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ORIGINAL PAPER

Life history and functional response to prey density of the flower bug *Orius sauteri* attacking the fungivorous sciarid fly *Lycoriella pleuroti*

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Abstract

Seldom have natural enemies been quantified in their ability to control fungivorous arthropods, despite the severe losses they can cause in production of edible fungus. Here, we evaluated the omnivorous predator *Orius sauteri* (Poppius) when preying on eggs and larvae of the fungivorous sciarid fly *Lycoriella pleuroti* (Yang *et* Zhang) and compared against a microencapsulated artificial diet. We also estimated the predation ability of *O. sauteri* feeding on different densities of *L. pleuroti* larvae and eggs. The results indicated that *O. sauteri* successfully oviposit on a mushroom substrate. Moreover, both *L. pleuroti* eggs and larvae were capable of supporting *O. sauteri* populations. A type II functional response was observed for both males and females of the predator. Further, moderate values for parameter *a′* (instantaneous attack rate) and greatly reduced T_h (handling time) revealed a high potential for *O. sauteri* in suppressing outbreaks of *L. pleuroti*. This is the first report of a generalist predator feeding and developing within an edible mushroom-pest system. *O. sauteri* is a prime candidate for testing as a biological control agent, either in inoculative or in inundative release, for targeted suppression of the fungivorous sciarid *L. pleuroti*.

Keywords Biological control · Development · Predator · Oyster mushroom · Anthocoridae

Key messages

This is the first report of a generalist predator feeding and developing in an edible mushroom-pest system.

Supplied with eggs or larvae of *L. pleuroti, O. sauteri* successfully oviposited on a mushroom substrate and established populations.

A type II functional response was found for both males and females of *O. sauteri*.

Results showed the high potential for use of *O. sauteri* as a biological control agent for suppression of outbreaks of *L. pleuroti*.

Introduction

The oyster mushroom *Pleurotus ostreatus* (Jacq.) P. Kumm. is the third most popular commercially cultivated edible mushroom worldwide (Wang et al. 2015) and is particularly popular in China. This mushroom is known for its taste, nutritional value (rich in protein, carbohydrates, vitamins and minerals) and resilience to a wide range of temperatures (Chang and Miles 2003; Dundar et al. 2009; Rizki and Tamai 2011; Yang et al. 2013). Largely for cultural reasons, mushroom cultivation typically occurs in isolated environments with limited environmental biodiversity, which can be susceptible to outbreaks of specialized fungivorous arthropods

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(Zhang and Yang 1999) such as the fungivorous sciarid fly, *Lycoriella pleuroti* (Diptera: Sciaridae) (Zhang and Yang 1999; Yang and Zhang 1987; Grewal 2000; Shi et al. 2009), which larvae bore into young mushrooms. As a predominant pest of mushroom cultivation facilities, *L. pleuroti* populations can develop throughout the year and cause yield losses usually of 15–30%, although occasionally up to 50% (Zhang and Yang 1999; Wang et al. 2003). Insect growth regulators such as methoprene and diflubenzuron, and insecticides such as benfuracarb, fenthion, furathiocarb and permethrin have been used for controlling fungivorous sciarids on commercial mushroom (Yi et al. 2008). The potential of resistance of the flies to pesticides and the toxicity of pesticide application have been reported by Smith (2002) and Jess et al. (2017). Mechanisms behind lack of effectiveness of pesticides can be behavioral avoidance by the larvae during spraying and complicated biological structures of the mushroom gills. Thus, the applications of chemical pesticides could be an unreliable means of managing *L. pleuroti* (Harris et al. 1996; Jandricic 2005). Further, these mushrooms can be highly sensitive to contamination of pesticides, because of their fast growth rate and the small time interval between spraying and harvest (Jess 2010). Over the past decade, biological control of *L. pleuroti* in several crop systems has been introduced using microbial entomopathogens (Wen et al. 2010; Zhang et al. 2010). However, to date there have not been any published reports on the biology or practical application of arthropod natural enemies for the biological control of this key insect pest for mushrooms.

The tiny flower bug *Orius sauteri* (Hemiptera: Anthocoridae) has been found to be an efficient natural enemy of various arthropod herbivores such as thrips, aphids, whiteflies and spider mites, in protected and open field crops within its native range of Asia (Nagai and Yano 2000; Zhao et al. 2017). *O. sauteri* as many other hemipteran predators (e.g. see Jaworski et al. 2013) prefer attacking herbivores smaller in body size and are easily able to penetrate deep into narrow spaces to search for prey. These characters might prove *O. sauteri* effective in controlling eggs and larvae of fungivorous pests which are usually located within mycelium and mediotrastum of edible mushrooms.

Herein, we assessed the suitability of *O. sauteri* as a biocontrol agent of *L. pleuroti* through a series of laboratory bioassays. We estimated several relevant life-history traits, such as the duration of juvenile phase, and survival and adult longevity and fertility of *O. sauteri* preying on *L. pleuroti*. We compared these results with those obtained by feeding the predators with a microencapsulated artificial diet, recently established for maintenance of generalist predator insectaries (Tan et al. 2013, 2014; Salehi et al. 2016). Furthermore, we assessed the functional responses of *O. sauteri* adult males and females to *L. pleuroti* egg and larva densities. The matching of functional response according to the prey consumption by the predator is a primary means of estimating the pest suppression ability of biological control agents, for example in the case of flower bugs (Zamani et al. 2009; Madadi et al. 2011; Salehi et al. 2016). The outcomes of this study will provide key information for possible implementation of *O. sauteri* in augmentative biological control programs against fungivorous sciarid flies.

Materials and methods

Insect collection and colony maintenance

Lycoriella pleuroti

More than 800 pairs of *L. pleuroti* adults were collected on *Pleurotus ostreatus* from an edible mushroom farm (Yongledian town, Tongzhou district, Beijing, China) during May 2015. The *L. pleuroti* and its host mushrooms were transported and reared at the Lab of Natural Enemy Research (LNER), Institute of Plant and Environment Protection (IPEP), Beijing Academy of Agriculture and Forestry Sciences (BAAFS, Haidian District, Beijing, China). Ventilated transparent plastic boxes (15.0 × 10.0 × 7.0 cm; 120 mesh net sized in 10.0 × 5.0 cm was pasted on the lid as ventilation opening) were used to rear 50 pairs of flies each with a sufficient amount of *P. ostreatus* as substrate (strain as JZB2101077, provided by Beijing Engineering Research Center for Edible Mushroom, Beijing Academy of Agriculture and Forestry Sciences, Beijing, China; GPS: N39°56′, S116°16′) supplied daily in the form of cultivated sticks. And more than 16 rearing boxes were used to keep *L. pleuroti* colony. The rearing environment was controlled using an automatic environmental regulation system (Suntech, Beijing, China), at 25 ± 1 °C, 60% R.H., 16: 8 h L: D at the illumination intensity of 1000 Lux.

Orius sauteri

Adults of *O. sauteri* were collected from the alfalfa field of the campus of BAAFS during spring 2015. Totally, 300 pairs of flower bugs were used to establish the colony at the Lab of LNER. Flower bugs were reared with microencapsulated artificial diets (MEC-AD) (Tan et al. 2013, 2015) in cages (60.0 × 60.0 × 50.0 cm) made by aluminum frames and 120 mesh plastic net, at a density of 40–50 pairs per cage with several broad bean *Vicia faba* pesticide-free seedlings as oviposition substrates (Tan et al. 2014). The environmental conditions were the same as described above.

Development and reproduction of *Orius sauteri* feeding on *Lycoriella pleuroti* larvae, eggs and on artificial diet

Thirty pairs of coetaneous and young *O. sauteri* adults were selected from the cultured population and placed in a plastic Petri dish (9 cm diameter). And a daily supply of third-instar *L. pleuroti* larvae was provided. The dishes were sealed by Parafilm (Chicago, IL, USA) with 10 drilled holes (about 0.01 cm in diameter) for ventilation. The samples were kept under the environmental conditions given above. Meanwhile, *P. ostreatus* sticks were provided as oviposition substrates and were checked daily under micro-stereoscope (Zeiss Stereo V20, Oberkochen, Germany). Five hundred newly laid eggs were sampled and maintained with substrates in Petri dishes (one *P. ostreatus* stick per dish) under the environmental conditions above. Then, newly hatched first-instar nymphs of *O. sauteri* were introduced to new Petri dishes for individual rearing and supplied with larvae of *L. pleuroti* as above. The development and survival of each individual were recorded daily. These will be hereafter referred to as juvenile development duration and survival, although we did not consider the egg incubation period and the egg hatching.

Soon after the adults emerged, a virgin male and a virgin female were paired in a new Petri dish. Mushroom sticks and larvae of *L. pleuroti* were provided daily. The number of eggs laid was checked daily until the death of the female. Moreover, the substrates bearing the eggs were reared until new nymphs hatched, for assessing the lifetime fertility, measured as the number of progeny produced. We repeated the above procedure but providing *O. sauteri* with *L. pleuroti* eggs instead of larvae and by providing microencapsulated artificial diet (MEC-AD) (Tan et al. 2013) independently as different treatments.

The biological data were used to calculate the intrinsic rate of natural increase (r_m) index, which is the innate capacity of a given species to increase in numbers, for *O. sauteri* feeding on *L. pleuroti* eggs and larvae and on microencapsulated artificial diet. The following formula is used:

$$r_m = \sum e^{r_m x} l_x m_x$$

where e^{r_m} is the antilog of r_m, l_x is the age-specific survival among individuals alive at age x, and m_x is the age-specific fertility, i.e., the number of progeny produced per each day of age (Biondi et al. 2013).

Orius sauteri functional response to prey density

A newly emerged female or male adult of *O. sauteri* which had been starved for 24 h was individually placed with newly laid (< 24 h) eggs of *L. pleuroti* in a plastic Petri dish (9 cm diameter) under the environmental conditions above. Different prey densities (40, 60, 80, 100, 120, 140 and 160 eggs) were provided to each female without any other edible fungus tissue. After 24 h, we checked the number of eggs which had been consumed by *O. sauteri* by using a stereomicroscope. The experiment was repeated using 20, 40, 60, 80, 100, 120 and 140 third-instar larvae of *L. pleuroti* as prey. The bioassay was replicated 30 times per each predator sex, prey instar stage and prey density. Moreover, we estimated predator voracity on eggs and larvae by matching the Holling II functional response model. The parameters are calculated as the following equation using the software MATLAB 9.0:

$$N_a = \frac{a'NT}{1 + a'T_\mathrm{h}N}$$

where N_a is the net prey consumption rate by predator during selected time period (present is 24 h = 1 day); a' is the instantaneous attack rate; N is the prey density; T is the selected predation period (1 day); T_h is the duration of one prey consumption by predator, i.e., the handling time. The potential maximum N_a (N_a-max) was estimated by dividing instantaneous attack rate by the handling time (Holling 1959).

Statistical analyses

The data collected in the experiments and the calculated residuals were tested for normality using the Kolmogorov–Smirnov test (all $P > 0.05$). The data on young instars and overall duration of juvenile development, female and male longevity, number of produced progeny were compared among different food prey treatments (eggs, larvae of *L. pleuroti* or microencapsulated artificial diets) by the general linear model (GLM) at $P = 0.05$. The overall juvenile survival (number of emerged adults/500 × 100%) among different food prey treatments was also compared by GLM. Then, we used the Chi-square test to analyze the difference between the actual values of egg/larvae consumed by *O. sauteri* male/female and the calculated theoretical values under different densities. All statistical analyses were performed using SPSS 20 (IBM, Chicago, USA).

Results

Development and reproduction of *Orius sauteri* feeding on *Lycoriella pleuroti* larvae, eggs and on artificial diet

The results reported in Table 1 indicate that the duration of development of *O. sauteri* from first to fifth instar and

Table 1 Mean (±SE) values of age-specific and overall juvenile development and survival of *Orius sauteri* feeding on larvae and eggs of *Lycoriella pleuroti*, and on microencapsulated artificial diet (MEC-AD)

Prey	Juvenile development duration (days)						Juvenile survival (%)
	1st	2nd	3rd	4th	5th	Overall	
L. pleuroti larvae	5.2 ± 0.2a	3.4 ± 0.1a	2.9 ± 0.1a	2.7 ± 0.1a	3.2 ± 0.2a	17.4 ± 1.3a	76.2a
L. pleuroti eggs	5.5 ± 0.3a	3.6 ± 0.2a	2.9 ± 0.3a	2.8 ± 0.4a	3.2 ± 0.5a	18.0 ± 1.5a	73.2a
MEC-AD	6.2 ± 0.3b	4.3 ± 0.1b	3.7 ± 0.3b	3.4 ± 0.3b	4.0 ± 0.3b	21.6 ± 1.4b	60.4b
F	4.6	5.5	4.3	5.3	10.9	10.6	11.7
GLM							
d.f.	2, 1181	2, 1139	2, 1113	2, 1077	2, 1046	2, 1046	2
P	0.023	< 0.01	0.047	0.022	< 0.01	< 0.01	< 0.01

Within the same column, different letters indicate significant differences (Duncan test at $P < 0.05$) among various prey types

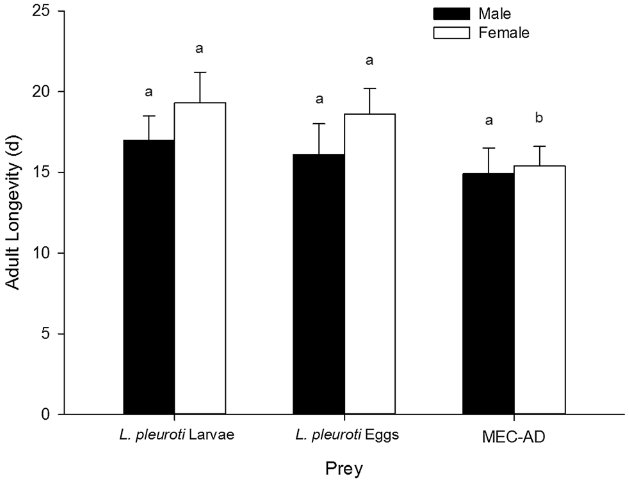

Fig. 1 Mean (±SE) values of longevity of *Orius sauteri* males and females feeding on *Lycoriella pleuroti* larvae, eggs and on artificial diet (MEC-AD). Within each sex, different letters indicate significant differences among various prey treatments (Duncan test at $P < 0.05$)

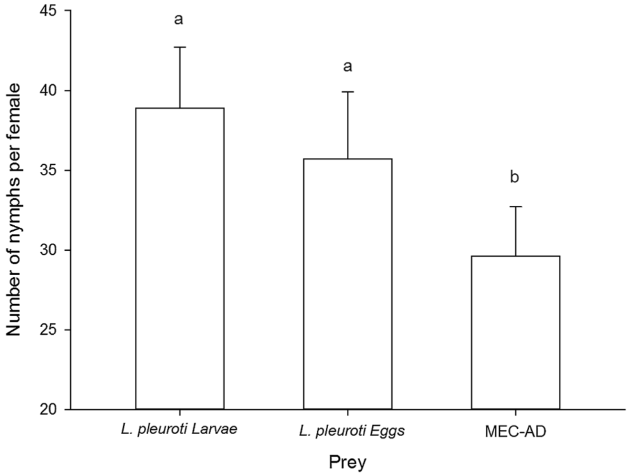

Fig. 2 Mean (±SE) values of total fertility of *Orius sauteri* female feeding on *Lycoriella pleuroti* larvae, eggs and on artificial diet (MEC-AD). Different letters indicate significant differences among various prey treatments (Duncan test at $P < 0.05$)

overall juvenile development time was not significantly affected by the feeding regime, while all were shorter than when fed on MEC-AD (F_1st = 4.6, *d.f.* = 2, 1181, $P = 0.023$; F_2nd = 5.5, *d.f.* = 2, 1139, $P < 0.01$; F_3rd = 4.3, *d.f.* = 2, 1113, $P = 0.047$; F_4th = 5.3, *d.f.* = 2, 1077, $P = 0.022$; F_5th = 10.9, *d.f.* = 2, 1046, $P < 0.01$; $F_{\text{overall}} = 10.6$, *d.f.* = 2, 1046, $P < 0.01$). Similarly, the juvenile survivorship was not significantly different between predators fed on larvae and eggs of *L. pleuroti* but significantly higher than when fed on microencapsulated artificial diet ($F = 11.7$, *d.f.* = 2, $P < 0.01$; Table 1).

The longevity of *O. sauteri* males was not influenced by feeding on the three prey types ($F = 4.0$, *d.f.* = 2, 463, $P = 0.34$; Fig. 1). However, females lived significantly longer when feeding on larvae or eggs of *L. pleuroti* than on MEC-AD ($F = 4.4$, *d.f.* = 2, 583, $P = 0.042$; Fig. 1).

The total *O. sauteri* fertility was indicatively not significant for females between feeding on fly larvae or eggs, but all significantly higher than feeding on the MEC-AD ($F = 6.1$, *d.f.* = 2, 583, $P < 0.01$; Fig. 2). This decreasing trend in fitness was similar for the estimated demographic parameter, r_m, as follows: *O. sauteri* feeding on *L. pleuroti* larvae = 0.118, on *L. pleuroti* eggs = 0.107 and on MEC-AD = 0.092.

Orius sauteri functional response to prey density

As shown in Table 2, all of the treatments, including both newly emerged male and female adults fed on either larvae or eggs of *L. pleuroti,* showed the same pattern of a significant increase in prey consumption with increase in prey density. Regressions were conducted for all treatments, with prey consumption and prey density using the type II Holling functional responses model. The fitted formulas and the parameters are

Table 2 Mean (±SE) values of the amount of consumed prey by *Orius sauteri* males and females, when different densities of *Lycoriella pleuroti* eggs or larvae were exposed for 24 h

Prey density	*L. pleuroti* larvae as prey		Prey density	*L. pleuroti* eggs as prey	
	Male	Female		Male	Female
20	16.9 ± 1.3a	16.4 ± 2.1a	40	38.1 ± 7.3a	35.7 ± 3.6a
40	33.6 ± 2.8b	31.5 ± 2.5b	60	53.3 ± 12.6b	52.4 ± 6.3b
60	47.9 ± 2.8c	49.4 ± 3.6c	80	66.5 ± 14.2c	64.4 ± 4.9c
80	61.3 ± 6.4d	58.7 ± 6.8d	100	79.3 ± 13.6d	75.8 ± 5.4d
100	72.5 ± 5.6e	69.4 ± 8.5e	120	89.4 ± 9.7e	87.6 ± 9.4e
120	77.6 ± 7.9ef	76.2 ± 6.1ef	140	104.7 ± 16.7f	98.8 ± 5.8f
140	81.2 ± 11.6f	80.4 ± 5.5f	160	110.2 ± 13.5f	106.4 ± 4.3 g
F	386.1	491.1	*F*	472.8	548.9
d.f.	6189	6189	*d.f.*	6189	6189
P	<0.001	<0.001	*P*	<0.001	<0.001

Within the same column, different letters indicate significant differences (Duncan test at $P<0.05$) among various prey densities

Table 3 Results of the Holling II functional response model calculated for *Orius sauteri* males and females, when different densities of *Lycoriella pleuroti* eggs or larvae were exposed for 24 h

Prey	Predator sex	Fitted formula	R^2	a'	T_h	$N_{a\text{-max}}$	X^2, P
L. pleuroti larvae	Male	$N_a=0.901\ N/(1+0.0033\ N)$	0.986	0.901	0.00361	249.6	6.19, 0.288
	Female	$N_a=0.894\ N/(1+0.0034\ N)$	0.973	0.894	0.00378	236.8	8.192, 0.325
L. pleuroti eggs	Male	$N_a=1.113\ N/(1+0.0042\ N)$	0.998	1.113	0.0038	295.4	5.342, 0.225
	Female	$N_a=0.996\ N/(1+0.0035\ N)$	0.991	0.996	0.0035	287.5	7.135, 0.305

$N_{a\text{-max}}=a'/T_h$

shown in Table 3. All theoretic prey consumptions under various prey densities were equivalent to the observational results with Chi-square tests.

Discussion

The exploitation of generalist natural enemies to suppress fungivorous pest populations has been neglected for a long time even though there are considerable economic losses caused by these pests to the edible fungus industry, and despite the difficulties in applying chemicals (Jess 2010; Shamshad 2010). For the first time, we have documented the ability of the tiny flower bug *O. sauteri*, to feed, develop and to functionally respond to the density of eggs and larvae of the fungivorous fly *L. pleuroti*, and that *L. pleuroti* proves to be a suitable prey for supporting the juvenile and adult development of *O. sauteri* populations.

As an aggressive generalist predator, the fitness of *O. sauteri* feeding on various arthropod prey has been evaluated several times in previous reports, including for whiteflies, thrips and aphids (Nagai and Yano 2000; Xu and Enkegaard 2009; Xing et al. 2010). However, most of these studies concerned arthropod pests inhabiting food webs and agroecosystems in which *Orius* spp. are naturally well represented. Here, we demonstrate how *O. sauteri* is extremely adaptive when facing a novel prey species infesting a non-plant substrate. This is supported by results herein, in which the duration of *O. sauteri* juvenile development was shorter, and nymph survival and adult reproduction were increased, when preying on these novel prey as compared to a standard artificial diet. Thus, *L. pleuroti* provides nutrition to *O. sauteri*, and they have the potential to be used as prey for mass rearing of this predator. More importantly, there are reasons to believe that *O. sauteri* could successfully establish and maintain populations following inoculative releases in *L. pleuroti*-infested mushroom cultivations.

The duration of *O. sauteri* juvenile development when feeding on *L. pleuroti* larvae and eggs in the assays herein was longer than when feeding on the two preferred prey *Tetranychus urticae* (Koch) and *Frankliniella occidentalis* (Pergande), which were 17.2 and 16.5 days, respectively (Wang et al. 2014). However, the duration of development was also shorter than when preying on *Myzus persicae* (Sulzer), *Aphis craccivora* (Koch), *Megoura japonica* (Matsumura) and *Aphis gossypii* (Glover), which are considered prey less suited by *O. sauteri*. All these results suggest that the *O. sauteri* population growth potential (r_m) is highest when preying on western flower thrips *F. occidentalis*, followed by the red spider mite *T. urticae*, and various aphid species such as *M. persicae,* then *L. pleuroti* larvae.

Because of the endophytic oviposition behavior of *Orius* spp. (the hole-drilling into host plant tissues for oviposition), oviposition substrates possess a number of variables which affect the growth of populations of these predators. Previous reports have showed that female *O. sauteri* may prefer the tender and smooth tissue of the host plant, such as petioles and young stems (Tan et al. 2014). According to our observation, *O. sauteri* females are also able to lay eggs in the *P. ostreatus* mushroom successfully. Further tests could be conducted to assess the suitability of edible mushrooms in supporting population growth of *O. sauteri* over multiple generations. This would benefit any potential mass rearing program which employed this particular substrate-pest model and could represent a valid banker plant system, which may enhance the *O. sauteri* application during conservation biological control (Lundgren et al. 2009; Parolin et al. 2012; Biondi et al. 2016) which would enable expanding use of *O. sauteri* to other cultivation environments. Such a scenario would be the first banker plant model employing a non-plant system.

The Holling functional response model has been used often to quantify predatory ability in the context of agricultural pests (Ganjisaffar and Perring 2015; Yazdani and Keller 2015). The two key parameters, instant attack rate (a') and the duration of a single prey consumption by predator (T_h), have been found to describe much of the variation in these prey and predator interactions. Our results indicated that the predation of *O. sauteri* fed on both larvae and egg of *L. pleuroti* fits the type II functional response. The net prey consumption of *O. sauteri* increases with increasing prey density, until a plateau is reached. Several previous works have reported the potential suppression ability of *Orius* spp. toward various arthropod pests in different agroecosystems. Some examples are *Orius niger* (Wolff) and *Orius minutus* (L.) for controlling *T. urticae* and *Thrips tabaci* (Lindeman) in potato, respectively (Fathi and Nouri-Ganbalani 2010), *Orius insidiosus* (Say) against *F. occidentalis* in bean, tomato and pepper plants (Coll and Ridgway 1995) and against aphid on soybean (Desneux et al. 2006; Desneux and O'Neil 2008), *Orius strigicollis* (Poppius) against *F. intonsa* in *Rosa chinensis* (Jacq) (Zhang et al. 2008), *Orius albidipennis* (Reuter) against *T. urticae* in different varieties of *Glycine max* (L.) (Zamani et al. 2009) and against *Tuta absoluta* (Meyrick) in tomato (Salehi et al. 2016), *Orius similis* (Zheng) against *M. persicae* (Wang et al. 1998) and *Frankliniella formosae* (Moulton) (Zhou and Lei 2002) in tomato. One functional response study showed that the surface characteristics of the host plants may influence the predation by *Orius* spp. to their aphid prey (Gholami Moghaddam et al. 2012). The potential predatory fitness to various target prey, especially some invasive herbivores in the native regions of *O. sauteri* (for instance in China and Japan), was reported by numerous previous reports by estimating their functional responses, including *Thrips palmi* (Karny), *F. occidentalis*, *Bemisia tabaci* (Gennadius), *Tetranychus cinnabarinus* (Dufour), *Thrips tabaci* (Lindeman), *Brevicoryne brassicae* (L.) and *M. persicae* (Nagai and Yano 2000; Xing et al. 2010; Wang et al. 2013a, b; Wu et al. 2010; Zhang et al. 2007). Among these, the predation of *O. sauteri* on the invasive greenhouse vegetable pest *F. occidentalis* has been described several times under various environmental conditions and agroecosystems (Zhang et al. 2007), and the net predatory efficiency when preying on *F. occidentalis* was lower than preying on *L. pleuroti* third-instar larvae and eggs. Even when preying on the same prey species, the net predatory efficiency can be different on different host species or instars. Despite these advances, our research is the first estimating the predation potential of an *Orius* species feeding on a fungivorous arthropod pest. Our results indicate a moderate instant attack rate and a short consequent handling time compared to other agricultural herbivores (Nagai and Yano 2000; Xing et al. 2010; Wang et al. 2013a, b; Wu et al. 2010; Zhang et al. 2007). Such results imply a high potential ability of *O. sauteri* in suppressing the outbreak of *L. pleuroti*. The estimation of the maximum prey consumption ($=a'/T_h$) gave the possibility of obtaining an optimal ratio between predator and target pest, which can be useful for optimizing the practice of inoculative releases. More field tests are thus needed for evaluating the effectiveness of *O. sauteri* in managing *L. pleuroti* by inoculative releases.

Contrary to traditional field crops, organic orchards and greenhouse vegetables, edible mushroom must be cultivated under cold, humid, short-light photoperiod and lower light intensity conditions. These particular agronomic conditions are quite dissimilar to the natural habitats of *O. sauteri*. Our previous study indicated that the light conditions may strongly influence various life traits, reproduction and individual locomotion of *O. sauteri* (Wang et al. 2013a, b). Nagai and Yano (1999) showed the temperatures did not influence the development of *O. sauteri* and adults may have greater longevity under cold conditions (Nagai and Yano 1999). Accordingly, more detailed examinations should be conducted in the future in order to better understand the dynamics of population fitness and predatory performance of *O. sauteri* under the conditions of edible mushroom cultivation. In addition, side effects of pesticides used in mushroom cropping systems on *O. sauteri* (e.g. through sublethal effects and/or impact on biocontrol services provided by the predator, Desneux et al. 2007, Lu et al. 2012) would have to be assessed before a possible successful development of IPM programs involving the use of *O. sauteri* (e.g. see Mohammed et al. 2018).

Author contribution statement

SXW, FZ and SW designed the research. SXW, ND[1] and XC conducted experiments. AB, SW and ND[4] analyzed data. SXW and ND[1] wrote the manuscript. All authors read, revised and approved the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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