Predation functional response and life table parameters of *Orius sauteri* (Hemiptera: Anthocoridae) feeding on *Megalurothrips usitatus* (Thysanoptera: Thripidae)

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Abstract

Bean flower thrips, *Megalurothrips usitatus* (Bagnall) (Thysanoptera: Thripidae), is a serious pest of cowpea in Hainan province, China. In this study, the predation functional response and life table parameters of the minute pirate bug, *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae), feeding on *M. usitatus* were measured in the laboratory. The functional response of *O. sauteri* to increasing *M. usitatus* density was described by Holling's disc equation, and the maximum predation rate was 45.3 over 24 h. The intraspecific interference of *O. sauteri* was significant with increasing *O. sauteri* density. *Orius sauteri* was able to complete its life cycle feeding on *M. usitatus*, with an intrinsic rate of increase (*r*) of 0.16 and fecundity of 95.4 eggs per female. Female and male minute pirate bugs consumed an average of 304.7 and 104.0 thrips over their lifetimes, respectively. These results show *O. sauteri* to be a potential biological control agent in the integrated pest management of *M. usitatus*.

Key Words: bean flower thrips; flower bugs; cowpea; biological control

Resumen

El trips de las flores de frijól, *Megalurothrips usitatus* (Bagnall) (Thysanoptera: Thripidae), es una plaga grave del caupí en la provincia de Hainan, China. En este estudio, se midieron en el laboratorio la respuesta funcional de predación y los parámetros de la tabla de vida de la chinche pirata, *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae), que se alimenta de *M. usitatus*. La respuesta funcional de *O. sauteri* al aumento de la densidad de *M. usitatus* fue descrita por la ecuación de disco de Holling y la tasa máxima de depredación fue de 45.3 para 24 horas. La interferencia intraespecífica de *O. sauteri* fue significativa con el aumento de la densidad de *O. sauteri*. *Orius sauteri* pudo completar su ciclo de vida alimentándose de *M. usitatus*, con una tasa intrínseca de aumento (*r*) de 0.16 y una fecundidad de 95.4 huevos por hembra. Las hembras y machos de la chinche pirata consumieron un promedio de 304.7 y 104.0 trips durante su vida, respectivamente. Estos resultados muestran que *O. sauteri* es un agente potencial de control biológico en el manejo integrado de plagas de *M. usitatus*.

Palabras Clave: trips de frijol; insectos de flores; caupí control biológico

Megalurothrips usitatus (Bagnall) (Thysanoptera:Thripidae) is known as bean flower thrips, Asian bean thrips, bean blossom thrips, blossom thrips, or flower thrips. Whatever it is called, *M. usitatus* is an important and widely distributed pest of legumes in Asia (Mound & Walker 1987; Palmer 1987).

In Hainan province of China, thrips feeding on legume crops, especially cowpeas and snap beans, have caused serious losses (Tang et al. 2015). In one study, nearly all of the thrips (97.9%) damaging to cowpeas were *M. usitatus* (Fan et al. 2013). Currently, chemical insecticides are the principal method for controlling this thrips, but their use is not always efficient due to the biological characteristics of thrips such as their habit of staying within flowers and their short life cycles. Alternative strategies for thrips control, therefore, are needed.

The natural enemies of *M. usitatus* include some parasitoids and several predators. The parasitoid *Ceranisus menes* (Walker) (Hymenoptera: Eulophidae) was observed parasitizing larvae of *M. usitatus* in adzuki bean fields by Chang (1990) in Taiwan and in the Philippines by Loomans (2006). In India, the predaceous bug *Orius maxidentex* Ghauri (Hemiptera: Anthocoridae) is a biological agent used for control of *M. usitatus* (Men 1999). In Taiwan, *Orius strigicollis* (Poppious) (Hemiptera: Anthocoridae) suppresses populations of *M. usitatus* on adzuki beans (*Vigna angularis* var. *angularis*; Fabaceae) and sweet potatoes (*Ipomoea batatas* L.; Convolvulaceae) (Lee et al. 1991). However, there have been no reports on the local natural enemies of *M. usitatus* in Hainan. *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae) is an efficient natural enemy, attacking a variety of thrips (Nagai & Yano 2000), and a number of methods have been found for augmenting species of *Orius* (Blaeser et al. 2004; Cocuzza et al. 1997a). *Orius* species have been successfully used for controlling thrips in several agricultural ecosystems in China. Previous work has found *O. sauteri* to be established in cowpea fields (Tang et al. 2016), and their control effect on *M. usitatus* observed. In this study, we examined the capacity of *O. sauteri*

to prey on *M. usitatus* (functional response), and we measured the predator's life table parameters on this thrips as its sole food, including the bug's longevity, fecundity, duration of development, and daily prey consumption. The potential of this *Orius* species to control *M. usitatus* is evaluated in view of its practical use in cowpea fields.

Materials and Methods

INSECTS

A laboratory colony of *M. usitatus* came from Wanning City in Hainan province of China (18.7851°N, 110.3910°E), and was fed on kidney bean pods (*Phaseolus vulgaris* L.; Fabaceae) in 2 L glass jars. *Orius sauteri* were provided by the Biological Control Lab of China Agricultural University, Beijing, China, and were fed with the eggs of Angoumois grain moth (*Sitotroga cerealella* (Olivier); Lepidoptera: Gelechiidae) in the glass jars. In addition, the kidney bean pods were used as the oviposition substrate for both species. All experiments were conducted with reared insects at 26 ± 1 °C, 65% RH, and 16:8 h (L:D) in incubators (QX-256, Jiangnan Instrument Factory, Ningbo, China).

FUNCTIONAL RESPONSE TESTS

Three-d-old adult females of *O. sauteri* were fed with 3-d-old adult females of *M. usitatus* for 48 h and starved for 24 h. Then the bugs were transferred individually to plastic petri dishes (9 cm diam) and provided with 3-d-old adult females of *M. usitatus* at different densities (10, 20, 40, 60, 80, 100, 120 prey per predator, respectively). After 24 h, the number of prey consumed by each bug was recorded. Bugs were used once only. Meanwhile, a control treatment was carried out without predators. Each density included 5 replicates.

INTRASPECIFIC INTERFERENCE EXPERIMENT

To measure the reduction in prey consumption when various numbers of adult *Orius* bugs were held in the same arena with prey, we ran an intraspecific interference experiment in which 45 adult female thrips were held in an arena with different numbers of adult *Orius* (1, 2, 3, or 4). The number of prey consumed by the group of predators was checked after 24 h, and converted to a per predator basis. A control treatment was conducted without predators. Each treatment included 5 replicates.

LIFE TABLE STUDY

To determine the life table parameter for *O. sauteri* when fed with *M. usitatus*, the survival of a group of bugs under those conditions was followed. Kidney bean pods with *O. sauteri* eggs that were < 24 hrs old were isolated from the rearing colony, and held in the incubator as described above. After egg hatch, 30 first instar nymphs were chosen randomly and reared individually with 45 *M. usitatus* 3-d-old adult females daily as prey in 10 mL bottles. The kidney bean pods provided for the *M. usitatus* prey as their food was replaced daily. Mortality and nymphal instar were recorded daily for each insect under a stereomicroscope (SZ656, Optec, Chongqing, China) until nymphs molted to the adult stage.

Separately, to measure adult fecundity of *O. sauteri* on this prey, a male and a female of *O. sauteri* that emerged the same d were placed in the same bottle, and their survival and the number of eggs laid per female were recorded daily. Females inserted eggs in the bean pods and eggs were visible under the stereomicroscope. Pods with *O. sauteri* eggs were held in the incubator, where the hatching rate and progeny sex ratio were recorded. One female from each pair was a replicate, and there were 30 replicates.

PREDATION RATE

Newly hatched first instar nymphs were provided 45 three-d-old adult female thrips daily during the life table experiment. There were 30 replicate *Orius* for this study. Their daily predation was determined by counting the dead thrips and then replacing them with another groups of 45 three-d-old adult female thrips at the end of each day.

DATA ANALYSIS

Data from the functional response experiment were analyzed with SPSS 21 and fitted to the Holling's disc equation (Holling 1959):

$$N_A = \frac{aTN}{1+aT_hN} \tag{1}$$

where N_A is the number of prey killed by predators during time T, which in this experiment was 1 d. T_h is the predator handling time for 1 prey (= T divided by maximum predation rate), while a is a constant equal to the search rate multiplied by the probability of finding a prey. N is the density of prey. The search rate was calculated as per Ding (1994):

$$E = \frac{a}{1+aT_hN} \tag{2}$$

where E is the search rate.

The results of the intraspecific interference experiment were analyzed according to Hassell & Varley (1969):

$$E = QP{-}m \text{ or } \log E = \log Q{-}m \log P \tag{3}$$

$$E = \frac{N_a}{NP} \tag{4}$$

where E is the predation rate, Q is the quest constant, P is the density of predators, N_a is the number of the prey killed by predators, m is the mutual interference constant, and N is the density of the prey. Moreover, the intensity of scramble competition (I) was calculated as per Zou et al. (1996):

$$I = \frac{E_I{-}E_P}{E_I} \tag{5}$$

where E_I is the predation rate for 1 predator, and E_P is the predation rate for the predators with a density of P.

Life table parameters, as per Birch (1948), were calculated from the data as follows:

$$R = \frac{\ln R_0}{T} \tag{6}$$

$$\lambda = e^m \tag{7}$$

$$R_0 = \Sigma l_x \bullet m_x \tag{8}$$

$$T = \frac{\Sigma l_x \bullet m_x \bullet x}{\Sigma l_x \bullet m_x} \tag{9}$$

where l_x was the age-specific survival rate; m_x was the age-specific fecundity. Population parameters are r, the intrinsic rate of increase; λ, the finite rate of increase; R_0, the net reproductive rate, and T, the mean generation time.

The predation rates of *O. sauteri* at all stages on *M. usitatus* were analyzed according to the following formulas (Chi & Liu 1985; Chi 1988):

$$N_A = \frac{\sum_{j=1}^{\beta} Sxj \bullet Cxj}{\sum_{j=1}^{\beta} Sxj} \tag{10}$$

$$C_0 = \sum_{x=0}^{\delta} \sum_{j=1}^{\beta} Sxj \bullet Cxj = \sum_{x=0}^{\delta} kx \bullet lx \tag{11}$$

$$Q_p = \frac{C_0}{R_0} \tag{12}$$

where s_{xj} refers to the age-stage specific survival rate (where x = age and j = stage); c_{xj} is the age-stage specific consumption rate; k_x is the age-specific predation rate; C_0 is the net predation rate, and Q_p is the transformation rate from the prey population to predator progeny. The parameters were calculated by using the TWOSEX-MSChart and CONSUME-MSChart programs designed by Chi (2009a, b).

Results

FUNCTIONAL RESPONSE OF *ORIUS SAUTERI* ON *MEGALUROTHRIPS USITATUS*

We found that *O. sauteri* was able to efficiently prey on *M. usitatus*, and its predation showed a decelerating (Type II) functional response to increasing *M. usitatus* number. When only 10 thrips were provided, *O. sauteri* consumed a mean of 9.4 thrips per predator per d, which indicates that the predators can efficiently find the thrips at low densities (Fig. 1). The functional response of *O. sauteri* adults to *M. usitatus* adults was calculated using Holling's disc equation, and the functional response parameters were estimated with equation (1). The maximum predation rate *O. sauteri* per individual adult female was 45.3 thrips per d (Table 1). At higher prey density, the predator search rate (per
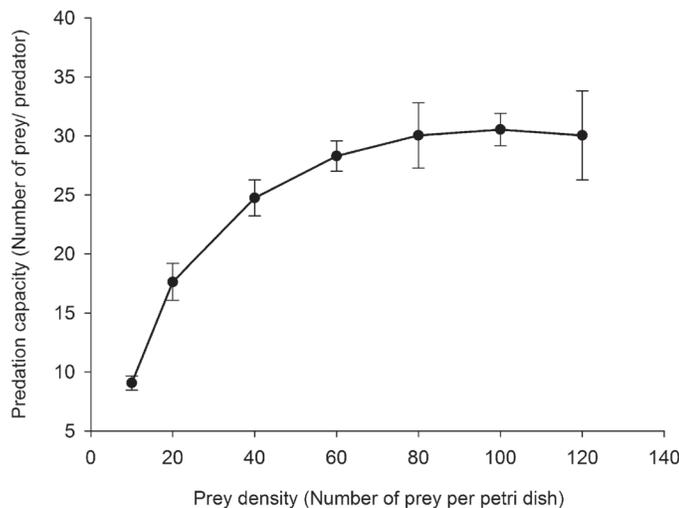
Table 1. Functional response of *Orius sauteri* adults to *Megalurothrips usitatus* adults as prey when reared at 26 °C. T_h = predator handling time (for 1 prey); a = a constant equal to the search rate multiplied by the probability of finding a prey.

Parameter	Value
Functional response equation[a]	1/Na = 0.022 + 0.84/N
R²	0.98
Th (d ± SE)	0.022 ± 0.0020
a (± SE)	1.19 ± 0.056
Maximum predation rate (prey eaten per d)	45.3

[a]The data of the experiment were estimated and normally distributed. Then the parameters of functional response were analyzed by using a least-square method and estimated through the maximization of Poisson likelihood. There was a significant correlation between the reciprocal of N and the reciprocal of Na ($P < 0.01$).

predator per d) declined, showing that *O. sauteri* needed to spend less time searching for prey at higher prey densities (Fig. 2).

INTRASPECIFIC INTERFERENCE OF *ORIUS SAUTERI*

The predation capacity (prey consumption per predator) of *O. sauteri* decreased with increasing *O. sauteri* density within the test arena, due to scramble competition. When the predator density was 4, the intensity of scramble competition (*I*) was 0.76, indicating that the intraspecific interference of *O. sauteri* was significant (Table 2, Fig. 3).

AGE-STAGE, TWO-SEX LIFE TABLE

We found that *O. sauteri* eggs from adults that were fed on *M. usitatus* had a high hatch rate, and resulting nymphs had high survival rates at 26 °C (Fig. 4). In addition, *O. sauteri* adults fed on *M. usitatus* had a long oviposition period. The hatch rate of *O. sauteri* eggs was 59.7%. The mortality of first instar nymphs of *O. sauteri* was higher, whereas no mortality occurred in the fourth or fifth instars. The mean development period, pre-oviposition period, sex ratio, fecundity, female adult longevity, and male adult longevity of *O. sauteri* were 15.9 d, 2.1 d, 2.8 females per male, 95.4 eggs per female, 21.1 d, and 9.7 d, respectively (Table 3). The longevity of adult males of *O. sauteri* was much shorter than of females. At peak oviposition, *O. sauteri* laid 5 to 8 eggs per d, declining thereafter to 1 to 4 eggs each d until death (Fig. 5).
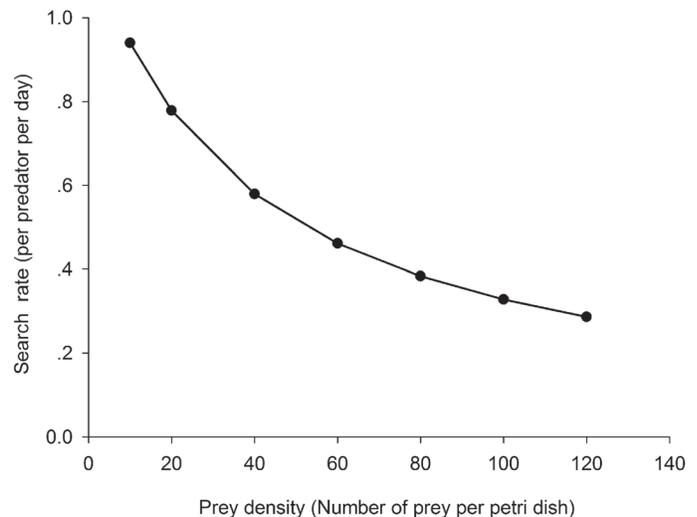

Fig. 1. Predation capacity of *Orius sauteri* adults for *Megalurothrips usitatus* adults at 26 °. Each value is the mean (± SE) of 5 replicates.

Fig. 2. Relationship between search rate of *Orius sauteri* adults and density of *Megalurothrips usitatus* adults at 26 °C.

Table 2. Predation (prey consumption per predator, mean ± SE), E_i (predation rate for 1 predator) and I (intensity of scramble competition) among *Orius sauteri* adults at 26 °C.

Predator per petri dish	Prey eaten per predator	E_i	I
1	31.4 ± 2.3	0.70	0.00
2	20.1 ± 1.8	0.45	0.36
3	10.8 ± 2.1	0.24	0.65
4	7.6 ± 5.2	0.17	0.76

Under the experimental conditions, net reproductive rate (R_0), mean generation time (T), the intrinsic rate of increase (r), and finite rate of increase (λ) of *O. sauteri* were 51.1 offspring per individual, 24.6 d, 0.16 d^{-1}, and 1.2 d^{-1}, respectively (Table 4).

PREDATION RATE

C_0 and Q_p, calculated using equations 11 and 12, showed that *O. sauteri* consumed an average of 186.0 thrips over the course of its life, and that to lay 1 egg required the consumption of 3.6 thrips (Table 4). Except for the egg stage, *O. sauteri* of all life stages could kill thrips (Fig. 6). Nymphs increased their thrips consumption from about 2 to 10 thrips a d. Male consumption was 3 to 9 thrips each d, which was less than that of females, while survival time for males was much shorter than for females. The total predation by *O. sauteri* nymphs, and by adult females and males, was 3.5 to 30.8, 233.1, and 39.5 per stadium, respectively (Table 5). Thrips consumption increased as *O. sauteri* progressed, and after the fourth instar the predation rate increased rapidly. Males consumed an average of 104.0 thrips over their entire lifetime, whereas females consumed an average of 304.7 thrips during their lifetime. The age-stage specific predation rate (k_x), the survival rate (l_x), and the age-specific net predation rate ($l_x k_x$) were calculated with equation 10. Predation peaked in 5 to 9-d-old adults, which coincided with peak oviposition (Fig. 7).

Discussion

Many thrips are serious pests in agriculture and forest ecosystems worldwide. Although biological control is an environmentally friendly
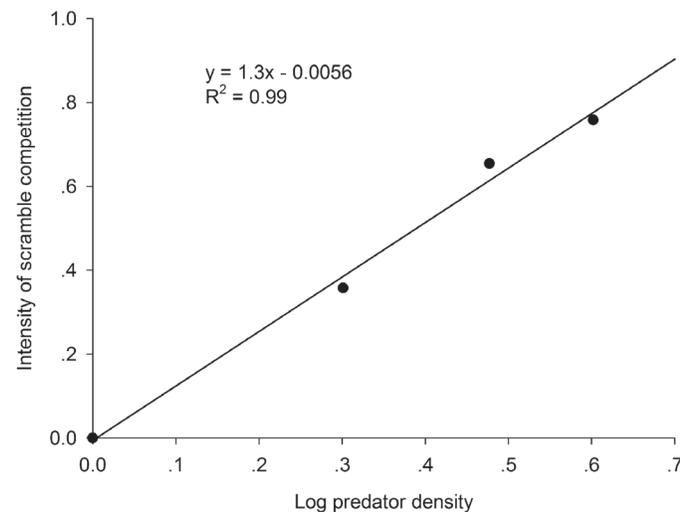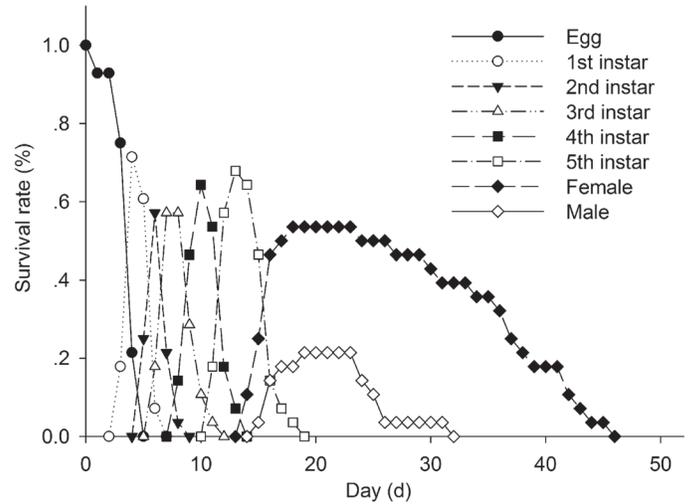

Fig. 4. Age-stage survival rate (s_{xj}) of *Orius sauteri* on *Megalurothrips usitatus* at 26 °C.

method for control of thrips, there have been few studies on the biological control of *M. usitatus* in the field in China. *Orius* species are effective natural enemies of thrips, and studies have found the thrips *Megalurothrips sjostedti* Trybom, *Neohydatothrips variabilis* (Beach), *Frankliniella occidentalis* Pergande, and *Thrips palmi* Karny (Thysanoptera: Thripidae) to be effectively preyed upon by various species of *Orius*, including *O. albidipennis* Reuter, *O. insidiosus* (Say), *O. majusculus* (Reuter), *O. laevigatus* (Fieber), and *O. sauteri* (Hemiptera: Anthocoridae) (Gitonga et al. 2002; Butler & O'Neil 2007; Montserrat et al. 2000; Hemerik & Yano 2010; Xu & Enkegaard 2009). The predation effects of *O. sauteri* on *M. usitatus* have not been previously reported, and we found that the daily peak of 45.3 thrips preyed on by *O. sauteri* was higher than that reported by Xu & Enkegaard (2009) or Hemerik & Yano (2010) under similar conditions at 26 °.

Food consumption rates can influence immature developmental rates (Hayes & Mcardle 1987), and is an important parameter for the evaluation of a potential biological control agent. In this study, the predation rates of female and male *O. sauteri* on *M. usitatus* were similar to that of *O. laevigatus*, *O. albidipennis*, and *O. sauteri* (Cocuzza et al. 1997b; Wang et al. 2014a).

The feeding preferences of generalist predators adjust to the local relative abundance of available prey (Jaworski et al. 2013; Klauschies et al. 2016), which means that a generalist predator such as *O. sauteri* may feed preferentially on the most abundant local prey. When fed

Fig. 3. Relationship between density of *Orius sauteri* adults and intensity of scramble competition (*I*) on *Megalurothrips usitatus* adults.

Table 3. Age-specific life table of *Orius sauteri* feeding on *Megalurothrips usitatus* in the laboratory at 26 °C.

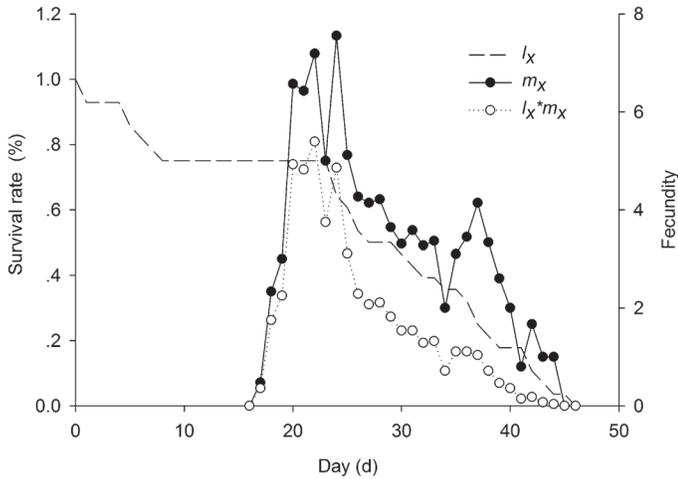| Parameters	N	Mean ± SE
Egg duration (d)	30	4.0 ± 0.13
1st instar duration (d)	28	1.8 ± 0.090
2nd instar duration (d)	25	1.3 ± 0.10
3rd instar duration (d)	24	2.3 ± 0.10
4th instar duration (d)	23	2.7 ± 0.10
5th instar duration (d)	23	3.7 ± 0.14
Pre-oviposition period (d)	23	2.1 ± 0.27
Sex ratio (Female : Male)	23	2.8
Fecundity (eggs per female)	17	95.4 ± 10.3
Female adult longevity (d)	17	21.1 ± 1.6
Male adult longevity (d)	6	9.7 ± 0.8

Fig. 5. Age-specific survival rate (l_x), and age-specific fecundity (m_x) of *Orius sauteri* on *Megalurothrips usitatus* at 26 °C.

Table 4. Population parameters (mean ± SE) of *Orius sauteri* feeding on *Megalurothrips usitatus* at 26 °C. R_0 = net reproductive rate; T = mean generation time; r = intrinsic rate of increase; λ = finite rate of increase; C_0 = net predation rate; Q_p = transformation rate.

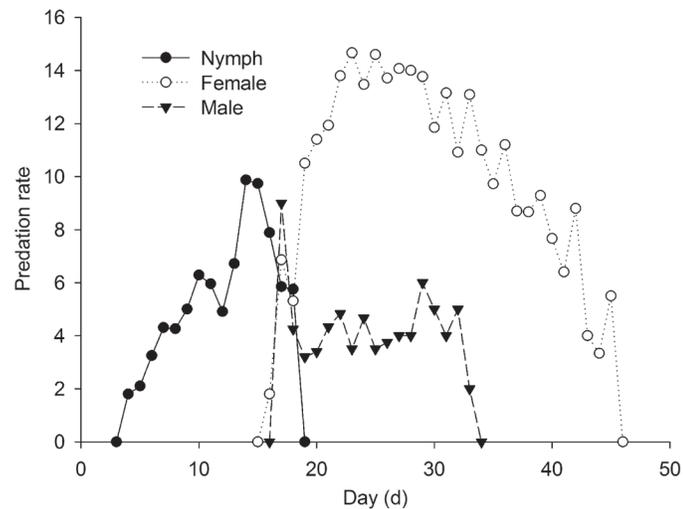| Parameters	Mean ± SE
R_0 (offspring per individual)	51.1 ± 10.6
T (d)	24.6 ± 0.43
r (d^{-1})	0.16 ± 0.0092
λ (d^{-1})	1.2 ± 0.010
$C0$ (prey per predator)	186.0 ± 28.1
Qp (prey per egg)	3.6 ± 1.9

Fig. 6. Age-stage predation rate (c_{xj}) of *Orius sauteri* on the age-stage, 2-sex life table at 26 °C.

on thrips ad lib, the developmental period of *O. sauteri* nymphs did not significantly differ between 2 prey (*M. usitatus* vs. *F. occidentalis*) (Wang et al. 2014b). The fecundity of *O. sauteri* feeding on *M. usitatus* was higher than that of *O. albidipennis* feeding on *M. sjostedti*, or that of *O. laevigatus* or *O. albidipennis* feeding on *F. occidentalis*, or that of

Table 5. Number of prey killed by different stages or sex (mean ± SE) of *Orius sauteri* at 26 °C.

	Female	Male
1st instar	5.7 ± 0.32 cd	3.5 ± 1.2 d
2nd instar	4.5 ± 0.46 d	4.8 ± 1.0 cd
3rd instar	10.3 ± 0.65 bcd	10.0 ± 2.1 bcd
4th instar	20.3 ± 1.1 abc	17.5 ± 1.7 abcd
5th instar	30.8 ± 1.9 ab	28.7 ± 2.7 ab
Adult	233.1 ± 23.1 a	39.5 ± 4.2 ab
All stages	304.7 ± 22.6	104.0 ± 7.5

Each value is the mean (± SE) amount of prey consumed by predator. Different letters indicate significant differences consumptions among stages and sexes of *O. sauteri*, by using Kruskal-Wallis analysis followed by Dunn-Bonferroni test for post hoc comparisons at $P < 0.05$.
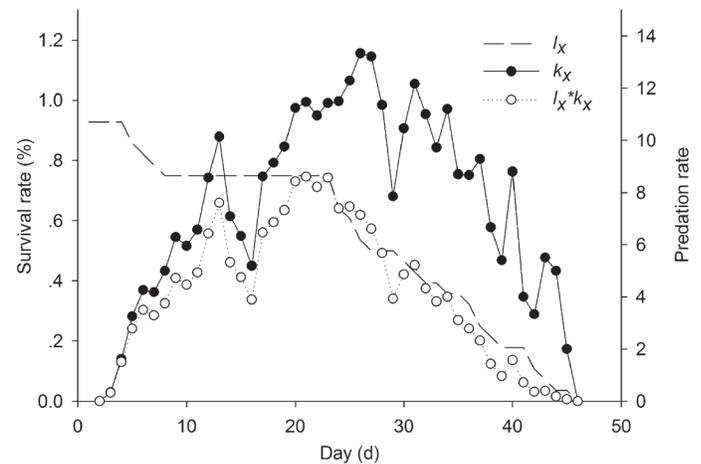

Fig. 7. Age-specific survival rate (l_x), predation rate (k_x), and age-specific net predation rate of *Orius sauteri* on *Megalurothrips usitatus* using the age-stage, 2-sex life table.

O. minutus (L.) or *O. niger* (Wolf.) feeding on *Thrips tabaci* Lindeman (Gitonga et al. 2002; Cocuzza et al. 1997b; Fathi 2009).

The efficiency of predator consumption of prey has been found to be influenced by a number of factors (Nagai & Yano 2000; Reitz et al. 2006). In our study, the density, developmental stage, and sex of the prey or predator were the factors that affected the predatory efficiency of *O. sauteri*. The complexity of the spatial environment, including consumption under field conditions and interference of other prey on the predators, all need to be studied further.

Acknowledgments

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