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Pesticide-induced susceptibility of rice to brown planthopper *Nilaparvata lugens*

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Abstract

The effects of rice plants treated with various pesticides (jingganmycin, bisultap and methamidophos) on feeding, survival rates and population growth of *Nilaparvata lugens* Stål (Homoptera: Delphacidae), susceptibility of the treated rice plants and amounts of free amino acids and sucrose were studied. Experiments indicated that the effects of the tested pesticides were dependent on nymphal age, pesticide and their dose and time after application. Jingganmycin at 75 g a.i. ha^{-1} significantly increased the *N. lugens* population. Both jingganmycin and bisultap increased the survival rate of *N. lugens* nymphs. The feeding rate of the insects was also affected by the pesticide application, but the effect varied between nymphal age and time after application and lasted no longer than 15 d. Results clearly indicated that pesticide application increased the susceptibility of rice plants to *N. lugens*. Although the free amino acids in rice plants did not change with the pesticide treatments, the concentration of sucrose significantly decreased 5 d after application and the C/N ratio significantly decreased in jingganmycin treated plants 5 d and 10 d after application.

Introduction

Field application of certain pesticides has been shown to induce resurgence of target pests (Chelliah & Heinrichs, 1980; C. X. Gao et al., 1988; Hardin et al., 1995). However, the effect of pesticides on natural enemies has been more widely examined (Fabellar & Heinrichs, 1986; Krishnaiah & Kalode, 1988). Pesticides may disrupt populations of natural enemies and affect the balance of natural enemies and their host. Additionally, some pesticides have been reported in stimulating growth and productivity of pests at sublethal doses (Chelliah & Heinrichs, 1980; Heinrichs & Mochida, 1984). Furthermore, pesticides may affect target insects indirectly through altering nutritional and other biochemical aspects of host plants (Jones & Parrella, 1984; Mellors et al., 1984).

Brown planthopper (BPH) *Nilaparvata lugens* Stål (Homoptera: Delphacidae) is a major insect pest of rice in Asia. In Southeast Asia and China, resurgence of the insect was typically caused by applications of chemical pesticides (Dyck & Thomas, 1979; Heinrichs & Mochida, 1984; Kenmore et al., 1984; C. X. Gao et al., 1988). Destruction of natural enemies by chemicals is taken as the primary cause of resurgence (Waage, 1989; Gu et al., 1984). Therefore, pesticides, which have minimal or no lethal effects on natural enemies, were considered as effective. But the overall effect of pesticides on target insects is complex. For example, insecticides, with low lethality to natural enemies, may cause outbreaks of insect pests just as well (Reissig et al., 1982). Bisultap, an insecticide used to control rice borers and rice leafroller in paddy fields in China, which was originally thought as safe to natural enemies, caused a serious decrease of predation function owing to its paralyzing effect on predators (Wu et al., 1997). Furthermore, pesticides may affect insects indirectly, through altering host plant nutrition and even lead to resurgence of the target pests (Hardin et al., 1995). Although considerable research on side effects of insecticides on the natural enemies of brown planthopper has been conducted, little is known about the effects of pesticides on BPH, mediated by the rice plants. In the current study, we evaluated the induced responses of rice plants to several commonly used pesticides and their effects on brown planthopper.

Materials and methods

Rice. The rice variety used in all experiments was Jindao 9520 (japonica rice). All plants were prepared as follows: Thirty-day old rice seedlings were transplanted in each of 16 cm diameter plastic pots, with one hill (six plants) per pot, and thereafter used, except in the experiment of change of rice susceptibility to BPH.

Insect cultures. Biotype II colony of brown planthoppers, provided by the Chinese National Rice Research Institute (CNRRI), was maintained on rice plants in a greenhouse at 28 ± 4 °C and L14:D10.

Pesticides. Three commonly used pesticides in paddy fields in the Jiangsu province, China, were used in this study:

Bisultap (Yanchen Biopesticide Factory, Jiangsu, China), a nereistoxin insecticide, commonly used against the rice borers, *Tryporyza incerfulas* (Walker) and *Chilo suppressalis* (Walker), and the rice leafroller, *Cnaphalocrocis medinalis* Guenée, is usually applied during the maximum tillering stage of rice and heading stage, at the commercial rate of 405–675 g a.i. ha^{-1}. Methamidophos (Suzhou Pesticide Group, China), an organophosphate insecticide/acaricide used for controlling brown planthoppers at the commercial rate of 750–1500 g a.i. ha^{-1}. Jingganmycin (Xishan Biopesticide Factory, China), an antibiotic compound, mainly used against sheath blight, *Thanatephorus cucumeris*, at the commercial rate of 75–150 g a.i. ha^{-1}. Rice was treated with the three pesticides, each at low and high rates, in the following tests.

Effect of pesticides on BPH population growth. Seven days after transplantation, potted rice plants were sprayed with pesticide using a Yangtse River 08 model sprayer with a nozzle of one mm diameter. Tap water was used as control. The experiment was arranged with a randomized complete block design, with four replicates. Seven days after pesticide application, eight 2nd-instar BPH nymphs were released on each pot, which were provided with nylon cylindrical cages (20 cm diameter × 60 cm height). When the 3rd instar nymphs of the next generation appeared in the cages, all nymphs (1st, 2nd and 3rd instars) and unhatched eggs were counted. The population growth index (PGI) was expressed by the ratio of N_1/N_0, which was calculated by dividing the total number (N_1) of nymphs and eggs by the number of nymphs released ($N_0 = 8$).

Effect of pesticides on BPH survival rate. Survival experiments of BPH nymphs on treated rice plants were carried out on potted rice. There were four pesticide treatments: low and high dosages of jingganmycin and bisultap, and two stages of nymph were used for infestation: 1st and 4th instar BPH nymphs. One week after the transplantation, the potted plants were treated with the pesticides and covered with the nylon cylindrical cages described above. Both fifty 1st instar and the 4th instar nymphs were released on each hill at 5 days after pesticide treatments. The experiment was arranged with a randomized complete block design, with six replicates for each treatment. In the case of the experiment where first instar nymphs were released, the nymphs were counted when they developed to the fourth instar, and then the survival rate of 1st–3rd instars ($S_{1st-3rd}$) was calculated as follows:

$$S_{1st-3rd}(\%) = \left(1 - \frac{\text{the number of 1st instars released} - \text{the number of fourth instars}}{\text{the number of 1st instars relaesed}}\right) \times 100.$$

In the case of the experiment where fourth instar nymphs were released, individuals were counted when they developed to adults. Then the survival rate of 4-5th instars ($S_{4th-5th}$) was calculated as follows:

$$S_{4th-5th}(\%) = \left(1 - \frac{\text{the number of 4th instars released} - \text{the number of adults}}{\text{the number of 4th instars released}}\right) \times 100.$$

The generation survival rate (GSR) was calculated: $GSR = S_{1st-3rd} \times S_{4th-5th}$.

Effects of pesticide application on BPH honeydew excretion. BPH honeydew was measured based on the method of Pathak et al. (1982), under indoor environment at 27 ± 5 °, 50 ± 10% r.h., and a photoperiod of L14:D10. One week after transplantation, the plants were treated with two different dosages of each of the three pesticides(jingganmycin, methamidophos and bisultap). Five and 10 days after treatments, a parafilm sachet was attached to the rice stem at about 10 cm above the soil surface and a 3rd instar BPH nymph was then confined, with an empty sachet as control. There were 20 replications for each treatment. In another experiment, 5th instar nymphs were used and honeydew was measured at 5 d and 15 d after pesticide treatment. Prior to the inoculation, the planthoppers were starved for 2 h. After 24 h feeding, the sachets were removed from the plants. Filter paper was used to absorb the honeydew on the parafilm and stem, and was weighed using a Mettler-toledo electronic balance (EC100 model) (1/10 000 g sensitivity) before and after absorption, respectively. The honeydew excretion per insect (H) was calculated as follows:

$$H = (W_{t1} - W_{t0}) - (W_{c1} - W_{c0}),$$

where W_{t1} and W_{t0} are the weights of the filter paper after and before absorption in treatment, respectively; W_{c1} and W_{c0} are the weights of the filter paper after and before absorption in the control, respectively.

Change of rice susceptibility to BPH. Tests were conducted in cement-made pools (1.5 × 8 cm). Rice plants (at the 6 leaf-seedling stage) were transplanted individually and 5 d later, treated with low and high dosages of two pesticides (jingganmycin and bisultap), with water spraying as control. There were 30 replications for each treatment. Thirty 3rd instar nymphs were confined on each plant 7 d after treatment. Every single rice plant was caged with a cylinder (top opening) made from a clear plastic film (25 by 25 cm) before infestation to keep the BPH nymphs from escaping. Injury to rice plant was recorded when BPH reached to adult stage (about 10 d after infestation). A nine-scale injury rating, which was modified from the screening method of varietal resistance (Choi, 1979), was used to record the injury level of the plant (Table 1).

The injury index was calculated as follows:

$$\text{Injury index} = \frac{\sum_{i=1,3,5,7,9} (\text{the number of plants with } i \text{ injury scale } \times i)}{\text{Total number of rice plants} \times (\text{the maximal injury scale})}.$$

Free amino acid and sucrose analysis. Five days after transplantation, the plants were treated with two dosages of jingganmycin and bisultap, respectively, and tap water was used as the control. There were five replicates for each treatment. Five days later, the plants were taken for free amino acid and sucrose analysis. Free amino acid was analyzed using a method similar with Rosen (1957). Five rice plants were cut and leaves were removed. Five grams of fresh leaf sheath was weighed and cut into pieces. The pieces were ground to a paste in a mortar after adding 5 ml of 10% acetic acid and then put into a 100 ml of measuring flask. The solution was then fixed to constant volume with non-ammonia water and then filtered after evenly shaking. One ml of extracted solution was absorbed and put in 25 ml of measuring flask and 3.5 ml of ninhydrin buffer developing solution added. Then 0.1 ml of ascorbic acid solution was added and thoroughly shaken. The mixture was developed in boiling water for 20 min, removed and cooled rapidly, and 10 ml of 80% alcohol was added, and then water was added to make 25 ml. Absorbance at 570 nm was detected using a 722 spectrometer (The 3rd Analytical Instrument Company of Shanghai, Shanghai, China). A standard curve was drawn with glutamic acid.

The sucrose level was measured using the method of Xue (1985). Three-five rice plants were cut and leaves were removed. The leaf sheath was dried in an electric oven at 80 °C and then ground. Fifty grams of leaf materials was weighed, 3 ml of alcohol added and then extracted for 30 min in water bath at 80 °C and the supernatant was absorbed. The extraction process was replicated three times. The extracted solution was put into a 10 ml measuring flask, and fixed to a constant volume, and then decolorized and filtered by the addition of 0.1 g of active carbon. One ml of filtered solution was absorbed into a test tube, in which 0.1 ml of 2N NaOH was added, bathed in boiling water for 10 min and then cooled by running water. A mixture of 3.5 ml of 30% HCl and 1 ml of 0.1% resorcin was added, and then put into bathing water at 80 °C and developed for 10 min and then cooled by running water. OD480 values were detected with the 722 spectrometer.

The C/N ratio was calculated by dividing the concentration of sucrose by that of free amino acids.

Statistical analyses. All data were analyzed by ANOVA (SAS Institute, 1985), and means were compared using the test of least significant differences (LSD). Survival percentages were transformed by calculating the arcsin of the square root of each proportion.

Results

Effect of pesticide on BPH population. The population of BPH on rice treated with jingganmycin 75 g a.i. ha^{-1} was 41.52% higher ($P < 00.1$) than that of the control (Table 2). There was no significant difference

Table 1. Scale of plant injury symptoms

Scale	Symptom description
1	Slight injuries, few yellow pitches on leaf sheaths
3	Leaf sheaths slightly yellow
5	Leaf sheaths clearly yellow, reduced tillering
7	Leaf sheaths severely yellow, plant dwarfing and severely reduced tillering
9	General withering

Table 2. Effects of three pesticides each at two dosages on the BPH population growth

Pesticide	Rate (g a.i. ha^{-1})	Average number N_1^*	N_1/N_0	Increase N_1/N_0 over control (%)
Jingganmycin	75	3023 ± 1236a	377.9	41.52
Jingganmycin	150	2426 ± 994ab	302.0	13.58
Methamidophos	750	1781 ± 1054ab	222.6	−16.62
Methamidophos	1500	2252 ± 1546ab	281.5	5.48
Bisultap	405	1815 ± 752ab	226.9	−15.03
Bisultap	675	2846 ± 367ab	355.8	33.24
Control	0	2136 ± 945b	267.0	

*Means±SE of four replicates. Means within column followed by the same letter are not significantly different ($P > 0.05$, LSD test).

among the other treatments. The survival rate of 1st to 3rd instar nymphs and generation survival rate after feeding on the rice plants treated with the pesticides increased significantly in comparison with that of the control (Table 3). Survival rate of 4–5th instar nymphs was higher in jingganmycin at 75 and 150 g a.i. ha^{-1} and bisultap at 675 g a.i. ha^{-1} than in the control and lower dose of bisultap. Experiments also indicated that the generation survival rates at the lower rate of the two pesticides were slightly higher than that at higher rates and that of the control.

Effect of pesticide treatments on BPH honeydew excretion. At five days after pesticide treatment, honeydew excretion by 3rd instar was not influenced by the pesticide application (Table 4). However, 10 days after treatment, the quantity of honeydew significantly increased ($P < 0.01$) in all treatments. Honeydew quantity increase ranged from 78.24% to 223.03%, compared with the control. The amount of honeydew excretion significantly increased in the 5th instars ($P < 0.01$) 5 days after the treatments, but at 15 days after treatments, no significant effect was observed (Table 5).

Effect of pesticides on plant resistance. In all cases, pesticide treatment significantly increased plant damage levels compared with the control plants ($P < 0.01$) (Table 6). Compared with the control, injury indices increased 158%, 275%, 242% and 58% for the treatment of jingganmycin at 75 g a.i. ha^{-1}, 150 g a.i. ha^{-1} and bisultap at 405 g a.i. ha^{-1}, 675 g a.i. ha^{-1}, respectively. Our results demonstrated that, treated with jingganmycin and bisultap, rice plants increased their susceptibility to BPH.

Effect of pesticide on free amino acid and sucrose levels. Total free amino acid content in plants following the pesticide treatment showed no significant difference in comparison with the control ($P > 0.05$) (Table 7). Sucrose contents significantly decreased at 5 days after treatment ($P < 0.01$), compared with the control. The ratios of C/N at 5 days and 10 days after jingganmycin treatment significantly decreased.

The measurement also indicated that, 20d after treatment, there was no significant difference in free amino acids, sucrose and C/N ratio between the treated plants and the control ($P > 0.05$).

Table 3. Average survival rates of BPH feeding on the rice treated with three pesticides at two different dosages

Pesticide	Rata (g a.i. ha^{-1})	Survival rate of 1st–3rd instars	Survival rate of 4–5th instars	Generation survival rate
Jingganmycin	75	0.693 ± 0.05a	0.767 ± 0.009a	0.531 ± 0.006a
Jingganmycin	150	0.713 ± 0.009a	0.713 ± 0.021a	0.508 ± 0.158ab
Bisultap	405	0.883 ± 0.047a	0.654 ± 0.076b	0.544 ± 0.089a
Bisultap	675	0.693 ± 0.009a	0.740 ± 0.038a	0.513 ± 0.026ab
Control	0	0.613 ± 0.031b	0.663 ± 0.042b	0.459 ± 0.028b

Means±SE of six replicates. Means within columns followed by the same letters are not significantly different ($P > 0.05$, LSD test).

Table 4. Honeydew production by 3rd instar BPH nymph feeding on rice plants treated with three pesticides at two different dosages

Pesticide	Rate (g a.i.ha^{-1})	Honeydew production (mg)	
		5 DAT	10 DAT
Jingganmycin	75	6.52 ± 4.55(18)a	17.67 ± 10.61(20)A
Jingganmycin	150	5.15 ± 3.94(18)a	14.65 ± 8.16(20)A
Methamidophos	750	6.73 ± 4.65(19)a	9.75 ± 7.64(19)A
Methamidophos	1500	4.17 ± 2.84(20)a	10.61 ± 10.08(18)A
Bisultap	405	4.11 ± 3.16(20)a	11.90 ± 7.88(19)A
Bisultap	675	5.71 ± 3.75(19)a	12.83 ± 6.22(20)A
Control	0	5.09 ± 4.72(19)a	5.47 ± 4.77(20)B

Means±SE(data in brackets was the number of the insects tested). Means within columns followed by the same letters are not significantly different ($P > 0.05$, LSD test); DAT = days after treatment.

Discussion

So far, studies on side effects of pesticides mainly concentrated on the mortality towards beneficial organisms, and the stimulating effects of sublethal dosages on insect pest fecundity (Elzen, 1989; Reissig et al., 1982; Heinrichs & Mochida, 1984). Our results indicated that pesticide treatment altered the plant quality and consequently affected the survival and feeding rate of brown planthopper and the damage level of plants.

Beneficial effects of insecticide treatment on herbivores have been reported before. For example, application of malathion or permethrin to lemon leaves increased fecundity and reduced mortality of the mite *Panonychus citri* (McGregor) feeding on these leaves (Jones & Parrella, 1984). In our experiment, the feeding rate of BPH increased significantly on the treated rice plants with jingganmycin and bisultap, which is in agreement with the results by Chelliah & Heinrichs (1980) who tested deltamethrin, parathion- methyl and diazinon. But the effects varied with the nymphal age and time after pesticide application. Our results suggested that the effect on the feeding rate lasted no longer than 15 d after treatment. For the 3rd instar nymph, the effect was not significant at 5 d after treatment, probably because of their relatively low feeding rate and/or effects of pesticide residue on plants. The survival rate of BPH nymphs also significantly increased when the insects were fed on the treated plants, indicating that there were changes in the plants when treated with jingganmycin or bisultap, which benefit the feeding insect. Fecundity is another important criterion for the fitness of insects. When insects are treated at sublethal dose of insecticide, their fecundity can be affected. Chelliah & Heinrichs (1980) found that, when BPH came into contact with certain insecticides, its reproductive capacity was positively influenced. In field tests, the number of BPH was greater in plots treated with deltamethrin and the number of eggs reached 340 per hill on treated rice, compared to 10 per hill on untreated plants (Heinrichs et al., 1982). But in our experiments, the population growth index of BPH was not affected significantly, except in the treatment of jingganmycin at

Table 5. Honeydew production by 5th instar BPH nymph feeding on rice plants treated with three pesticides at two different concentrations

Pesticide	Rate (g a.i.ha^{-1})	Honeydew production	
		5 DAT	15 DAT
Jingganmycin	75	10.88 ± 8.80(20)a	10.32 ± 8.13(20)A
Jingganmycin	150	11.13 ± 8.18(20)a	8.35 ± 8.26(20)A
Methamidophos	750	9.06 ± 6.18(20)a	9.21 ± 8.08(20)A
Methamidophos	1500	8.87 ± 5.68(19)a	7.97 ± 6.09(20)A
Bisultap	405	10.23 ± 9.12(19)a	9.39 ± 10.26(20)A
Bisultap	675	13.44 ± 12.20(20)a	8.54 ± 7.84(20)A
Control	0	6.82 ± 5.50(20)b	10.62 ± 10.04(19)A

Means±SE(data in brackets was the number of the insects tested). Means within columns followed by the same letters are not significantly different ($P > 0.05$, LSD test); DAT = days after treatment.

Table 6. Plant injury level under BPH feeding after treatment of two pesticides at two different concentrations

Pesticide	Rate (g a.i.ha^{-1})	Injury scale*	Injury index
Jingganmycin	75	4.47 ± 2.67A	49.63
Jingganmycin	150	6.61 ± 1.74A	72.22
Bisultap	405	5.93 ± 1.72A	65.93
Bisultap	675	2.73 ± 1.55B	30.37
Control		1.73 ± 1.11C	19.26

*Means±SE of 30 replicates. Means within columns followed by the same letters are not significantly different ($P > 0.05$, LSD test).

75 g a.i. ha^{-1}. Therefore, it appears that jingganmycin and bisultap do not influence fecundity.

Some insecticides may increase susceptibility of plants to insects. X. W. Gao et al. (1998) reported that deltamethrin and parathion-methyl make rice plants susceptible to BPH. Some insecticide treatments result in 100% hopperburn of rice plants, whereas untreated plots suffer only minor or no damage (Reissig et al., 1982). Our results indicated that jingganmycin or bisultap treatments significantly increased the susceptibility of rice plants to BPH, which might be caused by increased feeding of the insect. However, the effect was dependent on the pesticide and its application dose.

Physiological and biochemical alterations in plants after pesticide treatment were thought to attributed to the beneficial effects on the feeding insects (Jones & Parrella, 1984; Mellors et al., 1984). Some studies have reported that the nutritional physiology of rice plant was modified with ammonia N increasing and total sugars decreasing following insecticide application (Rao & Rao, 1983). Decamethrin was found to decrease the ratio of carbohydrates to nitrogen and to increase the level of free amino nitrogen in a susceptible rice strain (Buenaflor et al., 1981). Increase of free amino acid or decline of C/N is an important factor of stimulating BPH feeding. Amino acid content in resistant varieties was lower than that in susceptible ones (Sogawa, 1970, 1971; Lu et al., 1982; Zhang & Gu, 1992). Total soluble sugar content in highly resistant varieties was lower than that in susceptible ones (Lu et al., 1982), suggesting that changes in primary metabolites of plant may have profound effects on the plant-insect interaction. Insecticide-induced changes in plant quality even have been implicated in resurgence of brown planthopper on rice (Chelliah & Heinrichs, 1980; Buenaflor et al., 1981; Heinrichs & Mochida, 1984). When rice plants treated with jingganmycin, sucrose significantly declined at 5 d after treatments, the C/N ratio also significantly decreased at 5 d and 10 d after treatment. The result was consistent with one in the honeydew experiment that the effects of treatment may last no longer than 15 d. In the case of bisultap treatment, significantly difference was only found in sucrose content at 5 d after treatment. Our results indicated that there might be different between effects of jingganmycin and bisultap. No significant changes in content of total free amino acid of treated plants had been detected in our experiments.

Some specific amino acid may also play important role in the interaction of rice plant and *N. lugens*. Effective amino acids tend to reduce the number of attempts to probe and increase the honeydew excretion as a result of the promotion of sustained sucking, while others exert a marked sucking inhibitory effect on BPH (Sogawa, 1982). Feeding rate and fecundity

Table 7. Contents of free amino acids and sucrose in the rice plant 5 d and 10 d after treatments with two pesticides at two different dosages

Pesticide	Rate (g a.i.ha^{-1})	Free amino acid (μg g^{-1}) 5d	Free amino acid (μg g^{-1}) 10d	Sucrose (μg g^{-1}) 5d	Sucrose (μg g^{-1}) 10d	C/N 5d	C/N 10d
Jingganmycin	75	3.688 ± 0.722A	3.725 ± 0.527a	0.538 ± 0.054A	0.298 ± 0.062a	0.146A	0.080a
Jingganmycin	150	3.500 ± 1.190A	5.682 ± 1.159a	0.575 ± 0.031A	0.275 ± 0.076a	0.164A	0.048a
Bisultap	405	1.638 ± 1.087A	2.576 ± 1.086a	0.975 ± 0.053A	0.517 ± 0.126a	0.596B	0.201b
Bisultap	675	2.340 ± 0.297A	3.166 ± 0.317a	0.993 ± 0.357A	0.569 ± 0.327a	0.424B	0.180b
CK		2.757 ± 0.594A	3.110 ± 0.487a	1.785 ± 0.072B	0.869 ± 0.290a	0.648B	0.280b

There are no significant differences between treatments with the same letter within a column (P > 0.05, LSD test).

of BPH were found positively or negatively related with content of some specific amino acid (Zhang & Gu, 1985). Although the total free amino acid was not affected by the pesticide treatment in our experiments, some amino acids significantly altered after pesticide application. For example, the concentration of γ-aminobutyric acid, which exist in resistant cultivar Mudgo with high content (Sogawa, 1970), was significantly lower in bisultap and jingganmycin treated plants, with 21.17% and 35.58% lower than that in the control. Lysine, which is negatively related with survival rate of BPH (Zhang & Gu, 1985), also significantly decreased after bisultap and jianganmucin applications (J. C. Wu et al., unpublished data).

Bisultap, jingganmycin and methamidophos are commonly used for controlling rice pests in China. Each of them was applied 2–3 times every crop season. Better understanding of their effects on plant susceptibility and herbivores may provide new insight into the evaluation of effects of pesticides in this system and be beneficial for the IPM in fields. More interestingly, among the three pesticides, jingganmycin is an antibiotic pesticide. Few studies have concerned its side effects of its application in the fields. Our results clearly indicated that, applying on rice plants, jingganmycin also had significant effects on BPH feeding and plant susceptibility to the insects. Although our results were from laboratory and semi-field experiments, they suggest that further study may be deserved to elucidate the interactions of pesticides, plants and herbivores.

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