Quantitative measurement of the influence of repeated pesticide application on food intake of *Ummeliata insecticeps* by the fluorescence labeling method

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Abstract: By applying a patented technique, the quantitative analysis of food intake using the fluorescence tracer as it is transferred in the food chain, we studied the food intake of *Ummeliata insecticeps* (Bosenberg *et* Strand) when exposed to pesticide buprofezin repeatedly. The results showed that food intakes of the surviving spiders in all treated groups were much less than that in the control group. Food intake of surviving *U. insecticeps* sprayed with buprofezin for the first time was less than that of the surviving spiders sprayed with the pesticide for the second or third time when buprofezin was diluted. It took a long time for the surviving spiders to recover when sprayed with the pesticide at high concentrations. Since the applying pesticides could bring high mortality to the spider, food intake of *U. insecticeps* population greatly decreased in 13 days after being sprayed with buprofezin. Though the surviving spiders in the treated groups ate even more than the control individuals on the 13th day, no pesticide was worth spraying because food intake of the population in the treated groups was less than that in the control group due to the high mortality of the population.

Key words: *Ummeliata insecticeps*; *Sogatella furcifera*; fluorescence labeling method; food intake; repeated pesticide exposure

Spiders are among the essential predators which prey on insects in rice paddies. There are more than 370 spider species in Chinese rice planting areas, accounting for 51.2% to 89.5% of the total predator species (Wang *et al*., 1999). Spiders are effective predators because of several traits, including their vigorous predation habits, strong starvation endurance, and large population sizes in a variety of species (Wang, 1981; Reichert and Lockley, 1984; Sunderland *et al*., 1986; Nyffeler and Benz, 1987; Bogya and Mols, 1996; Marc *et al*., 1999; Xiao *et al*., 2006). *Ummeliata insecticeps* (Boesenberg *et* Strand) is one of the constant dominant spider species in most of the Chinese rice planting areas. Because applying pesticides to control pests is prevalent nowadays, predators like spiders in rice paddies suffer greatly from the chemicals. Pesticides affect the spider fitness by disturbing their survival, growth, development, immunity, activity, metabolism and so on (Xu *et al*., 1984; Baatrup and Bayley, 1993; Punzo, 1997; Jagers *et al*., 1995). Suffering from pesticides, the predator populations will lighten the predatory pressure on pest populations in the rice ecosystem, which may cause the resurgence of the target pests and the eruption of the non-target pests, and make the rice planting depend on pesticides even more. Therefore, studying the influence of pesticides on the predators' food intake is one of the most important items to comprehensively evaluate the ecological effect of pesticides. Due to lack of effective techniques, however, there were just a few reports on qualitative measurement of the food intake of predators exposed to pesticides (Xu *et al*., 2000; Widiarta *et al*., 2001).

By using the quantitative analysis technique (Wang *et al*., 2001), the food intake of *U. insecticeps* exposed to the pesticide repeatedly was quantitatively determined, and a theoretical basis was proved for intelligent use of pesticides and allows us to integrate pest management in rice cultivation. The lanthanide chosen for the experiment, europium, can be absorbed by the rice plant from the soil. *Sogatella furcifera* eats the plants, while *U. insecticeps* preys on

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S. furcifera for food. Therefore, the europium enters into the *S. furcifera* bodies and accumulates in *U. insecticeps* bodies. By applying a series of chemical analyses such as extraction/invert extraction to the treated *U. insecticeps* and *S. furcifera* specimens, the food intake of *U. insecticeps*, which has been sprayed with pesticides for three times, can be measured. By taking the mortality of the spiders into account, the food intake of the experimental spider population exposed to pesticides can also be measured.

1 MATERIALS AND METHODS

1.1 Materials

Rice variety Jinyou 974 was used, which was one of early-season hybrids. The test pest and spider species was *S. furcifera* and *U. insecticeps*, respectively. Both *U. insecticeps* and *S. furcifera* were collected from a rice paddy in a western suburb of Changsha, Hunan Province, China. Only healthy, uninjured individuals were collected for the test.

Pesticide buprofezin (25% wettable powder, Pesticide Factory of Jilin Chemical Corporation), whose molecular formula is $C_{16}H_{23}N_3OS$, was used in the study. It is a low-toxic chemical that kills the target insects by preventing the synthesis of chitin, and routinely applied at 20 – 30 g/667 m^2. The recommended concentration is buprofezin : water = 1:2 000 – 3 000.

1.2 Apparatus and Chemicals

Apparatus: Fluorescence spectrophotometer (RF-5301PC Shimadzu, Japan), Automatic Double Pure Water Distiller (BSZ-2, Shanghai Zhisun Instruments Co., Ltd.), Electronic Analytical Balance (FA1104, Shanghai Balance Instrument Factory), Cabinet-type Resistance Furnace (SRJX-3-9, Changsha Electric Furnace Factory), PH Meter (PHS-3C, Shanghai Zhisun Instruments Co., Ltd.), Conviron Plant Growth Chamber (LRH-250-GS, Guangdong Medical Appliance Factory), Constant Temperature Drying Oven (DHG-9031-A, Shanghai Jinghong Laboratory Instrument Co., Ltd.), Stereomicroscope, Separatory Funnel, Plastic Planting Tub, Gauze hood;

Chemicals: HNO_3, HCl, H_2O_2, Eu_2O_3, *etc*.

1.3 Methods

1.3.1 Sample collection: The rice sprouts were transplanted into plastic tubs covered by gauze hoods on April 28, 2006. A solution of Eu_2O_3 dissolved in water at a concentration of 40 mg/kg was poured into the planting tubs on May 10 so that the Eu^{3+} could be absorbed by the rice roots.

The *S. furcifera* adults were collected from a rice paddy in a west suburb of Changsha during the rice maturing stage. The *S. furcifera* were put into the gauze hood and allowed to feed on the rice plants for 72 h, after which they were recollected. Among the recollected *S. furcifera*, 19 individuals were used for measuring europium content in their bodies and others were offered to the treated spiders for food. The 19 individuals were separated into 8 portions. Each portion was tested twice. The average europium content of the 19 individuals was taken as the europium content in an individual *S. furcifera* body.

The *U. insecticeps* adults were collected at the same time as the *S. furcifera* adults were collected, but they were taken from a fallow field, which had not been sprayed with any chemicals for over 3 years. Each spider was weighed with the electronic analytical balance and then put into a 30 ml cuvette with a little wet cotton on the bottom to provide suitable humidity. No food was offered to the spiders for 48 h. The spiders were separated into four groups: three treated groups and one control group, each group with 20 individuals. The 3 diluted buprofezin at concentrations of 1:5 000, 2:5 000 and 3:5 000 were applied to the treated groups, while pure water to the control group. The treated groups were sprayed 3 times with the pesticide, on June 15, June 30, and July 15, respectively. A mini atomizer was used to spray the buprofezin solutions on the spider backs until their backs were wet (Fabellar and Heinrich, 1984). Then each spider was removed to a 250 ml beaker with wet cotton on the bottom and all the beakers were put into the plant growth chamber (20℃ ± 1℃). On the 2nd day, the 5th day, the 9th day and the 13th day after each spray of the pesticide solutions or water, two steps were taken: First, the number of dead *U. insecticeps* individuals in each group were checked, recorded, and the dead individuals were eliminated. Second, each surviving spider was supplied with 10 *S. furcifera* individuals, which had been fed on the europium-marked rice for 72 h. All the spiders were collected again 24 h later. The spiders collected at the same time and belonging to the same group were put together for measuring europium content in their bodies. The experiment was replicated 3 times. The mean value was taken as the europium content of *U. insecticeps* individuals of the corresponding group.

1.3.2 Measurement and analysis of the europium content: According to the technique patented by our laboratory, the quantitative analysis of food intake by the fluorescence tracer transferred into the food chain (Wang *et al*., 2001), the recollected fly louses and spiders were processed by steps as follows to get the europium content: (1) Cineration and nitration of the samples and its dissolution; (2) Extraction and invert extraction of europium from the solution to form the europium-complex; (3) The europium-complex is excited by the wavelength of 390 nm with RF-5301PC fluorescence spectrophotometer and emits fluorescence at the wavelength of about 612 nm; (4) Calculation of europium content in the plant hoppers or spider bodies according to the standard curve equation of the fluorescent tracing method.

1.4 Data analysis

Standard curve equation (Wang *et al*., 2001): $y = -0.8344 + 177.0988x$, x is the europium content (μg) and y is value of the fluorescent spike.

Europium content (μg) = (fluorescent spike value + 0.8344) /177.0988

Food intake of *U*. *insecticeps* (ind.) = Europium content of *U*. *insecticeps* (μg/ind.) /Europium content of *S*. *furcifera* (μg/ind.)

Mortality = the number of dead individuals/the number of treated individuals × 100%

Food intake rate of the spider community = [mean food intake of the individuals in the treated group × (1 − $\text{mortality}_{(t)}$)]/[mean food intake of the individuals in the control group × (1 − $\text{mortality}_{(u)}$)]

The data accorded with the normal distribution. The variances of all the data groups were homogeneous according to the methods of the *Bartlett test* for homogeneity of several variances (Neter *et al*., 1996). The variance analysis was conducted according to the fixed model of three-factor analysis of variance. Multiple comparison of the means was carried out by the method of LSD (least significant difference) (Thomas and Kevin, 2001). All the analyses were carried out with SPSS 11.5 software.

2 RESULTS AND ANALYSIS

2.1 Food intake of *U*. *insecticeps* individuals exposed to the pesticide repeatedly

2.1.1 Europium contents in *S*. *furcifera* and *U*. *insecticeps* individuals: The europium contents of *S*. *furcifera* and *U*. *insecticeps* specimens were determined by testing fluorescent intensities in their bodies. The results are listed in Table 1 and 2.

Dividing the total europium contents (0.166 μg) by the total number of individuals (19), we got *S*. *furcifera* individual content of europium (0.009 μg) averagely.

Table 1 Contents of Eu^{3+} in *Sogatella furcifera* individuals

Number of *S*. *furcifera* treated (ind.)	Total dry weight (mg)	Intensity of fluorescence	Contents of Eu^{3+} (μg)	Eu^{3+} content per individual (μg/ind.)
3	1.000	2.708	0.020	0.007
2	0.800	3.062	0.022	0.011
2	0.700	3.062	0.022	0.011
3	1.800	3.770	0.026	0.009
3	2.400	1.999	0.016	0.005
2	1.650	3.239	0.023	0.012
2	1.550	2.530	0.019	0.010
2	1.200	2.353	0.018	0.009
$\sum$ 19	$\bar{x}$ 0.584		$\sum$ 0.166	$\bar{x}$ 0.009

Table 2 Contents of Eu^{3+} in the *Ummeliata insecticeps* survivals exposed to the pesticide buprofezin

Concentration of pesticide	Spraying	Europium contents (μg/ind.)				Mean value
		2nd day	5th day	9th day	13th day	
0:5 000	CK	0.024	0.016	0.017	0.019	0.019
1:5 000	1st	0.005	0.006	0.009	0.008	0.007
	2nd	0.008	0.014	0.014	0.015	0.013
	3rd	0.010	0.015	0.015	0.015	0.014
	Mean value	0.008	0.012	0.013	0.013	
2:5 000	1st	0.006	0.006	0.009	0.013	0.008
	2nd	0.011	0.016	0.017	0.020	0.016
	3rd	0.009	0.015	0.017	0.017	0.015
	Mean value	0.008	0.013	0.014	0.017	
3:5 000	1st	0.004	0.010	0.013	0.023	0.013
	2nd	0.007	0.009	0.011	0.020	0.012
	3rd	0.009	0.011	0.011	0.023	0.013
	Mean value	0.007	0.010	0.012	0.022	

2.1.2 Food intake trend of *U. insecticeps* individuals sprayed with buprofezin for three times: According to the data of Europium contents in *U. insecticeps* and *S. furcifera* individuals, food intake of *U. insecticeps* individuals exposed to buprofezin is calculated. Food intake of the *U. insecticeps* surviving individuals sprayed 3 times with three concentrations of the pesticide are shown in Fig. 1, where the *y*-axis represents food intake of the surviving spiders, and *x*-axis respresents the day after spraying buprofezin.

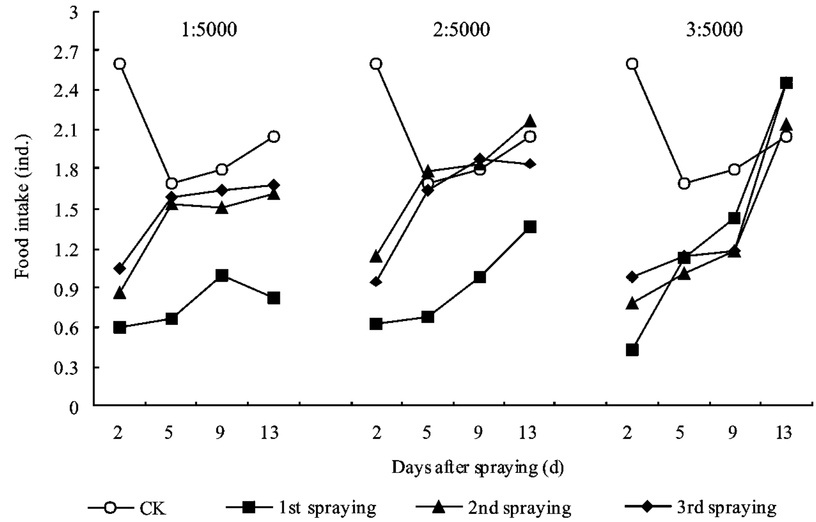

Fig. 1 Food intake of *U. insecticeps* survivals which were exposed 3 times to the pesticide

From Fig. 1 we notice that the food intake curve of the control group is concave. They preyed food most on the 2nd day and preyed least on the 5th day. Reasons could be that the spiders were starving on the 2nd day because no food had been supplied for 48 h before experiment. When they gorged themselves with *S. furcifera* for the first time they relaxed and didn't prey actively in the following couple of days. Then their food intake amount would get back to normal. It can also be seen from Fig. 1 that the food intake of the spiders sprayed with the pesticide for the first time was much less than those of the spiders sprayed with the pesticide for the second and the third time when the buprofezin diluted with water was 1 to 5 000 or 2 to 5 000. When spiders sprayed with buprofezin diluted in water at a concentration of 3 to 5000, food intakes of the treated groups were all greater than that of the control group on the 13th day.

2.1.3 Variance analysis on food intake of *U. insecticeps* groups: Taking three-way-variance analysis on the average food intake within 13 days of the control group and the treated groups which were sprayed with buprofezin three times, the results are shown in Table 3.

Table 3 Three-way-variance analysis on food intake of the spiders which were exposed to the pesticide three times

Source	Sum of squares	*df*	Mean square	*F*	Significance
Corrected model	8.829[a]	8	1.104	6.194	0.000
Intercept	108.478	1	108.478	608.796	0.000
Concentration of the pesticide	4.782	3	1.594	8.946**	0.000
Spray times	1.316	2	0.658	3.692*	0.034
The day after spraying	2.731	3	0.910	5.110**	0.004
Error	6.949	39	0.178		
Total	124.256	48			
Corrected total	15.778	47			

a: R Squared = 0.560 (Adjusted R Squared = 0.469). *: The difference is significant at the 0.05 level. **: The difference is significant at the 0.01 level.

It can be seen from Table 3 that among the three factors, influence of the spraying time on the food intake of *U. insecticeps* is statistically significant, while influences of concentration of the pesticide and the day after spraying are both extremely significant. Results of multiple comparisons on individual food intake of the groups are listed in Table 4.

Table 4 Multiple comparison on food intake of the spiders which were exposed to the pesticide three times

Comparing items	Comparing groups	Compared groups	Mean difference	Standard error	Significance	95% confidence interval	
						Lower bound	Upper bound
Concentrations of the pesticide	CK	1:5 000	0.825**	0.172	0.000	0.477	1.174
		2:5 000	0.628**	0.172	0.001	0.279	0.977
		3:5 000	0.675**	0.172	0.000	0.326	1.023
	1:5 000	2:5 000	-0.197	0.172	0.260	-0.546	0.151
		3:5 000	-0.151	0.172	0.388	-0.499	0.198
	2:5 000	3:5 000	0.045	0.172	0.788	-0.302	0.395
Spray times	1st time	2nd time	-0.335*	0.149	0.030	-0.637	-0.033
		3rd time	-0.365*	0.149	0.019	-0.667	-0.063
	2nd time	3rd time	-0.030	0.149	0.842	-0.332	0.272
Days after spraying	2nd day	5th day	-0.082	0.172	0.637	-0.431	0.267
		9th day	-0.232	0.172	0.187	-0.580	0.117
		13th day	-0.621*	0.172	0.001	-0.970	-0.272
	5th day	9th day	-0.149	0.172	0.391	-0.498	0.199
		13th day	-0.539*	0.172	0.003	-0.888	-0.190
	9th day	13th day	-0.340*	0.172	0.029	-0.738	-0.041

* :The mean difference is significant at the 0.05 level. ** :The difference is significant at the 0.01 level.

According to the results of Table 4, food intake of the control group is obviously greater than that of the treated groups, in which buprofezin concentrations are 1 : 5 000, 2 : 5 000 and 3 : 5 000, respectively. The difference between food intake of the control group and that of the treated groups is extremely significant. However, the food intake differences among the three treated groups are not statistically significant. As far as the spray times are concerned, food intake of the spiders sprayed with buprofezin for the first time is less than those of the spiders sprayed with buprofezin for two or three times, and the difference between them is statistically significant. When it comes to the day after spraying, it can be seen that food intake of the treated spiders increased with time. A significant difference exists between food intake of the spiders on the 13th day after spraying buprofezin and on other days.

2.2 Food intake of *U. insecticeps* population exposed to the pesticide repeatedly

2.2.1 Lethality of the pesticide to *U. insecticeps*: The mortality rates of the spider groups are shown in Fig. 2. The y-axis representatives the mortality and the x-axis representatives the day after spraying.

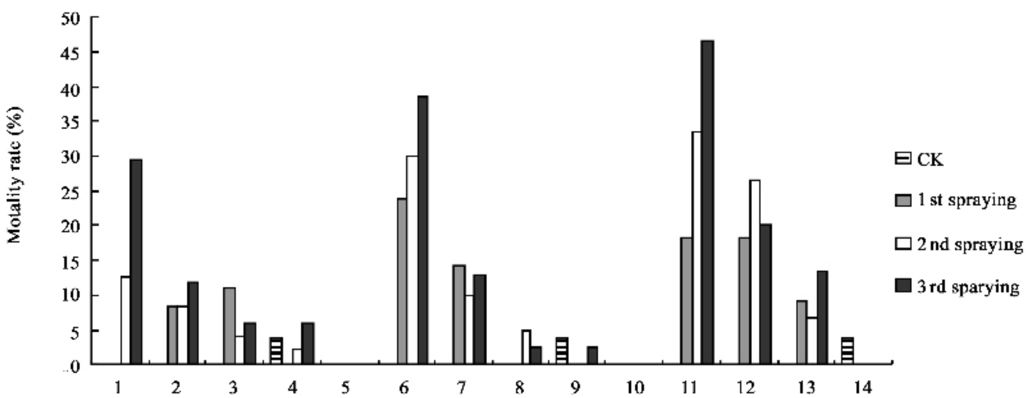

Fig. 2 Mortality rates of the treated groups

It can be seen that high death rates of the treated groups occurred in 2 - 5 days after spraying buprofezin. As the time interval increases, the mortality decreased gradually. Unlike the fact that the first time spraying effects the food intake of *U. insecticeps* surviving individuals more than that of the second or third time, the mortality of the spiders that suffered from buprofezin for the first time is relatively low. The death number became greater and greater as the treated groups repeatedly suffered form buprofezin and as the pesticide concentration became higher. Within 13 days, the total mortality of the treated groups sprayed with the solution of 1 : 5 000, 2 : 5 000 and 3 : 5 000 are 34.33%, 46.25% and 76.31%, respectively, which are much more than that of the control group (3.85%). It can be concluded that the toxicity of the pesticide caused high mortality to the treated spider groups.

2.2.2 Food intake of *U. insecticeps* population exposed to the pesticide repeatedly: Based on the data of mortality and the individual food intake of the treated groups and the control group, the population food intakes of the three treated groups is calculated in comparison with that of the control group (Table 5).

Table 5 Population food intake rate of the treated groups compared to the control group

Spraying	Population food intake rate (%)			Mean values
	1:5 000	2:5 000	3:5 000	
1st	31.58	34.03	32.81	32.81
2nd	43.56	48.63	25.80	39.33
3rd	40.93	26.90	14.71	27.51
Mean values	38.69	36.52	24.44	

If the mortalities of the spider groups are taken into account, food intake of the population in the treated groups is much less than that of the control group during the 13 days being exposed to the pesticide. When spiders were sprayed with the pesticide repeatedly, the population food intake of the group sprayed with buprofezin of high concentration (diluting 3 to 5 000) decreased the most, only about a quarter of the food intake of the control population (24.44%), while the population food intake of the groups sprayed with buprofezin at recommended concentrations (diluting 1 or 2 to 5 000) also decreased to about one third of food intake of the control population (38.69% and 36.52%). Therefore, application of the pesticide buprofezin affects the control capacity of *U. insecticeps* on *S. furcifera*.

3 DISCUSSION

3.1 Spider food intake can be quantitatively measured by the fluorescent labeling method

It is a challenge to measure the food intake of natural predators on target pests quantitatively. Some new techniques such as the serological method (Zhou, 1989) and enzyme-linked immunosorbent assay (Zhang *et al*., 1997; Lim and Lee, 1999) were applied to evaluate the natural enemy predation instead of traditional "eyeballing". However, these methods can only determine whether the predator eats the target insects or not. The fluorescent labeling method is one of the desired techniques for quantitatively analyzing food intake of the small predators. Some theses applying this method to measure spider food intake have been published in China (Hu *et al*., 2002; He *et al*., 2003; Wen *et al*., 2003; Xiao *et al*., 2006). By applying the fluorescent tracer into the food chain, this experiment determines the consumption rate of *U. insecticeps*, which were sprayed with the pesticide 3 times at various concentrations, on *S. furcifera* quantitatively. The fluorescent labeling method can be one of the quantitative techniques for evaluating the influences of pesticides on predator food intake.

3.2 Effects of concentration and spraying times of the pesticide on spiders food intake

In this experiment, food intakes of the surviving spiders in all treated groups are much less than that of the control group on the 2nd day after spiders were sprayed the pesticide solutions. That is, no matter which spraying time or what the concentration is, the pesticide affects the predation of *U. insecticeps* on *S. furcifera* in a short time. It can be deduced that the *U. insecticeps* survivals were poisoned when exposed to the pesticide. The pesticide would have decreased the spider metabolic rate or disordered their other physiological functions. Therefore, the survivals were not able to catch the prey successfully or probably they lost their appetite because of the toxicity of the pesticide.

Food intake of surviving *U. insecticeps* which were sprayed with the pesticide for the first time was less than that of the survivals sprayed for the second or third time when the pesticide was diluted in relatively low concentrations. It can be seen from Fig. 1 that at the first time the spiders suffered from the pesticide (in the diluted concentrations of 1:5 000 and 2:5 000), their food intake did not recovered within 13 days. When they were exposed to the pesticide for the second or the third time, however, it just took 5 days for their food intake to recover. This indicates that *U. insecticeps* individuals are hypersensitive when they contact the pesticide for the first time. They have strengthened their resilience when they were sprayed the pesticide repeatedly. That is why they can recover more quickly than the first time they were exposed to the pesticide.

It took a long time for the surviving spiders to recover when they were sprayed with the pesticide at high concentration (diluted in 3 to 5 000). But once they recovered they preyed on more *S. furcifera* for food than the individuals in the control group. The reason could be the two sides of the coin. On one hand, the physiological function of the surviving spiders is damaged a lot by the pesticide at high concentrations. They lost their appetite to the prey or their vigor and other capabilities in capturing their prey for a long time period. On the other hand, because the surviving spiders had been in the state of hunger or semi-hunger for a long time, they were hungry for food and would prey more actively when they recovered.

However, food intake of *U. insecticeps* which was exposed to the pesticide buprofezin was just measured in the laboratory. It is worthwhile to compare the results from the laboratory experiment to those from paddy fields to further study the effects of pesticides on spider food intake.

3.3 Not to apply the pesticide rashly

The chosen pesticide buprofezin is one of the insect growth regulators. It works by preventing the insects from synthesizing chitin and disturbing their metabolism. The target insects are killed by touching the poison or by the gastric toxicity created by the insecticide. The buprofezin concentrations used in the experiment are around 50%, 100% and 150% of the recommended concentration. The results showed that the population food intakes of all the treated groups decreased sharply after spraying the insecticide. The phenomenon that some surviving spiders ate even more than the control individuals on the 13th day after being sprayed with the insecticide is not worthwhile because it is at cost of some other individuals' death in the population. Besides, the pesticide decreased the predatory capacity of *U*. *insecticeps* population for about 2 – 9 days after spraying the pesticide, even if at the recommended concentration. The higher the concentration is, the more times *U*. *insecticeps* suffers from the pesticide, and the higher the spider mortality will be and the longer time the surviving individuals will need to recover their predatory capacity. Pests below economic threshold will not hurt the rice but a favorable condition is created for the stability of the predator populations. Integrative effect of predators on the pests should be take into account when dealing with the insect pest in paddy ecosystem. It is unadvisable to apply pesticides hastily as soon as the pests show up. The interval between the two times of applying pesticides should be as long as possible so that the predator population could rebuild and reactivate.

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References

Baatrup E, Bayley M, 1993. Effects of the pyrethroid cypemethrin on the ocomotor activity of the wolf spider *Pardosa amentata*: quantitative analysis employing computer automated video tracking. *Entomol*. *Environ*. *Safety*, 26: 138 – 152.

Bogya S, Mols PJM, 1996. The role of spiders as predation of insect pests with particular reference to orchards: a review. *Acta Phytopath*. *Entomol*. *Hung*., 31: 83 – 159.

Fabellar LT, Heinrich EA, 1984. Toxicity of insecticides to predators of rice brown planthoppers, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Environ*. *Entomol*., 13(3): 832 – 837

He YY, Wen DD, Hu LX, Wang HQ, 2003. A quantitative study on the food chain of late-season rice-*Nilaparvata lugens* Stål-*Pirata subpiraticus* (Bosenberg Strand). *Acta Entmol*. *Sin*., 46(6): 727 – 731. [贺一原, 文斗斗, 胡良雄, 王洪全, 2003. 水稻-褐飞虱-拟水狼蛛食物链的定量研究. 昆虫学报, 46(6): 727 – 731]

Hu ZQ, He YY, Yan HM, Yang HM, Zhu ZR, Wang HQ, 2002. Quantitative measurement of nutritive relationship of the food chain: rice plant-leafhoppers-spiders by the fluorescence labeling method. *Acta Ecologica Sinica*, 22(7): 1 079 – 1 084. [胡自强, 贺一原, 颜亨梅, 杨海明, 朱泽瑞, 王洪全, 2002. 荧光物示踪法定量测定水稻-叶蝉-蜘蛛食物链的营养关系. 生态学报, 22(7): 1 079 – 1 084]

Jagersop Akkerhuis, van Straalen NM, van Straalen NM, 1995. Water balance, respiration and immobilization in relation to deltamethrin poisoning and physical conditions in the epigeal spider. *Pestic*. *Sci*., 44: 123 – 130.

Lim UT, Lee JH, 1999. Enzyme-linked immunosorbent assay used to analyze predation of *Nilaparvata lugens* (Hommoptera: Delphacidae) by *Pirata subpiraticus* (Araneae: Lycosidae). *Environ*. *Entomol*., 28(6): 1 177 – 1 182.

Marc P, Canard A, Ysnel F, 1999. Spiders (Araneae) useful for pest limitation and bioindicattion. *Agri*. *Ecosyst*. *Environ*., 74: 229 – 273.

Neter J, Kutner MH, Nachtsheim CJ, Wasserman W, 1996. Applied Linear Statistical Models. 4th ed. Illinois: Irwin.

Nyffeler M, Benz G, 1987. Spiders in natural pest control: a review. *J*. *Appl*. *Ecol*., 104: 190 – 197.

Punzo F, 1997. Effects of Azadirachtin on mortality, growth, and immunoligical fnction in the wolf spider, *Schizocasa episina* (Araneae: Lycosidae). *Bull*. *Environ*. *Contam*. *Toxicol*., 58: 415 – 421.

Reichert SE, Lockley T, 1984. Spiders as biological control agents. *Ann*. *Rev*. *Entomol*., 29: 299 – 320.

Sunderland KD, Fraser AM, Dixon AFG, 1986. Field and laboratory studies on money spiders (Linyphiidae) as predators of cereal aphids. *J*. *Appl*. *Entomol*., 23: 433 – 477.

Thomas G, Kevin M, 2001. An Introduction to Biostatistics. The McGraw-Hill Companies, Inc.

Widiarta IN, Masaya M, Suzuki Y, Nakasuji F, 2001. Effects of sublethal doses of imidacloprid on the fecundity of green leafhoppers, *Nephotettix* spp. (Hemiptera: Cicadellidae) and their natural enemies. *Appl*. *Entomol*. *Zool*., 36(4): 501 – 507.

Wang HQ, Yang HM, Li CZ, Zhu ZR, He YY, Hu ZQ, Yan HM, Li HH, 2001. The Method of Quantitative Analysis on the Flow of Labeled Substance Trough Food Chain. China Patent Annoucement No. 01114479.37. Beijing: Intellectual Property Publishing House. [王洪全, 杨海明, 李承志, 朱泽瑞, 贺一原, 胡自强, 颜亨梅, 黎红辉, 2001. 食物链传递标记物定量分析法. 公布号: 01114479.37. 北京: 知识产权出版社]

Wang HQ, Yan HM, Yang HM, 1999. Preliminary studies on the community structure of paddy field spiders in China. *Acta Arachnologica Sinica*, 8(2): 95 – 105. [王洪全, 颜亨梅, 杨海明, 1999. 中国稻田蜘蛛群落结构研究初报. 蛛形学报, 8(2): 95 – 105]

Wang HQ, 1981. Research on Conservation and Utilization of Spiders in Paddy field. Changsha: Hunan Science and Technology Press. [王洪全, 1981. 稻田蜘蛛保护与利用. 长沙:湖南科技出版社]

Wen DD, He YY, Lü ZY, Yang HM, Wang HQ, 2003. A quantitative study of biomass flow in the rice-*Sogatella furcifera*-*Pirata subpiraticus* food chain using fluorescent substance tracing. *Acta Entmol. Sin.*, 46 (2): 178 – 183. [文斗斗, 贺一原, 吕志跃, 杨海明, 王洪全, 2003. 水稻-白背飞虱-拟水狼蛛食物链中生物量流动的定量研究. 昆虫学报, 46(2): 178 – 183]

Xiao YH, He YY, Yang HM, 2006. The starvation endurance of *Ummeliata insecticeps*. *Acta Ecologica Sinica*, 6(6): 1 725 – 1 731. [肖永红, 贺一原, 杨海明, 2006. 食虫沟瘤蛛饥饿耐受性研究. 生态学报, 6(6): 1 725 – 1 731]

Xiao YH, He YY, Liu F, Yang HM, 2006, Quantitative measurement of influence of herbicides on food intake of *Ummeliata insecticeps* by the fluorescence labeling method. *Acta Entomol. Sin.*, 49 (4): 630 – 635. [肖永红, 贺一原, 柳丰, 杨海明, 2006, 荧光物示踪法测定除草剂对食虫沟瘤蛛摄食量的影响. 昆虫学报, 49(4): 630 – 635]

Xu JX, Wu JC, Cheng XN, Ji MS, Dai JQ, 2000. The effects of two insecticides on predation function of predatory natural enemies. *Acta Ecologica Sinica*, 20(1): 145 – 149. [徐建祥, 吴进才, 程遐年, 2000. 两种杀虫剂对稻田捕食性天敌集团捕食功能的影响. 生态学报, 20 (1): 145 – 149]

Xu X, Luo YC, Zhu QM, 1984. Toxicity of several insecticides to spiders in paddy fields. *Natural Enemies Insects*, 6(1): 28 – 31. [许雄, 罗玉钏, 朱铨铭, 1984. 几种杀虫剂对稻田蜘蛛的毒性试验. 昆虫天敌, 6(1): 28 – 31]

Zhang GR, Zhang WQ, Gu DX, 1997. Application of ELISA method for determining control effects of predatory arthropods on rice plant hopper in rice fields. *Acta Entomol. Sinica*, 40(2): 171 – 176. [张古忍, 张文庆, 古德祥, 1997. 用 ELISA 研究稻田节肢类捕食者对稻飞虱的捕食作用. 昆虫学报, 40(2): 171 – 176]

Zhou HH, 1989. A study on predation of natural enemies to three rice insect pests by serological method. *Acta Phytophyacica Sin.*, 16(1): 7 – 11. [周汉辉, 1989. 血清法探讨天敌对三种稻田昆虫的抑制作用. 植物保护学报, 16(1): 7 – 11]

荧光物示踪法测定重复施药胁迫下食虫沟瘤蛛的摄食量动态

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摘要:定量评价农药对天敌的影响是 IPM 研究的重要内容之一,由于对天敌的捕食量缺乏有效的定量测量方法,农药对天敌摄食功能影响仍处于定性水平的研究,误差基数较大。本文采用一种定量的测定方法——荧光物示踪法,以稀土元素铕作为荧光示踪物质,定量地测定了食虫沟瘤蛛在重复接受噻嗪酮喷施后,其存活个体在药后 13 天内摄食量的变化趋势,且把药后食虫沟瘤蛛的死亡率加以考虑,计算药后整个试验食虫沟瘤蛛群体的摄食量变化。结果表明:任何浓度任何一次施药后 2 天左右食虫沟瘤蛛存活个体的捕食量均急剧下降 药物浓度较低时,第 1 次施药对食虫沟瘤蛛的影响最大 药物浓度较高时,食虫沟瘤蛛存活个体药后摄食量恢复周期较长。药后一段时间内整个食虫沟瘤蛛种群的摄食率相当低下,高浓度农药处理的食虫沟瘤蛛组 3 次施药后 13 天内的平均种群摄食率只有正常状况下的 1/4 左右(24.44%),推荐浓度及低于推荐浓度的食虫沟瘤蛛种群摄食率也仅为对照组的1/3左右(38.69%,36.52%)。因此在对水稻虫害防治时,应当尽可能地避免使用化学农药,充分发挥天敌对害虫数量的调控作用 ;当害虫数量超过经济阈值而必须施药时,也应当掌握农药用药剂量和次数的尺度,以利于食虫沟瘤蛛等稻田天敌的生理恢复和群落重建。

关键词:食虫沟瘤蛛;白背飞虱;荧光物示踪;摄食量;重复施药

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