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Toxicity of six insecticides to predatory mite *Amblyseius cucumeris* (Oudemans) (Acari: Phytoseiidae) in- and off-field

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ABSTRACT

Amblyseius cucumeris (Oudemans) is a beneficial non-target arthropod (NTA) and a key predator of tetranychid mites in integrated pest management (IPM) programs across China. Evaluating the toxic effects of insecticides on such predatory mites is essential for the success and development of IPM. We tested six insecticides to determine the risk of neonicotinoid insecticide toxicity to predatory mites, using the 'open glass plate method' and adult female *A. cucumeris* in a "worst case laboratory exposure" scenario. A 48-h toxicity test was performed using the hazard quotient (HQ) approach to evaluate the risk of each insecticide. The LR_{50} values (application rate that caused 50% mortality) of acetamiprid, thiamethoxam, imidacloprid, and dinotefuran were 76.4, 104.5, 84.9, and 224.6 g active ingredient (a.i.) ha^{-1}, respectively, with in-field HQ values of 0.40, 1.28, 0.49, and 0.82, respectively. The HQ values were lower than the trigger value of 2, and were consistent with off-field values. The risks of the four neonicotinoid insecticides to adult female *A. cucumeris* were acceptable in two exposure scenarios in field and off field. The 48-h LR_{50} values for bifenthrin and malathion were 0.008 and 0.062 g. a.i. ha^{-1}, respectively, which were much lower than the recommended field application rates. The HQ values were much higher than the trigger values for both in- and off-field, indicating that the risks of these two insecticides were unacceptable. Bifenthrin and malathion posed an extremely high risk to the test species, and their use should be restricted to reduce risks to the field with augmentative releases of *A. cucumeris*.

1. Introduction

The abundance and diversity of predators have a crucial effect on the functioning of agricultural and environmental systems (Bruno and Cardinale, 2008; Letourneau et al., 2009; Argolo et al., 2014). Predators significantly contribute to reducing the prevalence of insect-transmitted diseases in crops (Long and Finke, 2015). Most insecticides are sprayed directly onto infested plants, threatening the predators that are usually near the pests. The exposure to insecticides in agroecosystems may cause acute toxicity and kill predators instantly. Most insecticides influence the ability of predators to survive, thus damaging an essential criterion for integrated pest management (IPM).

The predatory mite, *Amblyseius cucumeris* (Oudemans) (Acari Phytoseiidae), is the most effective biological control agent of insect pests, such as two-spotted spider mites, western flower thrips, and whiteflies in agriculture crops and greenhouse vegetables (Williams, 2001; Mendel and Schausberger, 2011; Zhang et al., 2014). Because of the widespread and large-scale commercialized production of *A. cucumeris*, it has become a common biological pesticide. Studies have examined the toxicity of insecticides to this predatory mite (Sun et al., 2009). We used *A. cucumeris* as a toxicity test organism to determine the potential toxicity of four neonicotinoids and a pyrethroid (bifenthrin) and an organophosphate (malathion) insecticide.

The toxicity and risk of insecticides to predatory phytoseiid mites have been investigated previously (Lefebvre et al., 2011; Fernández et al., 2017; Kuk and Kim, 2018). However, there are only a few studies on the effect of these six selected insecticides on *A. cucumeris*. Although most studies have found that imidacloprid shows marginally toxic effects on phytoseiid mites, some studies report that this compound is highly toxic to *Neoseiulus fallacis* Garman and *Galendromus occidentalis* Nesbitt (James, 2003). Bifenthrin, a pyrethroid insecticide, was extremely toxic to adult *Amblyseius swirskii* Athias-Henriot and *Phytoseiulus persimilis* Athias-Henriot (Fernández et al., 2017; Alzoubi and Çobanoğlu, 2010), whereas, malathion, an organophosphorus insecticide, was moderately harmful to *Phytoseiulus persimilis* Athias-Henriot (Kavousi and Talebi, 2003).

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A variety of methods has been used to evaluate the risk of chemicals to predators. However, there are no fixed assessment criteria to evaluate the risk of insecticides to predators. The primary method is to assess the median lethal rates (LR_{50}), or application rates, in laboratory bioassays and use International Organization for Biological and Integrated Control of Noxious Animals and Plants (IOBC) classifications to categorize insecticides as harmless, slightly or moderately harmful, or harmful. This approach can identify the risk of insecticides tested at a defined rate, but do not take into account the field recommended application rates, or the drift of compounds in the environment. The field recommended application rates are those that pests and beneficial organisms are exposed to in-field. The HQ approach resolves these shortcomings by including the field rates of a specific insecticide, and the LR_{50} values of the test organisms. For example, the HQ value of imidacloprid to coccinellid *Serangium japonicum* on contact is 3.47, confirming a risk for *S. japonicum* (He et al., 2012). The insecticide fenobucarb had an HQ > 300,000, and was highly dangerous to the predatory mirid *Cyrtorhinus lividipennis* Reuter, whereas, pymetrozine, deltamethrin, and imidacloprid are considered “safe” (Preetha et al., 2010).

When a compound is released into the ecosystem, the rate of spray application in arable fields affects not only Non-target Arthropods (NTAs) within the treated area, but also those in the off-field habitats adjacent to the treated crop, especially via drift (Langhof et al., 2003). Relatively large droplets may settle in the target area, but smaller particles (< 100 μ) are carried away by wind and might settle away from the point of application (Salyani and Cromwell, 1992). Off-crop habitats with diverse vegetation have different prey or hosts and can be a suitable refuge after harvest or tillage, or even over-wintering sites (Landis et al., 2000) for generalist predators (Langhof et al., 2003). These off-crop boundaries harbor source populations and enable recolonization of predators in insecticide-treated fields (Longley and Jepson, 1997). However, refuges can also become contaminated via drift, which potentially adversely affects the predators adversely and increases the recolonization time.

In this study, we assessed the contact toxicity of six insecticides from different chemical families to adult female *A. cucumeris* by the “worst-case scenario” method (Bostanian et al., 2009). We used adult female *A. cucumeris* as test targets, rather than other stages. Because of the developmental duration of adult females is the longest in the whole life cycle of the predator mites, and therefore the number of adult female individuals is the largest in the mite population. In addition, adult females have larger size and greater mobility, thus, increasing the chance of exposure in compounds. Considering the crucial role of *A. cucumeris* in controlling target pests, it is very indispensable to evaluate the compatibility of biological control agents released in combination with commonly used pesticides. The results of this study will provide valuable information to optimize the use of these pesticides within the framework of IPM.

2. Materials and methods

2.1. Rearing of *A. cucumeris*

The test subjects were obtained from the Institute of Plant Protection, Fujian Academy of Agricultural Sciences, China. *A. cucumeris* were mainly fed *Tyrophagus putrescentiae* Schrank, which were maintained on brewers’ yeast and maintained in cylindrical plastic cages (9 cm in diameter, 3 cm in height), each covered with a round, plastic plate with a 2.5-cm diameter hole in the middle. The cylinder was sealed using a filter paper disk for ventilation. The predators and their prey were reared under controlled conditions with a temperature of 25 ± 1 °C, 75 ± 5% relative humidity (RH), and 16:8 h light: dark (L/D) photoperiod in the laboratory.

2.2. Pesticides and treatment methodology

The open glass plate method was used to assess the residual toxicity of insecticides to predatory mites according to the IOBC (Overmeer, 1988; Miles et al., 2003). Each experimental unit consisted of two cover slides (24 mm × 50 mm × 0.15 mm) that were placed on a piece of moist filter paper, which was placed on top of a piece of foam. The two slides were fixed together using a glass bar and glued horizontally. The border of each test unit was covered using a layer of hydrophilic cotton, and the foam and cotton were saturated with distilled water to prevent the mites from escaping. The area of each test unit measured approximately 12 cm^2.

The purity (% purity) of technical material in the insecticides was tested: acetamiprid (97%); thiamethoxam (98.2%); imidacloprid (97%); dinotefuran (95.2%); bifenthrin (96%); and malathion (90%). The insecticides were obtained from the Institute for the Control of Agrochemicals (ICAMA) and stored at − 20 °C. Technical formulations rather than commercial formulations were used. Stock solutions were dissolved in analytical-grade acetone due to their low solubility in water. The nominal concentrations of each insecticide were obtained by diluting the stock solution with deionized water. The recommended field application rate for each insecticide is listed in Table 1.

2.3. Acute toxicity test

The glass plates for each test were sprayed with pesticides using a Potter Spray Tower (Burkard Manufacturing, Rickmansworth, Herts, England), calibrated to a pressure of 10 psi (68.95 kPa); 2 mL was used for each spray (mg wet deposit per cm^2 for a mean deposition of 2 ± 0.2 mg/cm^2). After application, the glass plates were left to dry at room temperature. Thirty adult female *A. cucumeris* were placed onto the per treated glass plate and fed maize pollen (0.1 g), which was collected from local cornfields and maintained in a freezer at − 20 °C until use and was renewed once a day. To establish the rate-mortality relationship, the predatory mites were exposed to five to seven different rates of each compound with two fold increase in the geometrical ratio. Three replicate glass plates were used for each rate per chemical (including the solvent and blank controls). The plates were maintained in incubators at 25 ± 2 °C, 70 ± 10% RH, and a 16 h: 8 h (L/D) photoperiod. The mites that died and those that escaped were recorded 48 h after the start of each treatment. Escapees are those mites which were found on the test unit, or which were stuck in the cotton. In our definitive LR_{50} assays, the mites that stuck in the boundary generally accounted for around 70% of dead mites, with missing mites accounting for 60% (Blumel et al., 2000). The application rate of each insecticide is listed in Table 2.

2.4. Exposure assessment

The exposure assessment under in- and off-field scenarios was

Table 1
Field application rates and purity of technical material in the six insecticides used in this study.

Pesticides	Chemical family	Active ingredient purity (%)	Field recommended rate (g a.i./ha)
Acetamiprid	Neonicotionoid	97%	18–22
Thiamethoxam	Neonicotionoid	98.2%	15-– 60
Imidacloprid	Neonicotionoid	97%	21–30
Dinotefuran	Neonicotionoid	95.2%	90–150
Bifenthrin	Pyrethroid	96%	7.3–30
Malathion	Organophosphorus	90%	540–750

The values of field recommended rates of the selected pesticides are come from the China Pesticide Information Network: http://www.chinapesticide.gov.cn/hysj/index.jhtml.