous use of deltamethrin. To manage the development of pesticide resistance, the rotation of different pesticides needs to be applied over a long period of time.

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