不同干扰因素对斜纹猫蛛 (*Oxyopes sertatus*) 和红彩真猎蝽 (*Harpactor fuscipes*) 捕食作用的影响

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摘要: 斜纹猫蛛和红彩真猎蝽均是烟草上斜纹夜蛾的重要捕食性天敌。室内测定几种干扰因素对斜纹猫蛛和红彩真猎蝽捕食作用的影响, 结果表明这些干扰因素对斜纹猫蛛种内、红彩真猎蝽种内和两种捕食者种间的捕食作用均有明显的干扰作用, 随捕食者数量的增加, 其对斜纹夜蛾捕食作用率显著降低。斜纹猫蛛种内的干扰系数和红彩真猎蝽种内的干扰系数分别为 0.7278 和 0.6911, 而两者种间的干扰系数为 0.9464, 说明两者种间的干扰作用要明显高于同一种捕食者种内的干扰作用。两种捕食性天敌对斜纹夜蛾的捕食量和捕食作用率随烟草茎杆数的增加而降低, 表明空间异质性同样是影响两种捕食性天敌捕食作用的一个重要因素。

关键词: 斜纹猫蛛; 红彩真猎蝽; 斜纹夜蛾; 相互干扰; 捕食作用

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Effect of interference factors on predations of *Oxyopes sertatus* (L.) Koch (Araneae: Oxyopidae) and *Harpactor fuscipes* (F.) (Hemiptera: Reduviidae) on *Spodoptera litura* (F.)

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Abstract: Both *Oxyopes sertatus* and *Harpactor fuscipes* are important predators of common cutworm (*Spodoptera litura*) on tobacco. The effect of several interference factors on the predations of *O. sertatus* and *H. fuscipes* on the larvae of *S. litura* were examined in laboratory. The results indicated that there were significant mutual interferences on their predations with the existence of other individual in the same/different species. As the number of the predator increased, the predation rates decreased significantly. The interference coefficients (m) within *H. fuscipes* and within *O. sertatus* were 0.7278 and 0.6911, respectively, while the interference coefficient (m) between *O. sertatus* and *H. fuscipes* was 0.9464. These results showed that the effect of mutual interference on predation in interspecies was more obvious than that in intraspecies.

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The number of prey captured and the predation rate of predator dropped with increasing the number of tobacco stalks. This result suggested that spatial heterogeneity was also an important factor affecting the predation of predator on prey.

Key Words: *Oxyopes sertatus*; *Harpactor fuscipes*; *Spodoptera litura*; mutual interference; predation

Natural enemy-pest interactions are of applied importance and of fundamental interest to ecologists [1-5]. A model for prey and predators is formulated in which three essential nutrients can limit growth of both populations. Prey takes up dissolved nutrients, while predators ingest prey [6]. The predation of predator on prey is determined by predator-prey density dependence and spatial heterogeneity [5,7,8].

An important aspect of a predator-prey system is the functional response of the predator to changing prey densities [9]. Search and pursuit times dropped with increasing prey density [9,10]. The form of the functional response is crucial in determining the significance of the predation and a predator may play a role in the dynamics of prey [11]. The predator may increase in population size with increasing prey, either when the prey is characterized by a positive effect of its own population size on its own growth rate or when the prey is overexploited by the predator [12,13]. In addition, the predation of predator on prey may be affected by spatial heterogeneity, even in situations where the external environment is uniform, modern analysis has shown that heterogeneities can be internally generated by the effects of limited movement and local interactions in space [7].

In the search for alternative methods to insecticides, the utilization of natural enemy for protecting crop plants from insect pests has assumed more importance in recent years. Hence the evaluation of efficacies of natural enemies on insect pests is a valuable field of ecological research. Considering the efficacies of natural enemies, especially the predations of predators, are often affected by various factors in the complex agroecosystem, these evaluations must be conducted under some interference conditions. In respect to predator, the density of prey, the predator's own population size and a heterogeneous space, etc., may interfere with their predations, so these interference factors should be considered and be afforded by artificial manipulation even if the predation experiments are conducted in the laboratory.

Tobacco caterpillar, *Spodoptera litura* (F.) is a major insect pest on tobacco causing damage by defoliation. Only a few natural enemies, so far, were applied to control of *S. litura*. Predator is an important factor for control of this insect pest in tobacco field. *Oxyopes sertatus* and *Harpactor fuscipes* are two important predators of the larvae of *S. litura*, so that the evaluation of predatory efficacies of the two predator species on *S. litura* larvae will make for biological control of this insect pest with the two predators. However, *O. sertatus* and *H. fuscipes* were found very little effect in reducing this insect pest population in tobacco field, and so far the phenomena were not considered by entomologists or ecologists. Consequently, the effect of different interference factors on predation of *O. sertatus* and *H. fuscipes* on *S. litura larvae* needs to be clarified, and this experiment aims to understand why the predations of the two species on *S. litura* larvae were so low. In addition, the results of this study will provide objective evidence for conservation and utilization of the two predators in the tobacco fields.

1 Material and methods

1.1 Experimental conditions

The larvae of a stock culture of *S. litura* originally collected from a tobacco field in Nanxiong, Guangdong, China in May 2005, and 2^{nd} instar larvae were selected for this study. The female adults of *O. sertatus* and *H. fuscipes* collected from a tobacco field in Nanxiong in May 2005 were separated from the host and food for 24 hours before this test was started. This study was carried out at 26.5 – 28.5 ℃ in laboratory. Test containers were glass incubators (the size of incubator was diameter × high = 150 mm × 25 mm).

1.2 Experimental methods

To examine the functional responses of *O. sertatus* and *H. fuscipes* to the larvae of *S. litura*, host larvae in the 2nd instar at different densities (Nt = 10, 15, 20, 25, 35) and one female predator adult were introduced into each incubator. Two groups of experiment were carried out at the same time, one group with *O. sertatus*, another group with *H. fuscipe*. In addition, control treatment was only put 20 the 2nd instar host larvae into each incubator without the predators. Each density treatment was replicated thrice. All glass incubators were observed after 24 hours and the number of prey captured and the number still alive were recorded.

To determine the effect of mutual interference within *O. sertatus* on its predation, one, two, three, four and five female *O. sertatus* adults were put into one incubator, respectively. Each incubator contains thirty larvae of *S. litura*. Each treatment was replicated thrice. At the same time, control treatment was only put 20 the 2nd instar host larvae into each incubator without the predators. All glass incubators were observed after 24 hours and the number of prey captured and the number still alive were recorded. The same method was used for the study of the effect of mutual interference within *H. fuscipe* on its predation.

To determine the effect of mutual interference with the existence of other individual in the same/different species on their predation, one female *O. sertatus* adult, one female *H. fuscipes* adult, one female *O. sertatus* adult together with one female *H. fuscipes* adult, two female *O. sertatus* adults together with one female *H. fuscipes* adult, one female *O. sertatus* adult together with two female *H. fuscipes* adults, two female *O. sertatus* adults together with two female *H. fuscipes* adults were put into one incubator, respectively. Each incubator contains thirty larvae of *S. litura*. Each treatment was replicated three times. All glass incubators were observed after 24 hours, and the number of prey captured and the number still alive were recorded.

To determine the effect of spatial heterogeneity on the predation of *O. sertatus*, zero, one, two, three, four, and five tobacco stalks (the size of stalk was diameter length = 10 mm × 80 mm) were put into six incubators, respectively. Each incubator contains thirty larvae of *S. litura*. For each incubator, one female *O. sertatus* adult was introduced for study. All glass incubators were observed after 24 hours and the number of prey captured and the number still alive were recorded. The same method was used for the study of the effect of spatial heterogeneity on the predation of *H. fuscipe*.

1.3 Statistical analyses

The data of functional responses was analyzed by formula of Holling: $N_a = aT N_t / (1 + a T_h N_t)$ because both the functional responses of *O. sertatus* and *H. fuscipes* to the larvae of *S. litura* belonged to the equation of Holling type-Ⅱ [4]. In this formula, N_t is the initial density of prey, N_a is the number of prey captured, a is search rate (arena d^{-1}), T is the total time of the experiment (d) and T_h is handling time. Predation rate (%) was E (%) $= 100 \times N_a / N_t P$, where E is predation, P is the number of predator. Then, search constant (Q) and interference coefficient (m) were calculated by $E = Qp^{-m}$ [5], respectively. Competition strength (I) caused by the same species of predator was calculated by $I = (E_1 - E_p) / E_1$ [5], where I is competition strength, E_1 is predation rate caused by one predator and E_p is predation rate caused by "P" predators.

2 Results

2.1 Functional responses

The functional responses of *O. sertatus* and *H. fuscipes* to the larvae of *S. litura* were found that the number of prey captured increased as the number of prey increased in a certain density level of prey (Table 1 and Fig. 1). In the model of the functional response of *O. sertatus* on the larvae of *S. litura*, search rate (a) was 0.3102 and handling time (T_h) was 0.0338, and the equation of functional response could be expressed as $N_a = 0.3102N_t/(+0.0105\ N_t)$. In the model of the functional response of *H. fuscipes* on to the larvae of *S. litura*, search rate (a) was 0.4679 and handling time (T_h) was 0.0075, and the equation of functional response could be expressed as $N_a = 0.4679N_t/(+0.0035\ N_t)$. The maximum number of prey captured caused by *O. sertatus* and by *H. fuscipes* were 29.59 and 133.33 host larvae, respectively.

Table 1 Number of *Spodoptera litura* captured by *Harpactor fuscipes* and *Oxyopes sertatus* in one day

Number of prey	*O. sertatus*	*H. fuscipes*
10	3.00 ± 1.00 cC	4.33 ± 0.58 eC
15	3.67 ± 0.58 cBC	6.67 ± 1.16 dC
20	4.33 ± 0.58 bcBC	10.00 ± 1.00 cB
25	6.00 ± 1.00 bB	12.00 ± 1.00 bAB
35	11.33 ± 1.53 aA	14.67 ± 1.53 aA

Notes: The natural mortality of larvae was 0 in control treatment. Mean ± SE; means followed by different uppercase letters and lowercase letters within the same column are significantly different at $P < 0.01$ and $P < 0.05$ level, respectively (ANOVA followed by Ducan's multiple range test, DMRT)

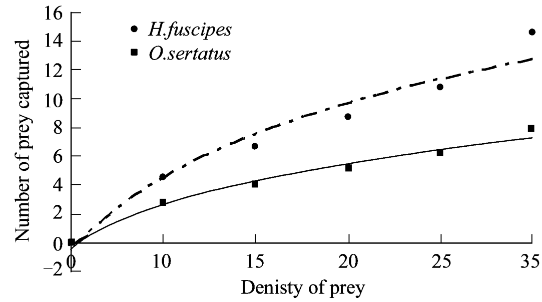

Fig. 1 Functional responses of *O. sertatus* and *H. fuscipes* to the larvae of *S. litura*

2.2 Mutual interference of predators on their predation

The results of our examination showed that the number of prey captured enhanced with increasing the density of *O. sertatus* or *H. fuscipes*, but their predation rates decreased. For *O. sertatus* or *H. fuscipes*, its predation rate caused by one predator was significantly higher than that of two predators or more than two predators (Table 2). These results showed that the effect of mutual interference on predation may exist in the same predator species. As seen in table 3, the same results were found, i.e. the predation rates dropped with increasing the density of the two predators, and testifying that the effect of mutual interference on predation may also exist between two different predator species.

Table 2 Effect of mutual interference on predation with the existence of other individual in the same species

Number of predator	Number of prey captured		Predation rate (%)	
	O. sertatus	*H. fuscipes*	*O. sertatus*	*H. fuscipes*
1	12.33 ± 1.53 dC	14.33 ± 2.08 cB	41.11 ± 5.09 aA	47.77 ± 8.34 aA
2	14.00 ± 1.00 cdBC	15.67 ± 1.53 bcB	23.33 ± 2.89 bB	26.12 ± 2.64 bB
3	16.33 ± 2.52 bcABC	17.33 ± 2.94 bcAB	18.14 ± 2.79 cBC	19.26 ± 2.31 bcB
4	18.67 ± 2.08 abAB	19.33 ± 2.08 abAB	15.56 ± 1.73 cBC	16.11 ± 1.73 cB
5	20.00 ± 1.00 aA	23.00 ± 1.73 aA	13.33 ± 0.67 cC	15.33 ± 1.41 cB

Notes: Mean SE. Means followed by different uppercase letters and lowercase letters within the same column are significantly different at $P < 0.01$ and $P < 0.05$ level, respectively (ANOVA followed by Ducan's multiple range test, DMRT)

Table 3 Effect of mutual interference on predation with the existence of other individual in the different species

Number of predator	Number of prey captured	Predation rate (%)
O. sertatus: 1	12.67 ± 1.16 aA	42.23 ± 3.85 aA
H. fuscipes: 1	14.00 ± 2.00 aA	46.67 ± 6.67 aA
O. sertatus: 1 + *H. fuscipes*: 1	13.33 ± 1.16 aA	22.22 ± 1.92 bB
O. sertatus: 2 + *H. fuscipes*: 1	13.67 ± 2.52 aA	15.19 ± 2.80 cB
O. sertatus: 1 + *H. fuscipes*: 2	14.00 ± 1.73 aA	15.56 ± 1.93 cB
O. sertatus: 2 + *H. fuscipes*: 2	14.67 ± 1.53 aA	12.23 ± 1.27 cB

Notes: mean ± SE. Means followed by different uppercase letters and lowercase letters within the same column are significantly different at $P < 0.01$ and $P < 0.05$ level, respectively (ANOVA followed by Ducan's multiple range test, DMRT)

Based on these data in table 2 and table 3, interference coefficient (m) and search constant (Q) were calculated for within the same predator species and between two different predator species (Table 4). The interference coefficients within *H. fuscipes* and within *O. sertatus* were 0.7278 and 0.6911, respectively, while the interference coefficient between *O. sertatus* and *H. fuscipes* was 0.9464. The results showed that the effect of mutual interference on predation in interspecies was more obvious than that in intraspecies. However, the difference in the search constant was found to be not significant among three interference factors.

Table 4　Interference coefficient (m) and search constant (Q)

Interference factor	m	Q
Within *H. fuscipes*	0.7278	1.6573
Within *O. sertatus*	0.6911	1.5990
Between *O. sertatus* and *H. fuscipes*	0.9464	1.6433

2.3　Competition strength of *O. sertatus* and *H. fuscipes*

For competition strength (I), as the number of predator increased, competition strength (I) of *O. sertatus* or *H. fuscipes* also enhanced, while the predation rate dropped (Table 5).

According to the data in table 5, the linear regression equations were calculated for competition strength and the number of *O. sertatus* and *H. fuscipes*, respectively (Table 6). Regression relationship of competition strength and the number of *O. sertatus* and *H. fuscipes* were expressed as $I = 0.0597 + 0.9571\lg P$ and $I = 0.0597 + 0.9571\lg P$, respectively. Both the linear regression equations revealed a significant positive correlation between I and $\lg P$.

Table 5　Competition strength (I) of *O. sertatus* and *H. fuscipes*

Number of predator	*O. sertatus*			*H. fuscipes*		
	$\lg P$	E	I	$\lg P$	E	I
1	0	0.4111	0	0	0.4777	0
2	0.3010	0.2333	0.4325	0.3010	0.2612	0.4532
3	0.4771	0.1814	0.5587	0.4771	0.1926	0.5968
4	0.6020	0.1556	0.6215	0.6020	0.1611	0.6628
5	0.6690	0.1333	0.6757	0.6990	0.1533	0.6791

Table 6　Regression relationship of competition strength (I) on predator's density (P)

Item	Regression equation	Correlation coefficient (r)
H. fuscipes	$I = 0.0686 + 0.9854\lg P$	0.9649**
O. sertatus	$I = 0.0597 + 0.9571\lg P$	0.9733**

** Independent variable and consequent variable are statistically correlation at $r < 0.01$ level

2.4　Effect of spatial heterogeneity on the predation of *O. sertatus* and *H. fuscipes*

The number of prey captured and the predation rate of predator on prey dropped with increasing the number of tobacco stalks (Table 7). There was a significant negative correlation between the predation rate and the number of tobacco stalks (Table 8).

Table 7　Effect of spatial heterogeneity on the predation of *O. sertatus* and *H. fuscipes*

Number of stalk	Number of prey captured		Predation rate (%)	
	O. sertatus	*H. fuscipes*	*O. sertatus*	*H. fuscipes*
0	12.00 ± 1.73aA	12.33 ± 1.16aA	40.00 ± 4.08aA	41.11 ± 3.85aA
1	11.33 ± 2.08aA	11.67 ± 1.53aA	37.77 ± 6.94aA	38.90 ± 5.09aA
2	11.00 ± 1.00aAB	11.33 ± 0.58aA	36.67 ± 3.34aAB	37.77 ± 1.92aA
3	9.67 ± 0.58abAB	8.67 ± 0.58bB	32.23 ± 1.92abAB	28.90 ± 1.92bB
4	8.33 ± 1.53bAB	7.00 ± 1.00cBC	27.77 ± 5.09bAB	23.33 ± 3.34cBC
5	7.67 ± 1.53bB	6.33 ± 0.58cC	25.57 ± 5.09bB	21.10 ± 1.92cC

Notes: mean ± SE. Means followed by different uppercase letters and lowercase letters within the same column are significantly different at $P < 0.01$ and $P < 0.05$ level, respectively (ANOVA followed by Ducan's multiple range test, DMRT)

3 Discussion

Although it may be practical to measure numerical responses in field settings, functional responses are usually determined in laboratory experiments. Quantitative components of the functional response curves such as handling time, search rate, *etc*. are difficult to be determined in the field because predation events are rarely observed [6-18]. Holling had reviewed in depth the two fundamental responses of predators to changes in the density of prey or predators. These were the functional responses, which was a change in the behavior of predator related to the change in the density of the prey and/or the density of the predators. Certainly, predator-prey interactions are complex and each component may need extensive study, and a model of full understanding is to be obtained [9]. Understanding how predators respond to variable conditions is a prerequisite to interpreting the consequences of predator-prey interactions on prey population size and community dynamics [6]. However, it is impossible that these studies are carried out, completely, in field. Thus, for reflecting predation of predator, the predation of predator on its prey should be determined at some interference factors in laboratory.

Table 8 Regression relationship of the predation rate (Y) on the number of stalk (X)

Item	Regression equation	Correlation coefficient ()
O. sertatus	$Y = 40.9486 - 3.0454X$	-0.9838^{**}
H. fuscipes	$Y = 42.9629 - 4.4451X$	-0.9705^{**}

* * Independent variable and consequent variable are statistically correlation at $r < 0.01$ level

In our experiments, the effect of several interference factors on predations of *O. sertatus* and *H. fuscipes* on *S. litura larvae* were evaluated in the laboratory. The results showed that the predations of *O. sertatus* and *H. fuscipes* on *S. litura* may be affected by the existence of other individual in the same/different species and by the spatial heterogeneity, and revealed that the complexity of space enhanced as the number of tobacco stalks increased, and result in the predatory resistance of predator strengthened. So these results of our experiment suggested that some predators reveal low predatory efficacies in field because they live in a complex environment. In addition, another aspect of our experiment indicated that a small quantity of *S. litura* larvae are captured by *O. sertatus* and *H. fuscipes* in tobacco field because the three species exist in a complex agroecosystem, synchronously.

Many predations of predators on prey in the laboratory are often observed in predators whose prey are distributed in the homogeneous spatial conditions [20-22]. However, we observed and determined the predations of two important predator species, i. e. *O. sertatus* and *H. fuscipes* on the larvae of *S. litura* in the heterogeneous spatial conditions in our experiments. Thus, the results reflected that the predatory abilities of the two predator species to prey were more close to those in the tobacco fields. At the same time, the results of our experiment will also supply some scientific references to conservation and utilization of the two predator species in the tobacco fields.

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