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Lethal and sublethal effects of emamectin benzoate on the rove beetle, *Paederus fuscipes*, a non-target predator of rice brown planthopper, *Nilaparvata lugens*

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ABSTRACT

The use of pesticides in rice can not only manage the pest but also influence non-target organisms. The rove beetle (*Paederus fuscipes*), which is an important predator of the brown plant hopper (*Nilaparvata lugens*) in rice ecosystems, was tested to investigate acute and chronic effects of emamectin benzoate. The results from this study show that the LC50 of emamectin benzoate to adults of *P. fuscipes* at 72 h was 3.07 (1.84–4.54) mg a.i. L^{-1}, whereas the LC50 of emamectin benzoate to the second instar larvae of *P. fuscipes* at 72 h was 2.58 (1.95–3.19) mg a.i. L^{-1}. Tested sublethal doses (LC10 and LC30) had significant effects on the second instar developmental time of *P. fuscipes* compared with that of the control. The LC30 dose had a negative influence on the pre-imaginal developmental duration and the feeding potential of treated *P. fuscipes larvae*. Additionally, the LC30 reduced the pre-oviposition period, the fecundity and the body weight of adults emerged from treated larvae of *P. fuscipes*. In the sublethal experiment with adults, the fecundity and the feeding potential were significantly reduced at the LC30 dose. These results revealed that sublethal doses of emamectin benzoate negatively affected the development and biological activities of *P. fuscipes*, and we conclude that more attention should be paid to the use of this chemical as part of integrated pest management strategies.

1. Introduction

Rice (*Oryza sativa* L.) is the most imperative staple food in many countries. Almost half of the total population, approximately 3 billion individuals, relies on rice as daily food (Nguyen, 2007). In 2006, the reported area under rice cultivation in China was 29.4 million hectares, which was 29% of the total world rice production (FAOSTAT, 2007). However, rice in China experiences numerous problems regarding insect pests (Han et al., 2011). The most prominent insects that include the rice borers *Tryporyza incertulas* (Walker) and *Chilo suppressalis* (Walker) and the plant hoppers *Nilaparvata lugens* (Stål), *Laodelphax striatellus* (Fallen) and *Sogatella furcifera* (Horváth) cause heavy losses in yields (Lou et al., 2013). The brown plant hopper *N. lugens* (BPH) is a critical herbivorous insect pest of rice that causes damage by sucking the phloem sap, resulting in enormous yield reductions (Zeng et al., 2012). Rice losses due to damage from BPHs are often more than 10% of yield (Liu and Sun, 2016).

A tremendous increase has occurred in the use of chemical pesticides to control insect pests and ensure high yields of rice in Asia. By 1996, the total pesticide supply in China reached approximately 340 thousand tonnes, and China is likely to become the largest pesticide consumer in the world (Huang et al., 2001). Simultaneously, the negative effects of pesticides also draw great attention from the public, because pesticides not only affect the health of humans and animals but also pollute the environment. The unplanned and extensive use of pesticides also causes resistance to develop among insect pests (Khan et al., 2017). Pesticide-induced resurgence involves ecological and physiological factors. The decimation of natural enemies by pesticides is an important ecological factor in the induction of brown plant hopper (BPH) resurgence, but stimulation of reproduction by pesticides is more responsible for the occurrence of a resurgence (Liu et al., 2015). Unfortunately, many biological control agents are susceptible to a wide spectrum of pesticides. Therefore, a potential problem developing from the application of these pesticides is the disruption of beneficial arthropod populations important in biological control processes (Talebi et al., 2008).

Paederus fuscipes (Coleoptera: Staphylinidae), a predator of rice fields, is found in Europe, north and central Africa, Asia, New Guinea,

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Australia, India, and Pakistan (Manley, 1977). Eggs are laid singly on moist substrate. The species has 2 larval instars, which are predators, as are the adults, in moist habitats. Pupation occurs in soil (Nasir et al., 2012). *P. fuscipes* is one of the most aggressive feeders in a rice field. The adults migrate to the young rice plants shortly after transplanting and remain among the tillers throughout the growing season (Manley, 1977). The beetles prey on soft-bodied insect pests; for example, whiteflies, mites, aphids, leafhoppers and maggots of fruit flies, in different crops (Nasir et al., 2012). Manley (1977) reported that an adult *P. fuscipes* consumes 10–12 second instar nymphs of BPH in 24 h (1 day) at room temperature. Therefore, because *P. fuscipes* is also exposed to the pesticides used to control planthoppers and leafhoppers in a rice field, the potential effects of pesticides on *P. fuscipes* must be evaluated.

Many studies have evaluated the toxicity of different chemicals to *P. fuscipes*. Echegaray and Cloyd (2012) assessed the risk of pesticides, biopesticides, and PGRs (Plant Growth Regulators) against *P. fuscipes*. The results showed that *Beauveria bassiana* (at both low and high rates), azadirachtin, spirotetramat, cyromazine, and the PGRs acymidol, paclobutrazol, and uniconazole did not affect rove beetle survival. However, kinoprene and *B. bassiana* negatively affected rove beetle prey consumption. The contact toxicity and residual effects of four insecticides were tested against adult *P. fuscipes* using different contact substrates (Bong et al., 2013). The results showed that *P. fuscipes* responded differently to the same pesticide with different contact substrates, and fenitrothion was the least effective insecticide against *P. fuscipes*. As a novel avermectin derivative, the usual use of emamectin benzoate in a rice field is for control of *C. suppressalis*, *Cnaphalocrocis medinalis* and other lepidopteran pests (He et al., 2008; Yang et al., 2018; Ishaaya et al., 2002). However, no reports are available about the biological effects of emamectin benzoate on *P. fuscipes*.

The current study was designed to assess the lethal and sublethal effects of emamectin benzoate on *P. fuscipes*, which is an important predator of the brown plant hopper *N. lugens*. For the short-term effect, the lethal concentrations were determined, and for the long-term effect, the effects of emamectin benzoate on developmental period, fecundity and feeding potential of second instar larvae and adults were assessed.

2. Materials and methods

2.1. P. fuscipes culture rearing

Wild type of *P. fuscipes* was randomly collected from a paddy field of Huazhong Agricultural University in 2017. Adults were supplied with artificial diet for *P. fuscipes* and nymphs of *N. lugens* synchronously in the laboratory at 27 ± 2 °C with 68 ± 5% RH and a 16:8 h (L:D) photoperiod. Artificial diet, which contained both liver powder and honey at the ratio of 5:1 by weight, was prepared as described in Meng et al. (2016). Wild adults were reared for more than one generation under these conditions before use as the test organism. The rearing method was followed as noted in Meng et al. (2016). *Paederus fuscipes* adults were reared in 2 L glass beakers, and each beaker had 40–45 adult *P. fuscipes*. A layer of wet cotton was settled in the bottom of the beaker to maintain humidity and covered with filter paper to provide a solid surface on which to crawl. Rice seedlings were reared with Yoshida solution in 100 ml glass beakers, and *N. lugens* nymphs fed on the rice seedlings. A 100 ml glass beaker with rice seedlings infested with 100–150 nymphs of *N. lugens* and artificial diet in a small petri dish (5 cm diameter × 1 cm depth) were put into a 2 L glass beaker as food for *P. fuscipes*. Every two days, the nymphs of *N. lugens* and the artificial diet were refreshed. After five days, adults were shifted into new beaker. The eggs deposited on the wet cotton or on the rice seedlings were collected and kept for hatching. After hatching, larvae of *P. fuscipes* were kept in a separate container and provided with first instar nymphs of *N. lugens* and artificial diet for *P. fuscipes*. The full-grown larvae near to pupation were transferred into a container containing organic soil. After the emergence of adults, they were again used in the rearing procedure.

2.2. Insecticide

Emamectin benzoate technical grade (70% active ingredient) was purchased from Qilu Synva Pharmaceutical Co., Ltd (Jinan, China). Analytical grade acetone was used as the solvent to dissolve the active ingredient to prepare the different concentrations for the experiment.

2.3. Acute toxicity testing of emamectin benzoate against second instar larvae and adults

For the determination of acute toxicity, progressive concentrations were prepared until the mortality ranged from 10% to 95%. A topical application method was adopted for adults and second instar larvae of *P. fuscipes*. The test insect was placed in a glass tube and then immobilized with exposure to CO_2. The ventral side of the abdomen was treated with different concentrations of emamectin benzoate topically. Topical application was performed with the help of a hand microapplicator (Burkard, England)(Nawaz et al., 2017). For second instar larvae, after immobilization, the ventral side of the abdomen was treated with 0.5 µl of a concentration, whereas in the control, 0.5 µl of acetone was used. Five concentrations (0.79–12.6 mg/L) that increased with a geometric ratio of twofold were used. For each concentration, fifteen individuals were one replicate, and 4 replications were set up. For adults 10 days after eclosion, 1 µl of tested concentration was delivered on each insect. In the control, 1 µl of acetone was applied to each adult. The tested concentrations were same as those used with larvae. Twenty individuals were one replicate, and 4 replications were set up. Treated insects were maintained in a climate chamber at 27 ± 2 °C with 68 ± 5% RH and a 16:8 h (L:D) photoperiod. Adequate nymphs of *N. lugens* and artificial diet for *P. fuscipes* were provided to each rove beetle continuously for three days. Treated insects were observed after 24, 48 and 72 h for mortality. Insects that did not move after a little agitation were considered dead.

2.4. Chronic toxicity test on second instar larvae and adults

2.4.1. Evaluation of toxicity on developmental period of second instar larvae

The method adopted is described in Meng et al. (2016) with some modifications. In brief, almost 450 eggs (< 24 h) of *P. fuscipes* were collected. Each egg was kept individually in a 5 ml (15 mm diameter x 50 mm depth) plastic container that contained wet cotton to maintain moisture. Eggs were raised to second instar larvae. After the first instars hatched, each larva was provided with artificial diet and a sufficient amount of nymphs of *N. lugens*. After removing unfertilized eggs and larvae that died during immature stages, 270 second instar larvae were obtained and divided into three treatment groups: control (acetone), LC10 (1.45 mg a.i. L^{-1}) and LC30 (2.04 mg a.i. L^{-1}). Each treatment contained 90 larvae. Each larva served as a single replication (Chi and Yang, 2003). The development of the treated insects was observed daily from the beginning of experiment to the emergence of adults. Data were collected regarding the effect of emamectin benzoate on second instar larvae, pre-pupa duration, pupa duration, pre-imaginal development time, pre-oviposition time and fecundity.

2.4.2. Evaluation of adult fecundity

A petri dish, 9 cm diameter, was used to study the fecundity of adults 10 days after eclosion and of those emerged from treated second instars. Moist cotton was in the bottom of the petri dish to maintain moisture and covered with filter paper to provide a solid surface on which to move. Parafilm was used to cover the dish, and small holes in the cap were opened for aeration. Ten pairs of newly emerged adults from treated larvae and 10 pairs of adults from the control, LC10