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Article

Joint Control Ability of *Labidura riparia* (Pallas) and *Sycanus croceovittatus* (Dohrn) Against *Ostrinia furnacalis* (Guenée)

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Abstract

In order to clarify the control ability of *Labidura riparia* and *Sycanus croceovittatus* on *Ostrinia furnacalis* larvae, the predation ability and preference of *L. riparia* and *S. croceovittatus* on the 3rd instar larvae of *O. furnacalis* were studied in this study. The results showed that the predation ability of the two species to the 3rd instar larvae of *O. furnacalis* conformed to the Holling II functional response. The combination of *L. riparia* and *S. croceovittatus* had the best predation effect on the 3rd instar larvae of *O. furnacalis*, which was significantly higher than that of *L. riparia* or *S. croceovittatus* alone. The *L. riparia* showed a positive preference for the 1-3 instar larvae and a negative preference for the 4-5 instar larvae. The *S. croceovittatus* showed a positive preference for the 3-5 instar larvae and a negative preference for the 1-2 instar larvae. In summary, compared with the use of a natural enemy insect alone, the combined use of *L. riparia* and *S. croceovittatus* has a more significant effect on the prevention and control of *O. furnacalis* larvae, and can be used for biological control of *O. furnacalis*.

Keywords: *Labidura riparia*; *Sycanus croceovittatus*; *Ostrinia furnacalis*; joint pest control

1. Introduction

Ostrinia furnacalis (Guenée) belongs to the genus *Ostrinia* of the Lepidoptera family. It is widely distributed in China and is an absolutely dominant species. It can damage 69 crops such as corn, sorghum, and cotton. It has strong ecological adaptability and is characterized by overlapping generations, polysexual diapause, omnivorous, and boring. It is an important agricultural pest in China¹²³. Its larvae can drill and damage the stems, tassels and ears of corn, resulting in broken stems and ears. It will not only interfere with the quality of pollen, but also induce corn ear rot, resulting in serious loss of yield and quality, which seriously threatens the safe production of corn in China and hinders the sustainable development of China 's planting industry⁴⁵. Because the *O. furnacalis* has the habit of boring, it is more difficult to control. The control effect of single application is not obvious, and multiple applications often lead to pest resistance⁶⁷⁸. With the commercial planting of transgenic maize in China, the resistance of *O. furnacalis*, as a target pest, is imminent. It is of great significance to explore effective biological control methods to control the harm of *O. furnacalis*, to ensure the safety of corn production, to reduce the use of chemical pesticides and to protect the ecological environment. The field investigation found that the *L. riparia* and the *S.*

croceovittatus have certain predation ability in nature, but their specific control effect on the *O. furnacalis* and the ability to control the damage when the two are combined need to be further studied.

Labidura riparia (Pallas) belongs to Dermaptera, Labiduridae. In the corn fields of the Huang-Huai-Hai region, *L. riparia* is widely distributed. It has the characteristics of strong environmental adaptability, long life, many species of predatory pests, and wide range of insect states. It has great potential for application⁹¹⁰¹¹. In recent years, studies have shown that *L. riparia* has strong predation ability to fall armyworm and garlic root maggot¹¹¹². At present, the ecological research and application of *L. riparia* have attracted more and more attention.

Sycanus croceovittatus (Dohrn), belonging to Hemiptera Reduviidae, is an important predatory natural enemy in agriculture and forestry¹³. The *S. croceovittatus* is an incomplete metamorphosis insect, with three stages of egg, nymph and adult. The nymph is divided into five instars. Its distribution area in China includes Guangxi, Fujian, Yunnan, Guizhou and other places, and it is distributed in Southeast Asian countries such as India and Myanmar¹⁴. *S. luteus* preys on the larvae of various lepidopteran pests, such as *Spodoptera frugiperda* (J.E.Smith)¹⁵, *Spodoptera litura* (Fabricius)¹⁶, *Plutella xylostella* (Linnaeus) ¹³, etc., and also has predation ability on locusts, sawfly, armyworm and aphids¹⁷.

As the dominant natural enemy insects of our team, *L. riparia* and *S. croceovittatus* have certain predation ability in nature, but their combined control effect on *O. furnacalis* larvae has not been reported. In order to explore the predation ability of the combination of the two natural enemy insects on the larvae of *O. furnacalis*, the predation functional response of the mixture of the two natural enemy insects on the 3rd instar larvae of *O. furnacalis* was carried out in this study. The predation ability and predation preference of different instar larvae of *O. furnacalis* provide a scientific basis for the three-dimensional biological control of the two natural enemy insects in the field in the future.

2. Materials and Methods

2.1. Test Insects and Instruments

L. riparia was trapped in the corn field of Henan Modern Agricultural Development and Research Base (113.71°N, 35.01°E)¹⁸. The adults of *S. croceovittatus* were collected from the fifth generation of the laboratory and subcultured populations in the corn field of Shuicheng Village, Baozang Town, Jiangcheng County, Yunnan Province (101.65°N, 22.68°E). Larvae of the *O. furnacalis*, *O. furnacalis*, were collected from a corn field in Yuanyang County, Henan Province (113.70 ° N, 35.01 ° E), The 40 th generation of the larvae was reared indoors. The above natural enemy insects and prey insects are raised in an artificial climate box with a temperature of 26 ± 1 °C, a relative humidity of $70 \pm 5\%$, and a photoperiod of 14L : 10D (Model : LC-QHX-70T, Shanghai Lichen Bangxi Instrument Technology Co., Ltd. China).

2.2. Observation on the Predation Behavior of *L. riparia* and *S. croceovittatus* on the 3rd Instar Larvae of *O. furnacalis*

After one *L. riparia* or *S. croceovittatus* was starved for 24 h, it was placed in a petri dish with a diameter of 9 cm. Five third-instar larvae of *O. furnacalis* were placed in the petri dish to observe and photograph the predation behavior of *L. riparia* and *S. croceovittatus*.

During the experiment, the whole process of finding prey, approaching prey, attacking prey and finally successful predation of two natural enemy insects was recorded in detail, and the time required for each predation was recorded. In order to ensure the accuracy of the observation results, each treatment was repeated 10 times, and new culture dishes and *O. furnacalis* larvae were replaced in each experiment to avoid environmental or prey factors affecting the experimental results. In the process of observation, we also paid special attention to the differences in predation behavior between the stream bank *L. riparia* and the *S. croceovittatus* bug, so as to make a comparative analysis in the future.

2.3. Predatory Functional Response of *L. riparia* and Yellow-Belted Rhinoceros to the 3rd Instar Larvae of *O.furnacalis*

An earwig was starved for 24 h, and then transferred into a culture dish with a diameter of 9 cm. In each culture dish, 5,10,15,20,25,30,35 third-instar larvae of *O. furnacalis* were placed in each dish, and an appropriate amount of *O. furnacalis* artificial feed was placed in each dish for *O. furnacalis* larvae to feed (Figure 1). After 24 h, the remaining amount of insects in the culture dish was recorded;

After starvation for 24 h, a *S. croceovittatus* was moved into a culture dish with a diameter of 9 cm, and 5,10,15,20,25,30,35 3rd instar larvae of *O. furnacalis* were placed in each culture dish. At the same time, an appropriate amount of *O. furnacalis* artificial feed was placed in each dish for *O. furnacalis* larvae to feed (Figure 2). After 24 h, the remaining amount of insects in the culture dish was recorded, and each treatment was repeated 10 times. The Holling II functional response formula is as follows 19:

$$Na=\frac{aTN}{1+aT_hN}$$

In the formula, “N” is the density of prey;
“Na” is the number of prey prey;
“T” is the time of prey exposure to predator (T = 1d);
“a” is the instantaneous attack rate;
“Th” is the time to process one prey.



Figure 1. Predatory functional response of *L. riparia* and *S. croceovittatus* to the 3rd instar larvae of *O. furnacalis*.

2.4. The Predation Ability of the Combination of *L. riparia* and *S. croceovittatus* on the 3rd Instar Larvae of *O.furnacalis*

The *L. riparia* and *S. croceovittatus* were starved for 24 h, and then they were moved into a plastic insect box with a diameter of 12 cm and a height of 10 cm, and different numbers of 3rd instar larvae of *O. furnacalis* were placed in each insect box.

The experimental treatments were as follows : CK (no *L. riparia* and no *S. croceovittatus* as a control), T1(2 *L. riparia*), T2 (1 *S. croceovittatus* and 1 *L. riparia*), T3(2 *S. croceovittatus*). The control was used to observe the natural mortality rate under the condition of no natural enemy insects. Each treatment group was set up with 6 density gradients of 20,30,40,50,60 and 70 (Figure 3). The number of remaining *O. furnacalis* in each culture dish was recorded at 3h, 6h, 12h, and 24h after the *O. furnacalis* larvae were placed as prey, and the predation of natural enemies against *O. furnacalis* in each treatment group was calculated for 24h.Predation, each treatment was repeated five times.



Figure 2. Predatory test of *L. riparia* and *S. croceovittatus* on the 3rd instar larvae of *O.furnacalis*.

2.5. Predatory Preference of *L. riparia* and *S. croceovittatus* on Stream Bank

Ten 1st-5th instar larvae of *O.furnacalis* were placed in each petri dish, and then one *L. riparia* and one *S. croceovittatus* were starved for 24 hours and transferred into the above-mentioned insect boxes respectively. After 24 hours, the number of 1st-5th instar larvae of *O.furnacalis* in each treatment was recorded, and the predation preference of *L. riparia* and *S. croceovittatus* to different instar larvae of *O.furnacalis* was calculated, each treatment was repeated five times. The formula is as follows 20:

$$\text{Preference index } (C_i) = \frac{Q_i - F_i}{Q_i + F_i}$$

In the formula : Q_i is the ratio of the predator to the prey of the i species; F_i is the proportion of the i th prey in the environment; when the predator has a positive preference for the first prey, $0 < C_i < 1$; when the predator has a negative preference for the i th prey, $-1 < C_i < 0$.

2.6. Data Processing

IBM SPSS Statistics 26 statistical analysis software was used to analyze the significant differences between the treatments ($P < 0.05$). The drawing was completed using Microsoft Office Excel 2016 software.

3. Results and Analysis

3.1. Predatory Behavior of *L. riparia* and *S. croceovittatus* on the 3rd Instar Larvae of *O.furnacalis*

Both the *L. riparia* and the *S. croceovittatus* can prey on the 3rd instar larvae of *O.furnacalis*. The earwig will use the chewing mouthparts to bite the *O.furnacalis* larvae (Figure 3a), and the *S. croceovittatus* will insert the mouthpin into the *O.furnacalis* larvae to suck all its body fluids (Figure 3b).

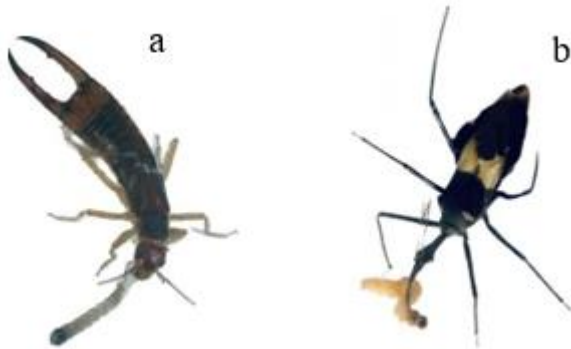


Figure 3. *L. riparia* and *S. croceovittatus* preying on *O. furnacalis*. a: *L. riparia* b: *S. croceovittatus*.

3.2. Predatory Functional Response of *L. riparia* and *S. croceovittatus* to the 3rd Instar Larvae of *O.furnacalis*

The predation of the 3rd instar larvae of the *O. furnacalis* increased with the increase of prey density. When the prey density reached a certain limit, the predation of the 3rd instar larvae of the *O. furnacalis* did not increase with the increase of prey density, but tended to be stable (Figure 4,5).

The maximum daily predation amount of *L. riparia* on the 3rd instar larvae of *O. furnacalis* was 43.5, the instantaneous attack rate was 1.181, the disposal time of one 3rd instar larvae was 0.023 d, and the predation efficiency was 51.3. The maximum daily predation amount of *S. croceovittatus* on the 3rd instar larvae of *O. furnacalis* was 108.7, the instantaneous attack rate was 1.025, the disposal time of the third instar larvae of the *O. furnacalis* was 0.009 d, and the predation efficiency was 113.9 (Table 1).

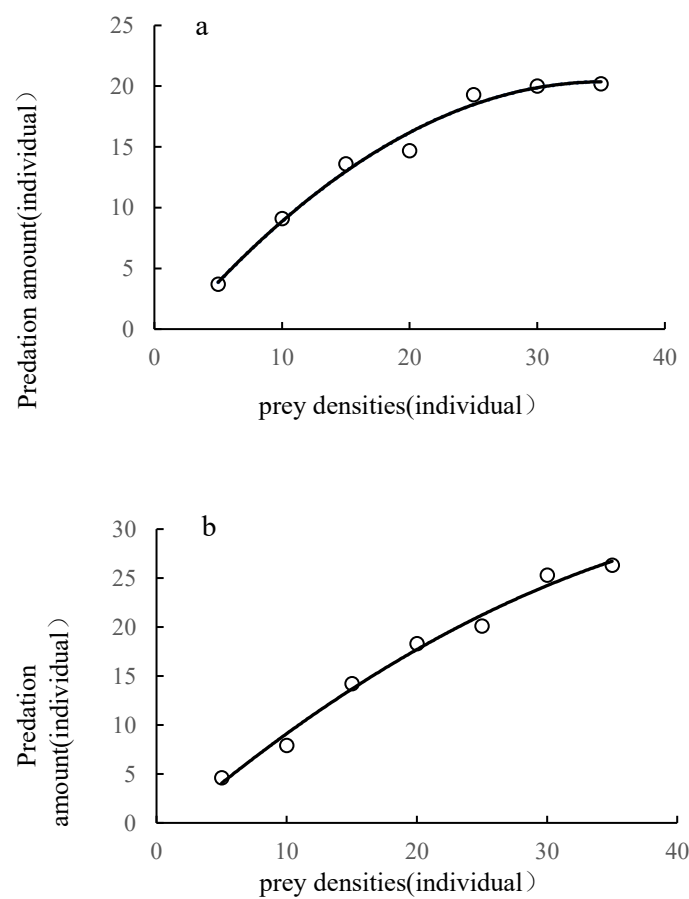


Figure 4. Predatory functional response of *L. riparia* and *S. croceovittatus* to the 3rd instar larvae of *O. furnacalis* a : *L. riparia* b : *S. croceovittatus*.

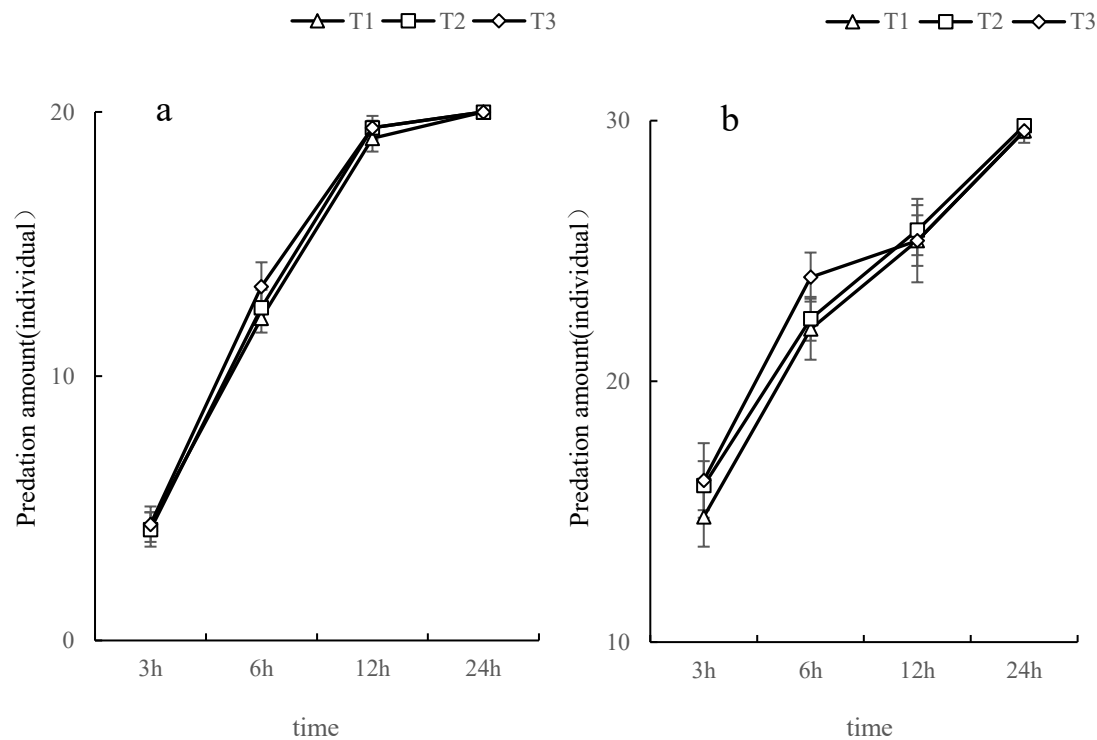
Table 1. Predatory functional response of *L. riparia* and *S. croceovittatus* to the 3rd instar larvae of *O. furnacalis*.

Types of natural enemies	Holling IIdisc equation	R ²	instantaneous attack rate	duration (d)	Predatory efficiency	daily maximum prey capacity (individual·d ⁻¹)
	Na=1.181N/					
<i>L. riparia</i>	(1+0.027N	0.967	1.181	0.023	51.3	43.5
	)					

Na=1.025N/						
S.	(1+0.009N	0.984	1.025	0.009	113.9	108.7
croceovittatus	)					

3.3. The Amount of *O. furnacalis* Predation by *L. riparia* and *S. croceovittatus* in Combination

The predation of *O. furnacalis* by different treatments was shown in Figure 6. When there were 20 (Figure 6a) and 30 (Figure 6b) 3rd instar larvae of *O. furnacalis* per dish, there was no significant difference in the predation of *O. furnacalis* among the three treatments in all observation periods. At 40 *O. furnacalis* larvae per dish (Figure 6c), after 24 h of predation, the predation amount of *O. furnacalis* in the treatment group of one *L. riparia* and one *S. croceovittatus* was significantly higher than that in the treatment group of two *L. riparia*, and there was no significant difference between the treatment group and the treatment group of two *S. croceovittatus*. When there were 50 (Figure 6d) and 60 (Figure 6e) *O. furnacalis* larvae per dish, the predation amount of *O. furnacalis* in the treatment group of one brookside *L. riparia* and one *S. croceovittatus* was significantly higher than that in the treatment group of two brookside *L. riparia* after 6h, 12h and 24h predation. The predation amount of *O. furnacalis* in the treatment group of one brookside *L. riparia* and one *S. croceovittatus* was also significantly higher than that in the treatment group of two *S. croceovittatus* after 12h and 24h predation. When there were 70 *O. furnacalis* larvae per dish (Figure 6f), the predation amount of *O. furnacalis* in the treatment group of one brookshore *L. riparia* and one *S. croceovittatus* was significantly higher than that in the treatment group of two brookshore earwigs after 6h, 12h and 24h predation, and the predation amount of *O. furnacalis* in the treatment group of one brookshore *L. riparia* and one *S. croceovittatus* was also significantly higher than that in the treatment group of two bugs after 24h predation.



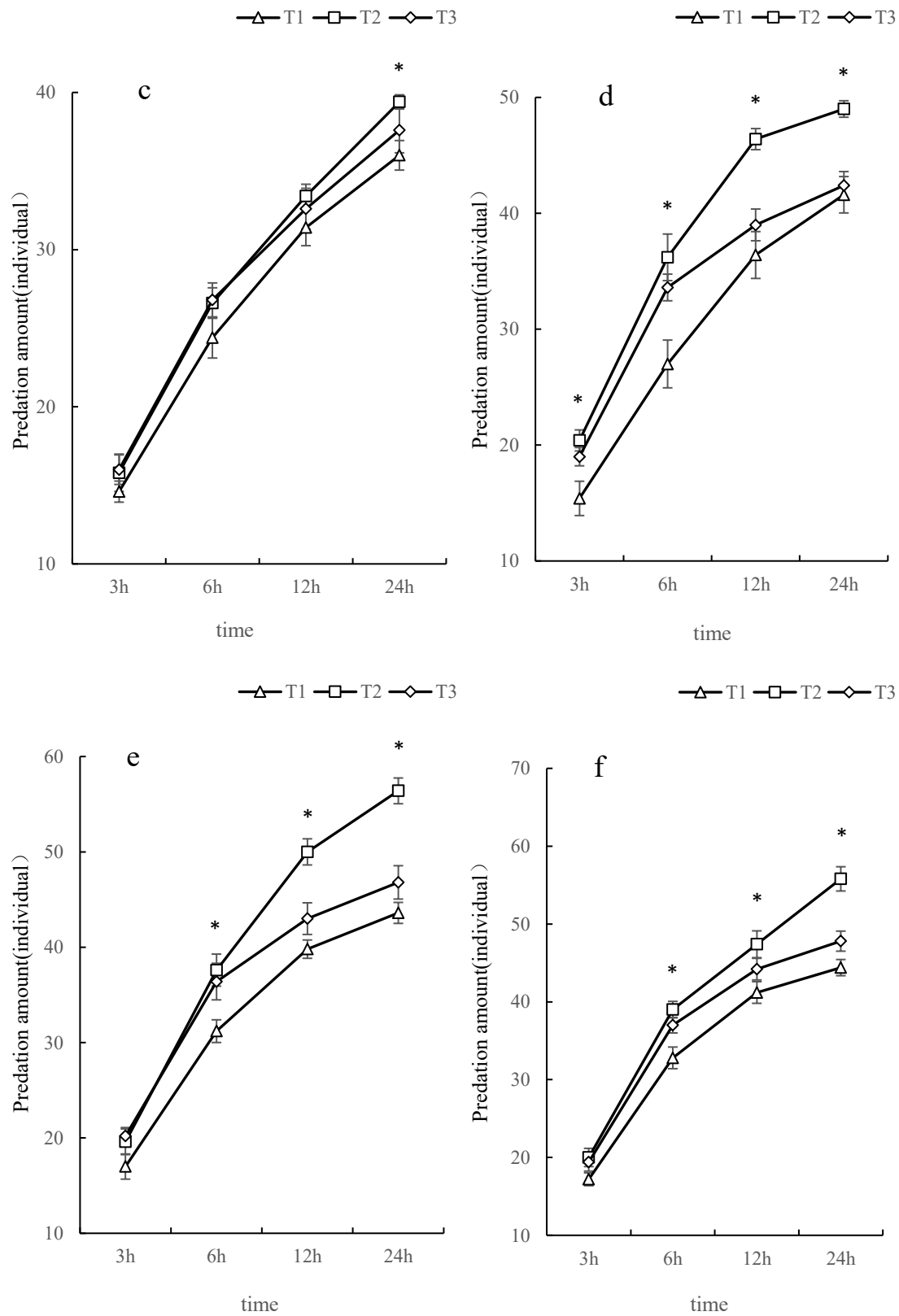


Figure 5. The predation ability of different treatments on *O. furnacalis* a : 20 heads / dish; b : 30 heads / dish; c : 40 heads / dish; d : 50 heads / dish; e : 60 heads / dish; f : 70 heads / dish. Note : * in the figure represents a significant difference between different treatments.

3.4. Feeding Preference of *L. riparia* and *S. croceovittatus* to Different Instars of *O. furnacalis*

The predation amount and preference index of *L. riparia* and *S. croceovittatus* on different instars of *O.furnacalis* are shown in Table 2. There was no significant difference in the predation amount of *L. riparia* on the 1st-3rd instar larvae of *O.furnacalis*, but they were significantly higher than those on the 4th-5th instar larvae of *O.furnacalis*. Among them, the predation amount of *L. riparia* on the 1st instar larvae was the largest, reaching 6.4 heads. *L. riparia* showed positive preference for the 1st-3rd instar larvae of *O.furnacalis* ($0 < C_i < 1$), but showed negative preference for the 1st-2nd instar larvae of *O.furnacalis* ($-1 < C_i < 0$). *S. croceovittatus* was no significant difference in the predation of 4-5 instar larvae of *O.furnacalis*, but they were significantly higher than that of 1-3 instar larvae. At the same time, the predation of 3 instar larvae of *O.furnacalis* was significantly higher than that of 1-2 instar larvae of *O.furnacalis*. The 4th instar larvae of *O.furnacalis* were preyed by *O.furnacalis*, with the largest number of 9.4, showing positive preference for 3-5 instar larvae of *O.furnacalis* ($0 < C_i < 1$), while showing negative preference for 1-2 instar larvae of *O.furnacalis* ($-1 < C_i < 0$).

Table 2. Predatory amount and preference index of *L. riparia* and *S. croceovittatus* to *O. furnacalis*.

<i>O. furnacalis</i>	<i>L. riparia</i>		<i>S. croceovittatus</i>	
	Predatory quantity (individual)	preference index (C_i)	Predatory quantity (individual)	preference index (C_i)
1st instar larva	6.4±0.8 a	0.23	1.4±0.4 c	-0.64
2nd instar larva	6.0±0.6 a	0.21	3.0±0.8 c	-0.37
3rd instar larva	5.6±0.8 a	0.16	7.2±0.7 b	0.08
4th instar larva	1.4±0.5 b	-0.53	9.4±0.5 a	0.22
5th instar larva	0.5±0.2 b	-0.75	9.2±0.4 a	0.21

Note : The different lowercase letters in the table indicate that *Labidura riparia* or *Sycanus croceovittatus* have significant differences in the predation of different instars of *O.furnacalis* larvae ($P < 0.05$).

4. Conclusions and Discussion

In this study, it was found that the *L. riparia* and the *S. croceovittatus* had strong predation ability on the 3rd instar larvae of *O.furnacalis*, and the predation amount increased first and then gradually stabilized with the increase of the density of *O.furnacalis* larvae, which was consistent with the holling type II predation functional response. The predation of *L. riparia* and *S. croceovittatus* on *S.frugiperda* larvae was consistent1121. With the increase of the number of prey, *L. riparia* and prey could prey more prey. After reaching the maximum predation amount, it no longer increased with the increase of prey density.

The three-dimensional control of pests is a comprehensive management strategy. Its core is to change the past mode of relying solely on chemical pesticides and to build a multi-level, multi-dimensional and environmentally friendly sustainable prevention and control system. Among them,

the scientific utilization of natural enemy resources is the key link to realize this strategy²². By introducing, protecting and supporting natural enemy populations, they can establish communities at multiple spatial levels such as underground, surface, canopy and even air of crops, forming a three-dimensional and dynamic biological defense network, which has significant economic, ecological and social benefits²³. This study found that in the first 6 hours of the experiment, there was no significant difference in the predation of the 3rd instar larvae of the *O. furnacalis* under the conditions of single brookshore *L. riparia*, brookshore *L. riparia* mixed with *S. croceovittatus*. With the prolongation of predation time, the predation of *O. furnacalis* by the mixed treatment of brookshore *L. riparia* and *S. croceovittatus* was significantly higher than that of single brookshore *L. riparia* and *S. croceovittatus*, and the gap was widening. The main reason is that with the increase of time, the *O. furnacalis* larvae in the insect box are scattered and dispersed, and are relatively evenly distributed in the upper and lower parts of the box. However, the *L. riparia* is just the opposite to that of the *S. croceovittatus*. The *L. riparia* likes to live on the ground, but the *S. croceovittatus* has the habit of moving upwards. The two have obvious levels in space. The corresponding phenomenon is also observed during the experiment. The *L. riparia* always moves at the bottom of the insect box, while the *S. croceovittatus* mostly moves on the upper part of the insect box. This also reflects the survival state of the two natural enemies in the field to a certain extent, which can reasonably allocate prey and maximize the predation of *O. furnacalis*. It can realize the three-dimensional prevention and control of *O. furnacalis*, while the *L. riparia* or *S. croceovittatus* alone will miss the prey in the infrequently active area and reduce the predation efficiency of *O. furnacalis*. Relevant studies have found that the joint release of *Dastarcus helophoroides* and *Scleroderma guani* can strengthen the prevention and control effect on *P. eryngii* ²⁴; the combination of *C. sinica* adults and *H. axyridis* adults had better control effect on aphids than using *C. sinica* adults alone²⁵. Under high density prey conditions, *H. axyridis* and *P. japonica* showed a certain synergistic effect²⁶, which is consistent with our research results.

The selectivity of predators to prey is often determined by nature and a more favorable direction for themselves²⁷. This study found that the stream bank *L. riparia* prefers to prey on the 1-3 instars of relatively small *O. furnacalis* larvae. On the one hand, due to the limitation of its own body size, it is easier to kill the prey that is very different from its own body size. At the same time, small prey is more convenient for its chewing mouth to eat. On the other hand, *S. croceovittatus* prefers to prey on the 3-5 instar *O. furnacalis* larvae with larger body size. On the one hand, it meets the sufficient intake of its food. On the other hand, *S. croceovittatus* has a long piercing mouthpiece, which needs to be inserted into the prey like a needle when preying on the prey. This requires that the prey has enough body size to provide its sucking juice. Obviously, it is difficult for young *O. furnacalis* larvae with too small body size to meet these conditions.

This difference in predation preference makes the *L. riparia* and the *S. croceovittatus* complementary in the prevention and control of *O. furnacalis*. When the two are used in combination, it can cover all instars of *O. furnacalis*, from young to old, to achieve a full range of prevention and control. This three-dimensional prevention and control strategy not only improves the predation efficiency, but also reduces the prevention and control loopholes caused by the omission of prey in infrequently active areas. In addition, the results of this study also provide a useful reference for the biological control of other pests, that is, more efficient and comprehensive pest control can be achieved by rationally utilizing the predation characteristics of different natural enemies.

In this study, it was shown in the laboratory that the *L. riparia* and the *S. croceovittatus* can complete the predation of the *O. furnacalis* larvae to the greatest extent in the upper and lower space, and can also complement each other in the predation preference of the *O. furnacalis* larvae at different ages. The mixture of the two natural enemies can improve the control effect on the *O. furnacalis*. However, due to the complexity of the real field conditions, the optimal control time and control effect of the two natural enemies against the *O. furnacalis* can be further explored in the real field conditions.

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