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Susceptibility of field populations of the diamondback moth, *Plutella xylostella*, to a selection of insecticides in Central China

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ABSTRACT

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is a globally distributed and important economic pest. Chemical control is the primary approach to regulate populations of this pest. However, resistance to insecticides evolves following heavy and frequent use. Therefore, the insecticide resistance in field populations of *P. xylostella* collected from Central China from 2013 to 2014 was determined with a leaf-dipping method. Based on the results of the monitoring, *P. xylostella* has developed high levels of resistance to beta-cypermethrin (resistance ratio = 69.76–335.76-fold), Bt (WG-001) (RR = 35.43–167.36), and chlorfluazuron (RR = 13.60–104.95) and medium levels of resistance to chlorantraniliprole (RR = 1.19–14.26), chlorfenapyr (RR = 4.22–13.44), spinosad (RR = 5.89–21.45), indoxacarb (RR = 4.01–34.45), and abamectin (RR = 23.88–95.15). By contrast, the field populations of *P. xylostella* remained susceptible to or developed low levels of resistance to diafenthiuron (RR = 1.61–8.05), spinetoram (RR = 0.88–2.35), and cyantraniliprole (RR = 0.4–2.15). Moreover, the LC_{50} values of field populations of *P. xylostella* were highly positively correlated between chlorantraniliprole and cyantraniliprole ($r = 0.88$, $P = 0.045$), chlorantraniliprole and spinosad ($r = 0.66$, $P = 0.039$), spinosad and diafenthiuron ($r = 0.57$, $P = 0.0060$), and chlorfenapyr and diafenthiuron ($r = 0.51$, $P = 0.016$). Additionally, the activities of detoxification enzymes in field populations of *P. xylostella* were significantly positively correlated with the log LC_{50} values of chlorantraniliprole and spinosad. The results of this study provide an important base for developing effective and successful strategies to manage insecticide resistance in *P. xylostella*.

1. Introduction

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is a serious pest of cruciferous vegetables worldwide [1], and the larvae cause extensive damage by feeding voraciously on foliage [2]. The annual losses from the control of *P. xylostella* were calculated at $US 1.4 billion worldwide [3]. To ensure yields of cruciferous vegetables in many countries, insecticide application targets this pest for control [3].

P. xylostella can develop resistance to insecticides rapidly, and in recent studies, *P. xylostella* developed resistance to new insecticides such as chlorantraniliprole, indoxacarb, and spinosad within two to three years [3–7]. According to the Arthropod Pesticide Resistance Database (APRD), by 2015, the diamondback moth had developed resistance to approximately 91 compounds with different modes of action, including organochlorine, organophosphorus, carbamate, pyrethroid, nereistoxin analog, benzoylurea, *Bacillus thuringiensis* (Bt), avermectin, spinosyn, phenylpyrazole, indoxacarb, diacylhydrazine, and diamide insecticides [8].

The most important aspect in the management of insecticide resistance is an understanding of the mechanisms that lead to pest resistance to insecticides. Previous reports indicated that the mechanisms of insect resistance to insecticides involved amino acid mutations of target, the over-expression or mutations of detoxification enzymes, penetration resistance and behavioral resistance [9–11]. However, the most common mechanism is metabolic resistance, with an increase in the activities of esterases, glutathione *S*-transferases, and cytochrome P450 monooxygenases [12–13]. In *P. xylostella*, elevated levels of esterase were correlated with the resistance to organophosphate, carbamate, pyrethroid, indoxacarb, avermectin, and benzoylurea insecticides [3,4,14–15], and the overexpression of glutathione *S*-transferase was responsible for the resistance to organophosphate, pyrethroid, and diamide insecticides, as well as indoxacarb [3,16–19]. Additionally, increases in the activities of cytochrome P450 monooxygenases of field-collected populations of *P. xylostella* contributed to the resistance to carbamate, pyrethroid, nereistoxin analog, and diamide insecticides [3,20–23].

To date, insecticides remain the primary approach for *P. xylostella* management, and the major groups of insecticides used for *P. xylostella* control in cruciferous vegetables in China are the diamides, avermectins,

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Fig. 1. Sample sites for *P. xylostella* in the following regions of China: 1. Luoyang, Henan Province; 2. Yichang, Hubei Province; 3. Yunmeng, Hubei Province; 4. Wuxue, Hubei Province; and 5. Yueyang, Hunan Province.

pyrethrins, and Bt [24]. With the development and spread of insecticide resistance in *P. xylostella*, the danger is that some insecticides will lose efficacy, and the resistance to insecticides in *P. xylostella* has been a major factor influencing the control and management of this pest in China. Therefore, the objective of the study was to investigate the efficacy of various insecticides, including abamectin, Bt, spinosad, spinetoram, chlorfluazuron, chlorfenapyr, diafenthiuron, indoxacarb, cyantraniliprole, chlorantraniliprole and beta-cypermethrin, against ten field populations of *P. xylostella* from the provinces of Hubei, Henan and Hunan in 2013 and 2014. Moreover, the potential cross-resistance to the insecticides frequently used against this pest was determined. Additionally, the activities of detoxification enzymes, including esterase, glutathione *S*-transferase, and cytochrome P450 monooxygenase, in the field populations of *P. xylostella* from 2013 to 2014 were determined.

2. Materials and methods

2.1. Insects

The field populations of *P. xylostella* used for the resistance monitoring in this study were collected from cabbage fields in four different geographical regions of Central China during 2013–2014 (Fig. 1, Table 1). More than 200 larvae or pupae were collected each year at each site. The collected insects were reared on cruciferous vegetables in controlled environmental conditions with a temperature of 25 ± 1 °C and a photoperiod of 16-h light/8-h dark.

2.2. Insecticides

The Institute of Plant Protection, Guangdong Academy of Agricultural Sciences in China provided seven commonly used insecticides, including abamectin (formulation, 2% EC; Trade name, avermectin; Manufacturer, Guangdong Plant Protection Technology Co. Ltd.), chlorfluazuron (5% EC; Atabron; Jiangsu Yangnong Chemical Group Co. Ltd.), chlorfenapyr (10% EC; Pirate; BASF Europe), diafenthiuron (20% EC; Polo; Guangdong Plant Protection Technology Co. Ltd.), indoxacarb (5% EC; Avaunttm; Guangdong Plant Protection Technology Co. Ltd.), beta-cypermethrin (20% EC; Fastac; Shenzhen Noposion Agrochemicals Co. Ltd.) and chlorantraniliprole (5% EC, Guangdong Plant Protection Technology Co. Ltd.). Moreover, The Du Pont Company supplied the cyantraniliprole (10% SC; Benevia; Du Pont), and the Hubei Biopesticide Engineering Research Center supplied BT WG-001 (16,000 IU/mg WP; BTV; Hubei Biopesticide Engineering Research Center). The Dow AgroSciences Company supplied the spinetoram (60 g/L SC; Ailvshi; Dow AgroSciences) and the spinosad (25 g/L SC; Laixi; Dow AgroSciences).

2.3. Bioassays

Insecticide toxicity was assayed using a leaf-dipping bioassay as described previously [25]. Leaf discs (6.5 cm diameter) were cut from young cabbage plants (*Brassica oleracea*) grown without exposure to insecticides in our greenhouse. The insecticides were serially diluted to five to seven required concentrations with distilled water containing 0.1% Triton X-100. Four leaf discs were grouped together and were dipped in insecticide solutions of different concentrations for 10 s. The

Table 1
Sample sites, collection dates and developmental stages of *P. xylostella* collected from fields of Central China.

Population	Location	Ref. map	Collection date	Geographic position	Developmental stage
LY-2013	Luoyang, Henan	1	May, 2013	34.12° N, 112.73° E	Larva and egg
LY-2014	Luoyang, Henan	1	May, 2014	34.12° N, 112.73° E	Larva and egg
YC-2013	Yichang, Hubei	2	May, 2013	30.50° N, 111.53° E	Larva and egg
YC-2014	Yichang, Hubei	2	May, 2014	30.50° N, 111.53° E	Larva and egg
YM-2013	Yunmeng, Hubei	3	May, 2013	30.75° N, 113.62° E	Larva and egg
YM-2014	Yunmeng, Hubei	3	May, 2014	30.75° N, 113.62° E	Larva and egg
WX-2013	Wuxue, Hubei	4	May, 2013	30.10° N, 115.60° E	Larva and egg
WX-2014	Wuxue, Hubei	4	May, 2014	30.10° N, 115.60° E	Larva and egg
YY-2013	Yueyang, Hunan	5	May, 2013	29.43° N, 113.02° E	Larva and egg
YY-2014	Yueyang, Hunan	5	May, 2014	29.43° N, 113.02° E	Larva and egg