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Original Article

Resistance of *Aphis gossypii* (Homoptera: Aphididae) to selected insecticides on cotton from five cotton production regions in Shandong, China

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Resistance of cotton aphid (*Aphis gossypii* Glover) collected from four leading cotton producing regions and one non-cotton producing region in Shandong Province, China, in 1985, 1999, and 2004 to fenvalerate, omethoate, imidacloprid, acetamiprid, carbosulfan, and endosulfan, was determined on cotton (*Gossypium hirsutum* L.). Dose-response results indicate that *A. gossypii* became highly resistant to fenvalerate, and the resistance ratios (RRs) increased from 30–370-fold in 1985 to 370–2150-fold from different regions as compared with the susceptible population (S). *A. gossypii* also exhibited strong resistance to imidacloprid and acetamiprid with RRs of 17- to 97-fold in 2004. Resistance of *A. gossypii* to omethoate varied greatly among the five geographical regions, and the RRs ranged from 5- to 80-fold. In contrast, the resistance to carbosulfan did not significantly increase from 1999 to 2004 in all regions. The information from this study would be helpful for management of *A. gossypii* on cotton in those regions. ©Pesticide Science Society of Japan

Keywords: *Aphis gossypii*, cotton, insecticide resistance, resistance management.

Introduction

Resistance of cotton aphid (*Aphis gossypii* Glover) to organophosphate insecticides was first reported in 1964.[1] Subsequently, resistance to carbamates and pyrethroids was reported.[2,3] Shandong Province has a long history of cotton production, and is also one of the major cotton production regions in China. In 1998, the total yield of cotton was 413,000 tons, the fifth among all provinces in China. *A. gossypii* is one of the most important pests of cotton, numerous field crops, and vegetables.[4,5]

Numerous chemical insecticides have been used to manage *A. gossypii*, and consequently, the aphid has developed resistance to numerous insecticides. Gong *et al*.[1] reported that *A. gossypii* became resistant to organophosphates. Since then numerous studies have been confirmed that *A. gossypii* became resistant to organophosphates,[6,7] carbamates,[7] and pyrethroid insecticides.[6,8–13] In the early 1980s, highly effective pyrethroid insecticides such as deltamethrin and fenvalerate were imported into China. When first used, 2.5% deltamethrin emulsion was diluted in ratios from 1 : 10,000 to 1 : 12,000. However, the resistance ratio (RR) of *A. gossypii* to pyrethroids increased by 171-fold in general, 3230-fold in some cotton fields in 1985.[10] *A. gossypii* has also become resistant to fenvalerate at high and extremely high levels in several other countries.[10,12,14–21]

After having studied *A. gossypii* resistance to numerous insecticides in Australia, Herron *et al*.[15–17] predicted that resistant *A. gossypii* have the potential to seriously impact the Australian cotton industry and their resistance management is now incorporated into the resistance management strategy for Australian cotton. In the past few years, neonicotinoid insecticides have been gradually used to control *A. gossypii* and other piercing-sucking pest insects in China. Of the neonicotinoids, imidacloprid and acetamiprid have offered excellent control of aphids, whiteflies, and other insects.[20,22] These compounds attack the nervous system of insects and cause the insects to stop feeding. Resistance of *A. gossypii* to imidacloprid has been documented in China[12] and elsewhere,[22]

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whereas there is no documented information on resistance of *A. gossypii* to acetamiprid on cotton.

Although *A. gossypii* resistance to numerous insecticides has been detected in Shandong,[11–13,20,23] there is no direct comparison of the resistance of *A. gossypii* from all five leading cotton-producing regions in the province. The objectives of this study were to generate baseline data for field-collected strains of *A. gossypii* and to determine their resistance to the six commonly used insecticides, acetamiprid, imidacloprid, endosulfan, omethoate, carbosulfan and fenvalerate in all leading cotton producing regions in Shandong, China.

Materials and Methods

1. *Aphis gossypii*

Susceptible population. The susceptible population of *A. gossypii* was originally collected from hibiscus (*Hibiscus rosa-sinensis* L.) in 1992 from Taian, Shandong, China, and has since been reared on cotton (*Gossypium hirsutum* L.) in a greenhouse without exposure to insecticides. This colony of aphids was susceptible to all insecticides,[12,13] and was considered a susceptible strain (S strain).

Field populations. Five populations of *A. gossypii* were collected from four cotton-producing regions, Binzhou (Nanjiao area), Dezhou (Dongjiao area, Xiajin County), Liaocheng (Xijiao area) and Heze (Bole area, Chengwu County) (Fig. 1). Various insecticides have been extensively used in those regions, and traditionally, *A. gossypii* exhibited greater resistance to numerous insecticides.[12,23] Another *A. gossypii* population was collected from Taian, a non-leading cotton producing region (the Experimental Farm of Shandong Agricultural University) in Shandong.

2. *Insecticides*

Six commonly used insecticides were used in this study: fenvalerate (95% active ingredient [AI], Jiangsu Jintan Hormone Research Institute, Jiangsu, China); omethoate (76.4% AI, Shandong Agricultural Chemical Industry Company Ltd., Jinan, Shandong, China), endosulfan (99% AI, Dow AgroSciences, Indianapolis, IN, USA), imidacloprid (95% AI, Changlong Chemical Engineering Inc., Changzhou, Jiangsu, China), acetamiprid (95.8% AI; Haizheng Insecticide Inc., Haizheng, Zhejiang, China), and carbosulfan (91% AI; Shandong Vicome Lunan Pesticide Co. Ltd., Linyi, Shandong, China).

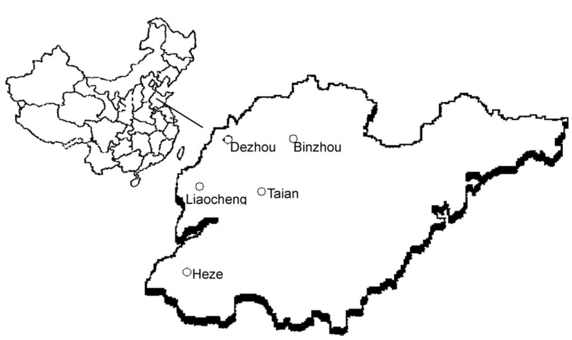

Fig. 1. Leading cotton-producing regions in Shandong Province, China, where cotton aphid, *Aphis gossypii*, were collected and tested.

3. *Bioassays*

A capillary topping bioassay method developed by Zhang[24] was used to expose aphids to insecticides. In brief, a section of a metal capillary tube that held an average of 0.042 μl liquid, as determined previously, was attached on the tapering end of a glass eyedropper, and a small hole ($\approx$0.5 mm in diameter) was made in the rubber bulb at the top to create a capillary action. Insecticides were diluted with acetone, and acetone alone was used as control. Seven or more concentrations were used for each insecticide. A droplet of diluted insecticide or acetone from a capillary tube was dropped onto the dorsal surface of each adult aphid. Sixty to 100 aphids from each population were treated and placed on three to five small cotton plants (3–4 true leaves and 10–15 cm high) for each replication, and each treatment had four replications. The plants with treated aphids were maintained in growth chambers at 27$\pm$2°C, 70–80% RH, and a photoperiod of 14 : 10 (L : D) hr. Aphids were examined for mortality at 24 hr after treatment. The aphids were considered dead if their appendages were motionless after being touched with a small brush.

4. *Data analysis*

Percentage of *A. gossypii* mortality on each host plant and insecticide were corrected using Abbott's formula,[25] and the corrected percentages of mortality were used to compute LD_{50} values and associated parameters.[26] Failure of 95% fiducial limits (FL) to overlap was used as the criteria for identifying significant differences among LD_{50} values for aphid population from different regions.

Results

1. *Resistance to fenvalerate*

Aphis gossypii had already become resistant to fenvalerate in 1985 with RRs (resistance ratios) from 215- to 370-fold in the four major cotton production regions as compared with the S (susceptible) population (Tables 1 and 2). The resistance of *A. gossypii* varied greatly among or between the years, and among the five regions. The aphids in Binzhou had the highest RRs among the regions all three years, ranging from 310-fold in 1985, 990-fold in 1999 and to 1100-fold in 2004. The aphid population from Heze became highly resistant to fenvalerate, and RRs ranged from 204-fold in 1985, increased to 990-fold in 1999, and to 2150 in 2004. Similarly, the aphid populations from Liaocheng and Dezhou also became highly resistant to fenvalerate from 1985, RRs were 370- and 215-fold, respectively, and increased to 407- and 523-fold in 1999. However, the resistance level of the aphid populations from Liaocheng remained at similar levels in 2004 to that in 1999. The aphid population from Dezhou increased from 215-fold

Table 1. Comparison of resistance of *Aphis gossypii* to six insecticides in five major cotton planting areas of Shandong, China in 1985, 1999 and 2004

Insecticide	Population	1985			1999			2004		
		Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a)]	Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a)]	Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a)]
fenvalerate	Binzhou	9.19+1.81x	4.87×10^{-3}	$10^{-3}\times$(3.66-6.48)a	6.42+1.87x	1.70×10^{-2}	$10^{-2}\times$(1.40–2.20)a	6.10+1.50x	1.80×10^{-2}	$10^{-2}\times$(1.40–2.50)b
	Heze	10.14+2.12x	3.20×10^{-3}	$10^{-3}\times$(2.77–5.00)a	6.35+1.74x	1.70×10^{-2}	$10^{-2}\times$(1.30–2.20)a	5.70+1.54x	3.50×10^{-2}	$10^{-2}\times$(2.60–4.70)a
	Liaocheng	9.12+1.85x	5.80×10^{-3}	$10^{-3}\times$(4.44–7.58)a	7.23+1.90x	7.00×10^{-3}	$10^{-3}\times$(5.00–9.00)b	6.56+1.37x	7.00×10^{-3}	$10^{-3}\times$(5.00–10.0)c
	Dezhou	9.33+1.75x	3.37×10^{-3}	$10^{-3}\times$(2.56–4.44)a	6.88+1.82x	9/00$\times10^{-3}$	$10^{-3}\times$(7.00–12.0)b	6.40+1.44x	1.10×10^{-2}	$10^{-3}\times$(8.00–15.0)bc
	Taian	9.58+1.39x	4.72×10^{-4}	$10^{-4}\times$(3.50–6.36)b	8.01+1.79x	2.00×10^{-3}	$10^{-3}\times$(2.00–3.00)c	6.77+1.48x	6.00×10^{-3}	$10^{-3}\times$(5.00–9.00)c
	Susceptible	12.79+1.62x	1.57×10^{-5}	$10^{-5}\times$(1.19–2.07)c	12.5+1.58x	1.72×10^{-5}	$10^{-5}\times$(1.29–2.29)d	12.69+1.61x	1.63×10^{-5}	$10^{-5}\times$(1.23–2.16)d
omethoate	Binzhou	8.00+1.92x	2.75×10^{-2}	$10^{-2}\times$(2.17–3.48)ab	7.18+1.75x	5.73×10^{-2}	$10^{-2}\times$(4.43–7.41)ab	7.17+1.84x	6.62×10^{-2}	$10^{-2}\times$(5.17–8.47)a
	Heze	8.28+1.90x	1.88×10^{-2}	$10^{-2}\times$(1.48–2.38)b	7.05+1.78x	7.04×10^{-2}	$10^{-2}\times$(5.74–9.07)a	6.55+1.47x	8.76×10^{-2}	$10^{-2}\times$(6.45–11.9)a
	Liaocheng	7.54+1.68x	3.05×10^{-2}	$10^{-2}\times$(2.33–3.99)a	7.71+1.93x	3.96×10^{-2}	$10^{-2}\times$(3.14–5.00)b	7.35+1.87x	5.54×10^{-2}	$10^{-2}\times$(4.35–7.06)a
	Dezhou	7.85+1.90x	3.16×10^{-2}	$10^{-2}\times$(2.49–4.01)a	7.06+1.80x	7.22×10^{-2}	$10^{-2}\times$(5.62–9.28)a	7.16+1.97x	8.02×10^{-2}	$10^{-2}\times$(6.39–10.1)a
	Taian	8.51+1.48x	4.22×10^{-3}	$10^{-3}\times$(3.11–5.73)c	10.1+2.51x	9.53×10^{-3}	$10^{-3}\times$(7.96–11.4)c	8.39+1.74x	1.13×10^{-2}	$10^{-3}\times$(8.70–15.0)b
	Susceptible	11.2+2.03x	8.40×10^{-4}	$10^{-3}\times$(0.67–1.05)d	10.6+1.92x	1.23×10^{-3}	$10^{-4}\times$(9.70–15.6)d	11.2+2.09x	1.10×10^{-3}	$10^{-3}\times$(8.90–13.7)c
imidacloprid	Binzhou				13.2+1.98x	6.73×10^{-5}	$10^{-5}\times$(5.34–8.47)a	8.12+1.23x	2.83×10^{-3}	$10^{-3}\times$(1.96–4.09)a
	Heze				13.5+2.05x	7.35×10^{-5}	$10^{-5}\times$(5.90–9.16)a	8.07+1.20x	2.78×10^{-3}	$10^{-3}\times$(1.91–4.05)a
	Liaocheng				13.3+2.03x	7.81×10^{-5}	$10^{-5}\times$(6.25–9.76)a	9.04+1.53x	2.32×10^{-3}	$10^{-3}\times$(1.73–3.12)a
	Dezhou				13.1+1.93x	6.77×10^{-5}	$10^{-5}\times$(5.36–8.55)a	8.22+1.22x	2.25×10^{-3}	$10^{-3}\times$(1.73–2.26)a
	Taian				12.9+1.80x	3.84×10^{-5}	$10^{-5}\times$(2.99–4.93)b	8.93+1.34x	1.15×10^{-3}	$10^{-4}\times$(8.20–16.1)b
	Susceptible				15.2+2.22x	2.60×10^{-5}	$10^{-5}\times$(2.12–3.18)b	14.2+2.04x	2.91×10^{-5}	$10^{-5}\times$(2.33–3.63)c
acetamiprid	Binzhou				10.8+1.75x	4.78×10^{-4}	$10^{-4}\times$(3.69–6.18)a	8.23+1.48x	6.52×10^{-3}	$10^{-3}\times$(4.80–8.86)b
	Heze				10.7+1.73x	5.33×10^{-4}	$10^{-4}\times$(4.11–6.92)a	8.59+1.80x	1.02×10^{-2}	$10^{-3}\times$(7.94–13.1)ab
	Liaocheng				11.0+1.80x	5.45×10^{-4}	$10^{-4}\times$(3.50–5.78)a	8.69+1.62x	5.22×10^{-3}	$10^{-3}\times$(3.95–6.70)bc
	Dezhou				9.97+1.52x	5.40×10^{-4}	$10^{-4}\times$(4.01–7.27)a	7.25+1.22x	1.45×10^{-2}	$10^{-2}\times$(1.01–2.10)a
	Taian				11.9+1.89x	2.07×10^{-4}	$10^{-4}\times$(1.62–2.63)b	9.17+1.68x	3.34×10^{-3}	$10^{-3}\times$(2.56–4.36)c
	Susceptible				13.7+2.31x	1.75×10^{-4}	$10^{-4}\times$(1.44–2.13)b	13.2+2.2x	1.91×10^{-4}	$10^{-4}\times$(1.56–2.34)d
carbosulfan	Binzhou				9.05+1.93x	8.04×10^{-3}	$10^{-3}\times$(6.36–10.2)a	8.73+1.84x	9.39×10^{-3}	$10^{-3}\times$(7.34–12.0)a
	Heze				9.77+2.02x	4.33×10^{-3}	$10^{-3}\times$(3.46–5.41)b	8.85+1.68x	5.14×10^{-3}	$10^{-3}\times$(3.93–6.73)b
	Liaocheng				8.81+1.82x	8.17×10^{-3}	$10^{-3}\times$(6.38–10.5)a	8.10+1.52x	9.27×10^{-3}	$10^{-3}\times$(6.89–12.5)a
	Dezho				9.26+1.98x	6.96×10^{-3}	$10^{-3}\times$(5.54–8.75)a	8.76+1.76x	7.38×10^{-3}	$10^{-3}\times$(5.72–9.53)ab

Table 1. Continued

Insecticide	Population	1985			1999			2004		
		Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a]	Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a]	Regression equation	LD_{50} $\mu g \cdot aphid^{-1}$	95% FL[a]
	Taian				10.7+1.90x	1.08×10^{-3}	$10^{-4}\times$(8.52–13.7)c	10.76+1.98x	1.22×10^{-3}	$10^{-4}\times$(9.70–15.3)c
	Susceptible				11.9+1.90x	2.40×10^{-4}	$10^{-4}\times$(1.89–3.04)d	12.20+1.95x	2.06×10^{-4}	$10^{-4}\times$(1.63–2.60)d
endosulfan	Binzhou				7.84+1.52x	1.37×10^{-2}	$10^{-2}\times$(1.02–1.84)ab	7.68+1.46x	1.52×10^{-2}	$10^{-2}\times$(1.12–2.06)a
	Heze				8.17+1.69x	1.33×10^{-2}	$10^{-2}\times$(1.02–1.74)ab	8.39+1.70x	1.02×10^{-2}	$10^{-3}\times$(9.90–13.3)a
	Liaocheng				8.03+1.58x	1.20×10^{-2}	$10^{-3}\times$(9.00–16.0)ab	7.80+1.52x	1.45×10^{-2}	$10^{-2}\times$(1.08–1.95)a
	Dezhou				7.98+1.63x	1.48×10^{-2}	$10^{-2}\times$(1.12–1.95)a	7.99+1.60x	1.36×10^{-2}	$10^{-2}\times$(1.03–1.80)a
	Taian				8.19+1.51x	7.75×10^{-3}	$10^{-3}\times$(5.75–10.4)bc	8.14+1.50x	8.20×10^{-3}	$10^{-3}\times$(6.10–11.2)ab
	Susceptible				9.95+2.32x	7.40×10^{-3}	$10^{-3}\times$(6.09–8.99)c	9.79+2.22x	6.92×10^{-3}	$10^{-3}\times$(5.64–8.48)b

[a] The same letters of the LD_{50} values of different populations to the same insecticide in the same year do not differ significantly if the 95% FL overlap among the aphid populations.

Table 2. Resistance of different populations of *Aphis gossypii* from five different regions in Shandong, China, compared with the susceptible population (S) in different years

Population	Resistance Ratio in different years[a]													
	Fenvalerate				Omethoate		Imidacloprid		Acetamiprid		Carbosulfan		Endosulfan	
	1985	1999	2004	1985	1999	2004	1999	2004	1999	2004	1999	2004	1999	2004
Binzhou	310	990	1100	33	47	60	3	97	3	34	34	46	2	2
Heze	200	990	2150	22	57	80	3	96	3	53	18	25	2	2
Liaocheng	370	410	430	36	32	50	3	80	3	27	34	45	2	2
Dezhou	215	520	675	38	60	73	3	77	3	76	29	36	2	2
Taian	30	120	370	5	8	10	1	40	1	17	5	6	1	1
Susceptible	1	1	1	1	1	1	1	1	1	1	1	1	1	1

[a] The resistance ratios were rounded to integers.

in 1985, to 523-fold in 1999, and to 675-fold in 2004. In contrast, the Taian population, RRs increased from 30-fold in 1985, to 116-fold in 1999, and to 370-fold in 2004.

2. Resistance to omethoate

Aphis gossypii had exhibited some resistance to omethoate in 1985 with RRs ranging from 22- to 38-fold in the four major cotton production regions, and 5-fold from the Taian population (Tables 1 and 2). The RRs of the aphid populations from Binzhou, Heze, and Dezhou exhibited a similar trend, and RRs changed from 47- to 60-fold in 1999, and then did not increase significantly in 2004. The resistance levels for the cotton aphid populations in Liaocheng did not increase from 1985 to 1999, but significantly increased to 50-fold in 2004. The aphid populations from Taian, however, slightly increased from 5-fold in 1985 to 8-fold in1999 and 10-fold in 2004.

3. Resistance to imidacloprid

The LD_{50} s of imidacloprid in 1999 differed significantly among the six *A. gossypii* populations (Table 1). Of those, the populations from the four major cotton production regions were not significantly different, but were slightly greater than the Taian and S populations with RR values around 3-fold. *A. gossypii* became resistant to imidacloprid in 2004, and RRs ranging from 77-fold for the Dezhou, 80-fold for the Liaocheng, 96-fold for the Heze and 97-fold for the Binzhou populations (Tables 1 and 2). The aphids from Taian also became resistant to imidacloprid, although at a lower level with a RR value around 40-fold.

4. Resistance to acetamiprid

Although the LD_{50} s of acetamiprid to *A. gossypii* from all cotton producing regions were significantly greater than those of the Taian and S populations in 1999 (Table 1), RRs were generally low (3-fold) (Table 2). However, the toxicities of *A. gossypii* from all cotton production regions increased significantly in 2004, and the RRs were as high as 76-fold for the Binzhou populations, and 17-fold for the Taian populations.

5. Resistance to carbosulfan

Aphis gossypii became moderately resistant to carbosulfan in 1999 with RRs ranging from 34-, 18-, 34-, 29-, and 5-fold for the Binzhou, Heze, Liaocheng, Dezhou, and Taian populations, respectively (Tables 1 and 2). However, RRs for the aphid populations from Binzhou, Heze, Liaocheng, and Dezhou increased to 46-, 25-, 45-, and 36-fold in 2004, respectively, whereas the RR for the Taian population did not change significantly.

6. Resistance to endosulfan

The LC_{50} s and RRs of *A. gossypii* to endosulfan were not significantly different among all five aphid populations from those cotton production regions (Tables 1 and 2).

Discussion

By ranking the resistance of *A. gossypii* collected from the five regions in Shandong Province, it clearly shows that the aphids from Binzhou and Heze had the highest resistance to all six insecticides, followed by the populations from Liaocheng and Dezhou, and the lowest for the populations from Taian which traditionally is not a major cotton production region (Tables 1 and 2). This resistance pattern was related to overall cotton production and insecticide use. Those insecticides had been used in Binzhou and Heze more extensively than in other regions.[12] In addition, those insecticides have been also extensively used on vegetables and other field crops in Binzhou and Heze, as well as Dezhou and Liaocheng. Taian is not a leading cotton and vegetable producing region, and fewer applications of those insecticides led to lower resistance by *A. gossypii*. Similar results have been reported.[27]

We have found that *A. gossypii* in all cotton production regions has become resistant to fenvalerate, and RRs were extremely high. The results were similar to those we found earlier.[12] Although applications of fenvalerate have been reduced in recent years in cotton and vegetables in those areas,[12] the resistance of *A. gossypii* to this insecticide still maintained at extremely high levels, suggesting that cross resistance with imidacloprid may contribute to the high levels of resistance.[13] We expect that resistance of *A. gossypii* to fenvalerate will be likely remaining at high levels as long as neonicotinoid insecticides are used for managing aphids, whiteflies and other piercing-sucking pest insects on cotton and vegetables in the same area.

Resistance of *A. gossypii* to the pyrethroids from the five regions to omethoate in 2004 varied greatly, and RRs were 60-, 80-, 50-, 73-, and 10-fold from Binzhou, Heze, Liaocheng, Dezhou, and Taian, respectively, because omethoate had been widely used in the four regions from the mid-1980s until the early 2000s.[12,23]

Our results clearly indicate that the populations of *A. gossypii* from Binzhou, Heze, Liaocheng, and Dezhou exhibit moderate to high levels of resistance to imidacloprid and acetamiprid with RRs from 77- to 97-fold. There are no doubts that continuous applications of these insecticides contributed to the resistance. Although acetamiprid has been only used in the cotton producing regions for a relatively short period of time, resistance to acetamiprid is likely caused by cross resistance from the imidacloprid-resistant population in the regions. Imidacloprid has been used in the cotton-producing regions for $>$10 years. Wang *et al*.[20] only detected a RR of 10-fold in 1999 in Binzhou compared with a RR of 97-fold in this study. It is evident that resistance to imidacloprid and neonicotinoids has been accelerated in recent years in those cotton-producing areas. It is expected that *A. gossypii* would become more resistant to acetamiprid if no resistance management strategies are in place to avoid using the insecticides having the same chemistry and mode of action. In addition, development of *A. gossypii* to imidacloprid and acetamiprid was slightly detected in Taian, a non-cotton production area (Tables 1 and 2). The possible explanation is that in recent years, more and more ornamentals and vegetables have been grown in Taian area under field and protected conditions, and imidacloprid and acetamiprid have been extensively used to control *A. gossypii* and other sucking insects, such as *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood). The detectable resistance to these neonicotinoids could be the results of interbreeding of insecticide resistant populations from field crops with those on the wild hosts.

In an earlier resistance selection study, Wang *et al.*[20] found that *A. gossypii* developed resistance to imidacloprid at a much slower pace than to fenvalerate. They also found that the RR to imidacloprid was 4.4-fold in one generation, but increased to 9.1-fold in another four generations. These results indicate that once *A. gossypii* became resistant to neonicotinoids, its resistance level can increase quickly. Therefore, application of neonicotinoids has to be careful and a resistance management plan has to be in place before neonicotinoids are widely used. The resistance management plan should include avoiding the continuous use of all neonicotinoids to control *A. gossypii* in the rotation programs.

Although carbosulfan has been extensively used in Shandong and other cotton production regions in China for controlling *A. gossypii* since the mid 1990s, *A. gossypii* has not become significantly resistant. Therefore, carbosulfan could be a good candidate as an alternative to imidacloprid or acetamiprid for managing aphids on cotton and other crops.

Endosulfan has been only sparingly used for management of cotton pests in those five different cotton production regions. As we expected, *A. gossypii* did not become highly resistant to endosulfan. The results also show that the differences of LD_{50} values in *A. gossypii* were not significant among the five regions. However, the R-fenvalerate strain became slightly cross-resistant to endosulfan (RR=5.8 and 7.4 on cotton and cucumber, respectively).[13] In India, the aphid became resistant to several insecticides, including endosulfan.[28]

Cross resistance must be considered before selecting alternative insecticides.[11,13] For example, the aphid that became resistant to fenvalerate, but did not show resistance to monocrotophos or omethoate, did not show cross resistance to pyrethroid, and those that became resistant to monocrotophos and pyrethroids were most susceptible to omethoate.[11] However, the increase in omethoate use in cotton is bound to be followed by the decreasing efficacy of omethoate, but perhaps increase the susceptibility of *A. gossypii* to pyrethroids. Exploitation of negative cross resistance may be a way to manage aphid resistance, but it must be done on a wide-spread area for many years.

At present, *A. gossypii* cross resistance to all pyrethroid pesticides has occurred. However, both *A. gossypii* and the bollworm, *Helicoverpa armigera* (Hübner), are most resistant to fenvalerate, a leading cotton pesticide in China. With the increasing acreages of Bt cotton in China, considerable concerns have been focusing on emerging secondary pests. There could be more aphids and other secondary insect pests in fields of Bt cotton than in conventional cotton fields. The fact is that because Bt cotton requires much less chemical pesticide than conventional cotton, these other insects, such as *B. tabaci*, an invasive pest, can survive better in Bt cotton fields. Scientifically, reduction of impact on non-target insects is actually considered one of the environmental benefits of Bt cotton. However, there is no doubt that Bt cotton cannot contribute 100% protection against cotton pests. Because secondary pests sometimes need to be controlled, farmers using Bt cotton usually use some pesticides during the growing cycle. By using Bt cotton in 2000 in Shandong Province alone, the reduction of pesticide use was 1500 tons (Wang, K.-Y., Personal commutation). It not only reduced the environmental pollution, but also reduced the rate of harmful accidents to humans and animals caused by the overuse and misuse of pesticides.

Effectively managing *A. gossypii* on cotton is a complex issue. Growers are encouraged to implement a resistance management strategy. Integrated control tactics have been recommended to suppress aphids and other pests and to manage insecticide resistance, including applying insecticides only when pests reach economic thresholds, selecting and using the most selective pesticides and avoiding pyrethroids early in the season in order to preserve natural enemies, reducing frequency of sprays of any registered aphicides, rotating insecticides, especially the ones with completely different modes of action and the ones differing from seed treatment or at planting use, using aphid resistant and tolerant varieties.[29] In addition, growers should also aim to reduce the availability of on-farm overwintering hosts, and plant 'non-host' rotation crops with cotton. Further studies will be necessary since both neonicotinoids and pyrethroids play important roles in pest management in cotton and other crop systems.

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