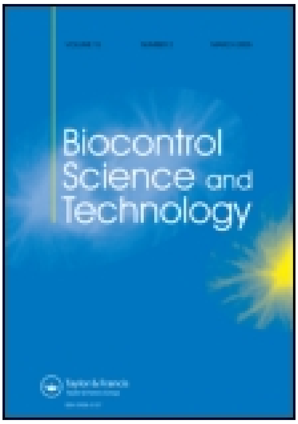

Biocontrol Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/cbst20

Acceptance and suitability of four plant substrates for rearing Orius sauteri (Hemiptera: Anthocoridae)

Xiao-Ling Tan[a], Su Wang[b] & Tong-Xian Liu[a]

[a] State Key Laboratory of Crop Stress Biology for the Arid Areas, Key Laboratory of Northwest Loess Plateau Crop Pest Management of Ministry of Agriculture, Northwest A&F University, Yangling, China

[b] Institute of Plant and Environment Protection, Beijing Academy of Agriculture and Forestry Sciences, Beijing, China

Accepted author version posted online: 29 Oct 2013.Published online: 29 Oct 2013.

To cite this article: Xiao-Ling Tan, Su Wang & Tong-Xian Liu (2014) Acceptance and suitability of four plant substrates for rearing Orius sauteri (Hemiptera: Anthocoridae), Biocontrol Science and Technology, 24:3, 291-302, DOI: 10.1080/09583157.2013.860079

To link to this article: http://dx.doi.org/10.1080/09583157.2013.860079

Biocontrol Science and Technology, 2013
Vol. 24, No. 3, 291–302, http://dx.doi.org/10.1080/09583157.2013.860079

RESEARCH ARTICLE

Acceptance and suitability of four plant substrates for rearing *Orius sauteri* (Hemiptera: Anthocoridae)

Xiao-Ling Tan[a], Su Wang[b] and Tong-Xian Liu[a]*

[a]*State Key Laboratory of Crop Stress Biology for the Arid Areas, Key Laboratory of Northwest Loess Plateau Crop Pest Management of Ministry of Agriculture, Northwest A&F University, Yangling, China;* [b]*Institute of Plant and Environment Protection, Beijing Academy of Agriculture and Forestry Sciences, Beijing, China*

(*Received 19 September 2013; returned 14 October 2013; accepted 23 October 2013*)

Orius sauteri (Poppius) is an important hemipterous predator that has been mass-reared for biological control of numerous pests in protected crop-production systems. To find a good oviposition substrate for mass-rearing this predator under insectary conditions [25°C, 65 ± 5% relative humidity, and a photoperiod of 16:8 (L:D) h], we compared kidney bean, soybean, broad bean sprouts and fresh leaves of kidney bean. We found that *O. sauteri* made more punctures and laid more eggs in kidney bean sprouts than in the other substrates examined. However, there were no significant differences among substrates in the proportion of punctures receiving eggs. Female *O. sauteri* laid the most eggs (as many as 68 eggs) in kidney bean sprouts and also had the shortest pre-oviposition period on this plant material. In addition, there were no significant differences in total oviposition durations or female longevity among the four plant substrates. The hatch rates of nymphs in the sprouts and leaves of kidney bean (>90%) were higher than those in soybean and broad bean sprouts. Thus, we found that the kidney bean sprout was the most suitable substrate for mass-rearing of *O. sauteri*.

Keywords: flower bug; mass rearing; oviposition substrate; fecundity; longevity; reproduction

1. Introduction

The flower bug, *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae), is a biological control agent of numerous insect pests in its native Asian region (Murai, 1988; Yano, 1996; Yano et al., 2005). This predatory bug can suppress the outbreaks of many economically important arthropod pests, including *Bemisia tabaci* (Gennadius) (Zhang, Lü, Wan, & Lövei, 2007), *Trialeurodes vaporariorum* (Westwood) (Yano, 2004), *Thrips palmi* Karny (Nagai & Yano, 2000), *Frankliniella occidentalis* (Pergande) (Nakashima & Hirose, 1999), *Myzus persicae* (Sulzer), *Macrosiphum euphorbiae* (Thomas) and *Aphis gossypii* Glover (Nakata, 1995b).

Zhou and Wang (1989) pioneered a study to develop artificial diets for rearing *O. sauteri*. Since then, numerous *Orius* species, including *O. sauteri* (Nakata, 1995a), *O. insidious* (Say) (Ferkovich & Shapiro, 2004a, 2004b; Isenhour & Yeargan, 1981), *O. laevigatus* (Fieber) (Arijs & De Clercq, 2004) and *O. niger* (Wolff) (Nisha & Gupta,

*Corresponding author. Email: txliu@nwsuaf.edu.cn

2010) have been mass-reared and are commercially available around the world for pest management (Cohen, 2004; Glenister, 1998). The eggs of *Ephestia kuehniella* Zeller have been successfully used to feed *O. laevigatus*, *O. albidipennis* (Reuter), *O. minutus* (L.) and *O. sauteri* (Carvalho, Bueno, & Silveira, 2003; Cocuzza et al., 1997; Honda, Nakashima, & Hirose, 1998).

In the past, the development of both artificial diets and suitable plant substrates for oviposition of *Orius* spp. has been explored. Pure artificial diets, which consist of some animal viscera tissues and poultry egg yolk proteins are also used in the mass-rearing of *Orius* (Arijs & De Clercq, 2001, 2004; Ferkovich & Shapiro, 2005, 2007; Tan, Wang, & Zhang, 2013). Many plant species serve as oviposition substrates for *Orius* females that lay their eggs directly inside plant tissues. Although, several leguminous plants were evaluated as oviposition substrates for *O. sauteris* (Zhou, Wang, & Qiu, 1991), differences among host plant species and physical structures of the plant affect the rearing efficiency of *Orius* bugs (Stone, Pitre, & Thompson, 1984). Herbaceous plants, especially leguminosae species, have been commonly used as oviposition substrates for *Orius* rearing (Castane & Zalom, 1994; Shapiro & Ferkovich, 2006). Kidney bean pods and sprouts have been used as primary oviposition substrates for rearing various *Orius* species (Nakashima & Hirose, 2003; Richards & Schmidt, 1996; Ruberson, Bush, & Kring, 1997). Soybean and broad bean sprouts have also been reported as suitable oviposition substrates for *O. insidiosus*, *O. minutus* and *O. sauteri* (Kiman & Yeargan, 1985; Ito & Nakata, 1998). Moreover, other botanic tissues, such as vegetable leaves, flower stems and cotton seedlings, have been evaluated as the oviposition substrates for maintenance of *O. laevigatus* and *O. albidipennis* (Vancante, Cocuzza, De Clercq, Van der Veire, & Tirry, 1997). Guo and Wan (2001) used *Kalanchoe blossfeldiana* Entretien and *Crassula argentea* Thunb. [=*Crassula ovate* (Miller)] leaves as oviposition substrates for rearing *O. sauteri*, but these woody plants were not suitable for propagation in mass-rearing in the greenhouse and environmental chambers conditions.

In the past several years, we used several leguminous plants as oviposition substrates for rearing *O. sauteri*, and encountered many problems from low longevity and fecundity of adults to low numbers of nymphs hatched. Therefore, we determined to seek more suitable oviposition plant substrates for *O. sauteri* in our mass-rearing programme. We evaluated the acceptance and suitability of four leguminous plant substrates, sprouts and fresh leaves of kidney bean (*Phaseolus vulgaris* L.), and sprouts of soybean [*Glycine max* (L.) Merr.] and broad bean (*Vicia faba* L.) for *O. sauteri* rearing in micro-rearing cages.

2. Materials and methods

2.1. *O. sauteri* and *Aphis craccivora*

Over 10,000 fresh *Aphis craccivora* Koch (egg, nymph and adult stages) were collected from a peanut field in the experimental farm of the Beijing Academy of Agriculture and Forestry Sciences (BAAFS), Haidian District, Beijing (116°16′ 47.21″ E; 39°56′30.64″ N) between 5 and 10 May 2011. The aphids were reared on the foliage of broad bean, *Phaseolus vulgaris* L. (Xin Seed Co., Ltd. Beijing, China) in the Entomology Research Laboratory, BAAFS. The aphids and plants were maintained in rearing chambers at 25°C, 65 ± 5% relative humidity (RH), and a photoperiod of 16:8 (L:D) h with an illumination intensity of 3000–3250 lx (the environmental conditions were managed by GCL-10 Automatic System, Beijing Champion Automation Tech Co. Ltd, Beijing, China).

O. sauteri adults (351 males and 296 females) were originally collected from an alfalfa field in Wangjiayuan Farm, BAAFS-CASIOZ (Institute of Zoology, Chinese Academy of Sciences) Joint Biodiversity Research Station, Changping County, Beijing (116°2′35.64″ E and 40°10′42.56″ N). No fungicide or insecticide was used in field before the predators were collected. The predators were reared using *A. craccivora* as prey in glass reinforced cages (75 × 80 × 50 cm) (top and bottom with glass and four sides with fibre net) screened with 100 × 100 mesh fibre net in an insectary at 25 ± 5°C, a photoperiod of 16:8 (L:D) h, and 65 ± 5% RH. Newly hatched *O. sauteri* nymphs were placed into specially designed micro-rearing cages (Figure 1), three per cage, and fed aphids until they moulted to adults. Pairs of newly emerged virgin adults were placed in a 5-ml EP test tube with 20 aphids as prey. The plastic cover was removed and a piece of parafilm with tiny ventilation holes (14–15 holes/cm^2) was used to cover the tube opening. The insects were visually monitored for mating. When the couples of *O. sauteri* mated in 24 h, they were separated, and the mated female adults were used in all experiments.

2.2. Oviposition substrate preparation

To obtain fresh sprouts of kidney bean and broad bean, the seeds were soaked in tap water for 24 h, and were then placed in shallow culture plates (peat and vermiculite = 1:2) (35 × 26 × 9 cm). Four to five days after seed germination, when the whole sprout was approximately 10–12 cm in height or before the first true leaf was fully developed, the roots of the sprouts were removed. Only tender sprouts were used in all experiments. To obtain kidney bean leaves, the sprouts of kidney bean were allowed to grow up to 4–5 leaves (25–30 cm in height) or the leaf area of each leaf was 35–40 cm^2 in nutritional soil. The leaves with petioles were detached, and were individually inserted into a propagation vial (2.5 cm in diameter and 6 cm in length). To obtain soybean sprouts, which served as the control treatment in our research, the seeds were soaked in tap water for 12 h, and were then imbedded in a layer of vermiculite (3–4 cm in depth). The seeds were maintained for 3 days until they sprouted. The sprouts were then taken out from the vermiculite and were washed. They were used when the first true leaf became fully expanded.

2.3. Oviposition preference of O. sauteri on different substrates

This study was undertaken in micro-rearing cages as described in earlier section. Sprouts of kidney bean, soybean and broad bean, and the fresh leaves of kidney bean were individually inserted into a nutritional tube, and two-third of the sprout or the leaf was kept in the cultural Petri dish with abundant aphids (>60 aphids). One mated female adult (<24 h after moulting) was introduced into each cage, and the cage was covered with a cap and sealed with a piece of parafilm. The oviposition substrates with aphids were replaced daily. The sprouts and leaves were checked carefully under a stereomicroscope, and numbers of punctures made by the females' ovipositors were counted daily for 10 consecutive days. *Orius* females lay eggs within the plant tissues by making small punctures (<1 mm). Generally, these females lay only one egg in each puncture. However, the number of punctures may not be the same as the number of eggs laid. This is because the female may choose not to lay an egg in each puncture.

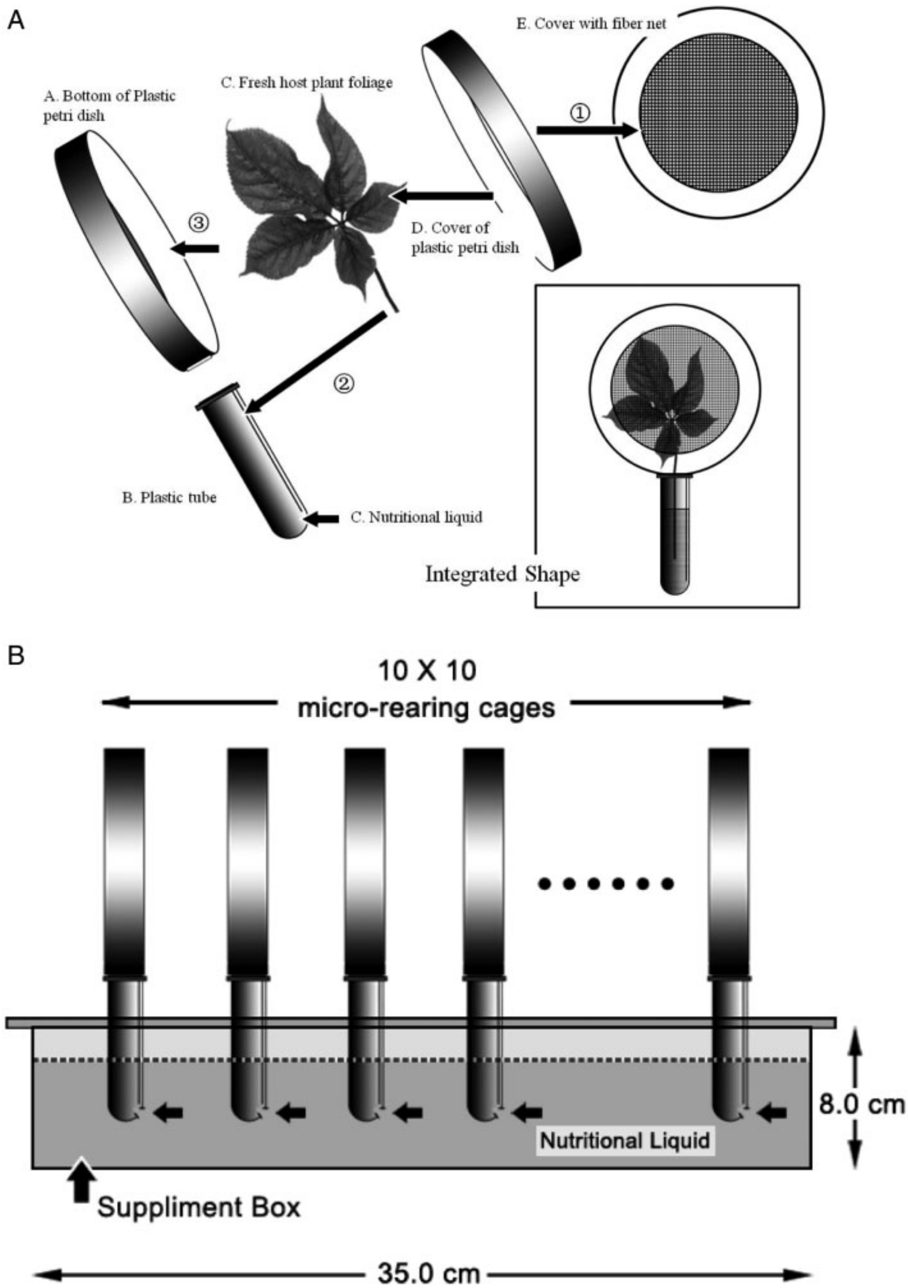

Figure 1. The rearing cage of *O. sauteris* with botanic nutritional liquid in a plastic vial to sustain the vitality of the leaf (A) and the arrangement of the rearing cages. They were inserted in a container filled with nutritional liquid (B).

We can see the preculum of eggs protruding from the puncture under a stereomicroscope (60× or high magnification). Plant tissues with punctures were not dissected to check the presence of eggs in order to avoid any damage to the eggs. The plant tissues were also maintained in the micro-rearing cages every 12 h. We then counted the number of eggs and punctures under a stereomicroscope. Newly hatched nymphs were counted and then removed using a soft brush. Each treatment was replicated 10 times, and each replicate contained 10 oviposition substrates of each type.

2.4. Reproductive capacity and longevity of O. sauteri

All bean sprouts or leaves as oviposition substrates were placed in a micro-rearing cage with abundant prey (>60 aphids). Then, a newly mated *O. sauteri* female was introduced in each cage. The substrates were replaced daily with fresh ones with similar numbers of prey (>60 aphids). The number of punctures and eggs in each substrate sprout or leaf treatment was recorded using the microscope daily, until the female died. Newly hatched nymphs were counted and then removed using a soft brush. Total number of eggs laid per female (fecundity), pre-oviposition period, total oviposition duration and longevity of the female adults were recorded simultaneously. Each treatment had 10 replications, and each replicate contained 10 oviposition substrates of each type.

2.5. Data analysis

All data, including numbers of punctures, fecundity, pre-oviposition and oviposition durations, female longevity and nymphal hatch rates of *O. sauteri* were analysed using one-way analysis of variance (ANOVA). The data of nymphal hatch rate (%) were transformed by the arcsine square-root transformation before analysing by using ANOVA; means among the different oviposition substrates were separated using the least significant difference test (Tukey-Kramer) at P = .05 (SPSS 16.0, SPSS Inc., Chicago, IL, USA). One way ANOVA with repeated measures was used to compare the differences of the daily oviposition of *O. sauteri* females.

3. Results

3.1. Oviposition preference

The numbers of punctures made by the female *O. sauteri* on the four different substrates were significantly different (F = 95.902; df = 3, 396; P < .001) (Figure 2). The kidney bean sprouts had the most punctures (19.8), followed by kidney bean leaves (13.3) and soybean sprouts (3.7) and broad bean sprouts (3.5). The numbers of punctures on soybean and broad bean sprouts were <20% of those on kidney bean sprouts and <30% of those on kidney bean leaves.

The number of eggs laid by female *O. sauteri* in different oviposition substrates showed a similar trend as those of punctures made by the females (Figure 2). The numbers of eggs laid were significantly different among all four substrates (F = 71.317; df = 3, 396; P < .001). *O. sauteri* laid the most eggs on kidney bean sprouts, followed by kidney bean leaves, and the least eggs were laid in soybean and broad bean sprouts.

The proportion of punctures containing eggs did not differ among the four substrates (F = 2.478; df = 3, 396; P = .077) (Figure 3A). But the percentages of eggs that successfully hatched were significantly different among the four substrates (F = 24.458; df = 3, 396; P < .001) (Figure 3B). The highest nymph hatch rate was found in kidney bean sprouts, followed by those in kidney bean leaves, and lowest hatch rates were in soybean and broad bean sprouts.

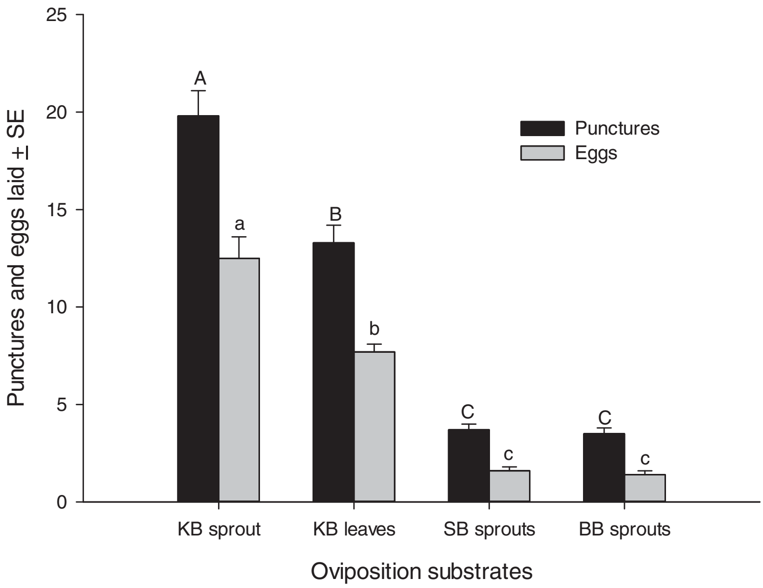

Figure 2. Number of punctures (mean ± SE) made by *O. sauteri* in four oviposition substrates. Bars with the same for punctures and lowercase letters for eggs indicated that the means among the treatments are not significantly different (KB, kidney bean; SB, soybean; BB, broad bean) (Tukey-Kramer Test, P = .05).

3.2. Reproductive capacity and longevity of O. sauteri

The fecundity of *O. sauteri* females in each oviposition substrate was significantly different among the four substrates examined (F = 16.918; df = 3, 396; P < .001) (Figure 4A). *O. sauteri* laid the most eggs in kidney bean sprouts (12.5), the least in

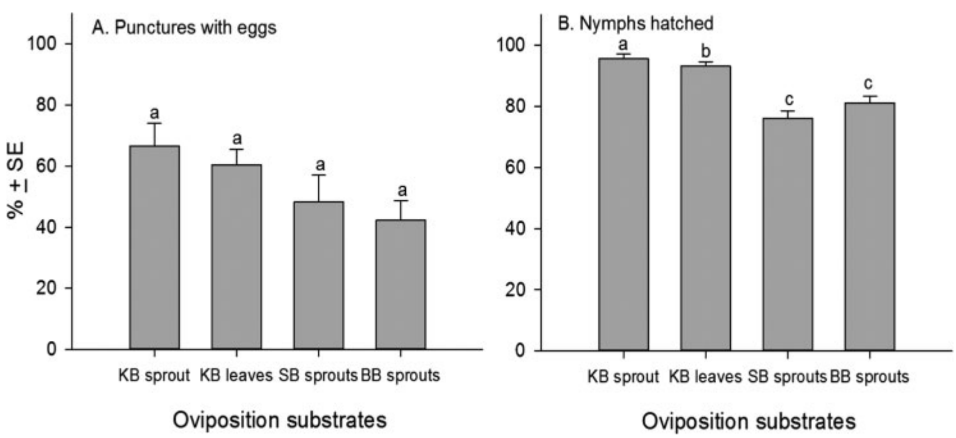

Figure 3. The percentages (mean ± SE) of eggs laid in the punctures made by *O. sauteri* in four oviposition substrates (A), and nymphs hatched from the eggs in the punctures (B). Bars with the same letters indicated that the means among the treatments are not significantly different (KB, kidney bean; SB, soybean; BB, broad bean) (Tukey-Kramer Test, P = .05).

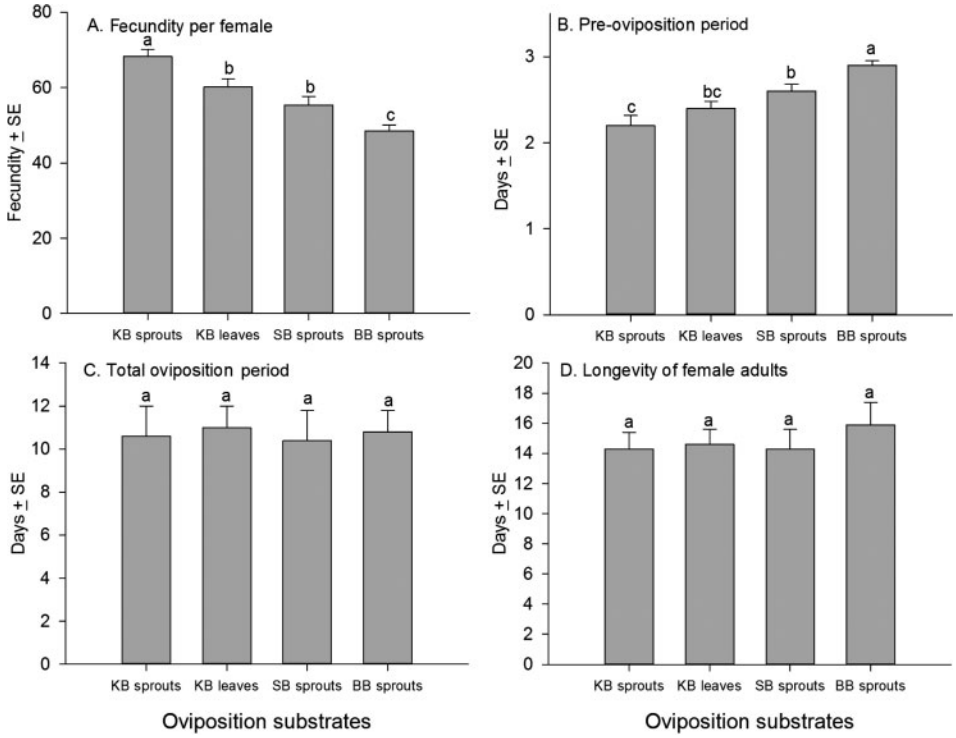

Figure 4. The total lifetime fecundity (A), pre-oviposition duration (B), oviposition duration (C) and longevity of female *O. sauteri* for four oviposition substrates. Bars with same letters indicate that the means among the treatments are not significantly different (KB, kidney bean; SB, soybean; BB, broad bean) (Tukey-Kramer Test, P = .05).

broad bean sprouts (1.4), and intermediate results were obtained in the kidney leaf (7.7) and soybean (1.6) treatments.

The pre-oviposition period of *O. sauteri* was 1–3.2 days, and was generally shorter than 3 days. The oviposition substrates had a strong effect on the pre-oviposition time of *O. sauteri* females (F = 13.17; df = 3, 396; P < .001) (Figure 4B), although the difference was shorter than 1 day. The pre-oviposition time in the broad bean sprout treatment was the longest among the four treatments, followed by those in the soybean sprout and kidney bean leaf treatments, and that in the kidney bean sprout treatment was the shortest. However, there were no significant differences in the overall oviposition period when the adults fed on aphids on the four different substrates (F = 0.046; df = 3, 396; P = .987) (Figure 4C). Similarly, the longevity was also not significantly different when the females fed on aphid on the different oviposition substrates (F = 1.122; df = 3, 396; P = .646) (Figure 4D).

4. Discussion

This study was the first to compare a variety of common beans as substrates for *O. sauteri*. Our results showed that *O. sauteri* females were able to lay eggs in all plant substrates offered, but the numbers of punctures made, eggs laid and nymphs hatched differed among the four substrates. In spite of many plants being suitable for egg development, it appears that the adult females prefer certain plant species and plant parts for oviposition. As a shelter for eggs, plant tissues play a very important role in the life cycle of *O. sauteri*. Likewise, the differences among oviposition substrates can directly affect their oviposition behaviour and reproductive capacity. The number of ovipositor punctures and eggs laid clearly showed that kidney bean sprout was a superior substrate for oviposition (Figure 2). Murai, Narai, and Sugiura (2001) reported high reproductive fitness of *O. sauteri* with germinated broad bean as an oviposition substrate. The oviposition substrate is mostly related to the early development of the offspring. High nymph hatch rate may be one of the most important criteria and may reflect the performance of the offspring. This research showed that kidney bean sprout and kidney bean leaf were much better than soy or broad bean sprouts as egg-laying substrates for *O. sauteri*. Several previous studies inferred that broad bean or soybean was a suitable substrate for *Orius* but did not compare kidney bean or other beans (Murai et al., 2001; Zhou et al., 1991). More in-depth research is needed to explore a variety of chemical compositions, and nutrition among different plant substrates for predatory bugs to lay eggs. According to the preference–performance hypothesis (Jaenike, 1978), female should oviposit on the host plants which could enhance the performance of their offspring (Heisswolf, Obermaier, & Poethke, 2005). Optimal oviposition theory (Jaenike, 1978) predicts that oviposition preference should correlate with host plant suitability for offspring development as females are assumed to maximise their fitness by ovipositing on high-quality hosts (Awmack & Leather, 2002). The chemical composition and nutrition in the plant substrates play important roles in oviposition and fencundity of the predatory bug. We have found that the stem and leaf tissue of broad bean were apparently tougher than other bean plants. In the same way, primary prey of *O. sauteri*, like *B. tabaci* and *F. occidentalis*, tends to prefer tender parts of the host plants as their optimal oviposition sites (de Kogel, van der Hoek, & Mollema, 1997; de Kogel, Balkema-Boomstra, van der Hoek, Zijlstra, & Mollema, 1997; Simmons, 1994). In addition, females distinguish plants based on the toughness of their external tissues, including the epidermis, collenchyma layers and trichome densities. *O. insidiosus* females prefer plants as ovipositional hosts that have the thinnest external tissues (Lundgren, Fergen, & Riedell, 2008).

For mass-rearing of *O. sauteri* and other predatory bugs, the substrate plant is not only important for the oviposition processes, but also must be suitable for nutritional maintenance of females during periods of prey scarcity or for supplemental water (Lundgren et al., 2008; Murai et al., 2001). Moisture retention level of substrates was one characteristic that influenced oviposition choices of substrates by *O. insidiosus* (Richards & Schmidt, 1996). Host plant substrates have been shown to affect the development, survival and fecundity of *Orius* species (Bonte & De Clercq, 2010; Coil, 1996; Murai, Narai, & Sugiura, 2001; Richards & Schmidt, 1996). In our study, the great number of eggs laid by the *O. sauteri* females and the relatively short pre-oviposition duration in kidney bean sprouts and leaves indicated that net reproductive efficiency and fecundity could be significantly improved by use of these plant substrates.

Plant acceptability as an oviposition site may also be affected by the plant's suitability for egg hatching and subsequent immature development (Lundgren & Fergen, 2006). The high nymphal hatch rate also indicates the suitability of kidney bean sprout as an oviposition substrate. The 90% hatch rate for *O. sauteri* nymphs indicates the potential advantages for artificial rearing of predatory *O. sauteri* on a large scale, important in keeping an adequate supply of natural enemies for augmentative biological control of pest insects. On the other hand, the plant food quality plays an important role, and it may also influence the *O. sauteri* fertility in oviposition substrate preference (Armer, Wiedenmann, & Bush, 1998).

Kidney bean sprouts and leaves yield superior oviposition of *O. sauteri*. The peak oviposition period of *O. sauteri* was only 1 or 2 days, and therefore, the quality control of plant substrates is very important during this period. Kiman and Yeargan (1985) reported that the diets were the key factor to the daily oviposition for *O. insidious*. Similarly, daily oviposition was affected by both diet and plant substrate; *E. kuehniella* eggs and soybean sprouts were more suitable than other diets (Yano, Watanabe, & Yara, 2002).

Oviposition substrates with a relatively shorter propagation period and a longer persistence could enhance the development and reproductive efficiency of arthropods. *O. sauteri* prefer to lay eggs in the oviposition substrates that maintain high vigour and freshness for a period that is long enough for the predator to complete their life cycle. Additionally, the predators feed on tender substrates and the eggs require high humidity to keep fresh and proper development. *O. sauteri* that fed on aphids and oviposited in kidney bean sprouts and leaves had a relatively shorter pre-oviposition period, and higher fecundity. We have found that soybean and broad bean sprouts normally wilt in a few days under laboratory conditions; as a result, the insects could not complete their development. Compared to other leguminous plants, kidney bean sprouts and leaves can be maintained for over 20 days with eggs and nymphs of *O. sauteri* under laboratory conditions (22–25°C), which was much longer than for other host plant substrates and long enough for *O. sauteri* to complete at least one generation (Tan and Liu, unpublished data).

We found that *O. sauteri* females choose the delicate parts of plant tissue to make punctures and lay eggs, likely because these tender plant tissues were easier to puncture than other plant tissues. Thickness of the external covering may also render some species unsuitable as oviposition sites (Castane & Zalom, 1994). Lundgren and Fergen (2006) evaluated a range of plants for oviposition of *O. insidiosus* and found that the adults accept and prefer leaf or leaflet petioles to lay eggs. In the same way, the physical and internal anatomy of host plant also presented high impact to the oviposition and development of the progeny of the predator (Lundgren et al., 2008). Similarly, it has been reported that *O. insidious* and *O. minutus* prefer to lay eggs in the tender parts of the host plant (Isenhour & Yeargan, 1981; Schmidt, Richards, Nadel, & Ferguson, 1995).

Literature and results from this study suggest that the influence of plant substrates on both adult and offspring fitness may be playing a role in plant acceptability and suitability for oviposition by predators. Further study is needed to understand the nutritional values and the physical characteristics of kidney bean sprouts for maximum production of *O. sauteri*. Also, trials on mechanisms behind oviposition substrate selection and *O. sauteri* reproduction will help to identify specific plant substrate qualities that may influence the fecundity, longevity of *O. sauteri*.

Acknowledgements

We are grateful for the assistance of all staff and students in the Key Laboratory of Applied Entomology, Northwest A&F University at Yangling, Shaanxi, China.

Funding

This research was partially supported by each of the following grants: the National Natural Science Foundation of China [No. 31272089]; National Basic Research programme of China [973 Projects No. 2012CB114105 and No. 2012CB017359]; China Agriculture Research System [CARS-25-B-06]; and the Youth Scientific Research Foundation, BAAFS [#QNJJ201008].

References

Arijs, Y., & De Clercq, P. (2001). Rearing *Orius laevigatus* on cysts of the brine shrimp *Artemia fanciscana*. *Biological Control*, *21*, 79–83. doi:10.1006/bcon.2000.0910

Arijs, Y., & De Clercq, P. (2004). Liver-based artificial diets for the production of *Orius laevigatus*. *BioControl*, *49*, 505–516. doi:10.1023/B:BICO.0000036440.02590.fa

Armer, C. A., Wiedenmann, R. N., & Bush, D. R. (1998). Plant feeding site selection on soybean by the facultatively phytophagous predator *Orius insidiosus*. *Entomologia Experimentalis et Applicata*, *86*, 109–118. doi:10.1046/j.1570-7458.1998.00271.x

Awmack, C. S., & Leather, S. R. (2002). Host plant quality and fecundity in herbivorous in insects. *Annual Review of Entomology*, *47*, 817–844. doi:10.1146/annurev.ento.47.091201.145300

Bonte, M., & De Clercq, P. (2010). Impact of artificial rearing systems on the developmental and reproductive fitness of the predatory bug, *Orius laevigatus*. *Journal of Insect Science*, *10*, 104. http://www.insectscience.org/10.104

Carvalho, L., Bueno, V., & Silveira, L. (2003). Nymphal development of three *Orius* species reared on eggs of *Ephestia kuehniella* Zeller. *IOBC/WPRS Bulletin*, *26*, 131–134.

Castane, C., & Zalom, F. G. (1994). Artificial oviposition substrate for rearing *Orius insidiosus* (Hemiptera, Anthocoridae). *Biological Control*, *4*, 88–91. doi:10.1006/bcon.1994.1015

Cocuzza, G. E., De Clercq, P., Van der Veire, M., De Cock, A., Deheele, D., & Vacante, V. (1997). Reproduction of *Orius laevigatus* and *Orius albidipennis* on pollen and *Ephesita kuehniella* eggs. *Entomologia Experimentalis et Applicata*, *82*, 101–104. doi:10.1046/j.1570-7458.1997.00118.x

Cohen, A. (2004). *Insect diets science and techology*. New York, NY: CRC Press.

Coil, M. (1996). Feeding and ovipositing on plants by an omnivorous insect predator. *Oecologia*, *105*, 214–220.

de Kogel, W. J., Balkema-Boomstra, A., van der Hoek, M., Zijlstra, S., & Mollema, C. (1997). Resistance to *western* flower thrips in greenhouse cucumber: Effect of leaf position and plant age on thrips reproduction. *Euphytica*, *94*, 63–67. doi:10.1023/A:1002937709157

de Kogel, W. J., van der Hoek, M., & Mollema, C. (1997). Oviposition preference of *western* flower thrips for cucumber leaves from different positions along plant stem. *Entomologia Experimentalis et Applicata*, *82*, 283–288. doi:10.1046/j.1570-7458.1997.00142.x

Ferkovich, S. M., & Shapiro, J. P. (2004a). Increased egg-laying in *Orius insidiosus* (Hemiptera: Anthocoridae) fed artificial diet supplemented with an embryonic cell line. *Biological Control*, *31*, 1–15. doi:10.1016/j.biocontrol.2004.04.018

Ferkovich, S. M., & Shapiro, J. P. (2004b). Comparison of prey-derived and non-insect supplements on egg-laying of *Orius insidiosus* maintained on artificial diet as adults. *Biological Control*, *31*, 57–64. doi:10.1016/j.biocontrol.2004.04.005

Ferkovich, S. M., & Shapiro, J. P. (2005). Enhanced oviposition in the insidious flower bug, *Orius insidiosus* (Hemiptera: Anthocoridae) with a partially purified nutritional factor from prey eggs. *Florida Entomologist*, *88*, 253–257. doi:10.1653/0015-4040(2005)088[0253:EOITIF]2.0.CO;2

Ferkovich, S. M., & Shapiro, J. P. (2007). Improved fecundity in the predator Orius insidiosus (Hemiptera: Anthocoridae) with a partially purified nutrional factor from insect cell line. *Florida Entomologist*, *90*, 321–326. doi:10.1653/0015-4040(2007)90[321:IFITPO]2.0.CO;2

Glenister, C. S. (1998). Predatory heteropterans in augmentative biological control: An industry perspective. In M. Coll & J. Ruberson (Eds.), *Predatory Heteroptera: Their ecology and use in biological control* (pp. 199–208). Lanham, MD: Thomas Say Publ Entomol, Entomological Society America.

Guo, J. Y., & Wan, F. H. (2001). Use kalanchoe bolssfeldiana as oviposition plant for mass-rearing Orius sauteri (Hemiptera: Anthocoridae). *Chinese Journal of Biological Control*, *17*, 53–56. (In Chinese).

Heisswolf, A., Obermaier, E., & Poethke, H. J. (2005). Selection of large host plants for oviposition by a monophagous leaf beetle: Nutritional quality or enemy-free space? *Ecological Entomology*, *30*, 299–306. doi:10.1111/j.0307-6946.2005.00706.x

Honda, J. Y., Nakashima, Y., & Hirose, Y. (1998). Development, reproduction and longevity of *Orius minutus* and *Orius sauteri* (Heteroptera: Anthocoridae) when reared on *Ephestia kuehniella* eggs. *Appllied Entomology and Zoology*, *33*, 449–453.

Isenhour, D. J., & Yeargan, K. V. (1981). Effect of temperature on the development of *Orius insidiosus*, with notes on laboratory rearing. *Annals Entomological Society America*, *74*, 114–116.

Ito, K., & Nakata, T. (1998). Diapause and survival in winter in two species of predatory bugs, *Orius sauteri* and *O. minutus*. *Entomologia Experimentalis et Applicata*, *89*, 271–276. doi:10.1046/j.1570-7458.1998.00408.x

Jaenike, J. (1978). On optimal oviposition behavior in phytophagous insects. *Theoretical Population Biology*, *14*, 350–356. doi:10.1016/0040-5809(78)90012-6

Kiman, Z. B., & Yeargan, K. V. (1985). Development and reproduction of the predator *Orius insidiosus* (Hemiptera: Anthocoridae) reared on diets of selected plant material and arthropod prey. *Annals Entomological Society America*, *78*, 464–467.

Lundgren, J. G., & Fergen, J. K. (2006). The oviposition behavior of the predator *Orius insidiosus*: Acceptability and preference for different plants. *BioControl*, *51*, 217–227. doi:10.1007/s10526-005-0609-2

Lundgren, J. G., Fergen, J. K., & Riedell, W. E. (2008). The influence of plant anatomy on oviposition and reproductive success of the omnivorous bug *Orius insidiosus*. *Animal Behaviour*, *75*, 1495–1502. doi:10.1016/j.anbehav.2007.09.029

Murai, T. (1988). Studies on the ecology and control of flower thrips, *Frankliniella intonsa* (Trybom). *Bulletin of the Shimane Agricultural Experiment Station*, *23*, 1–73.

Murai, T., Narai, Y., & Sugiura, N. (2001). Utilization of germinated broad bean seeds as an oviposition substrate in mass rearing of the predatory bug, *Orius sauteri* (Poppius) (Heteroptera: Anthocoridae). *Applied Entomology and Zoology*, *36*, 489–494. doi:10.1303/aez.2001.489

Nagai, K., & Yano, E. (2000). Predation by *Orius sauteri* (Poppius) (Heteroptera: Anthocoridae) on *Thrips palmi* Karny (Thysanoptera: Thripidae): Functional response and selective predation. *Applied Entomology and Zoology*, *35*, 565–574. doi:10.1303/aez.2000.565

Nakashima, Y., & Hirose, Y. (1999). Effects of prey availability on longevity, prey consumption, and egg production of the insect predators *Orius sauteri* and *O. tantillus* (Hemiptera: Anthocoridae). *Annals Entomological Society America*, *92*, 537–541. doi:10.1303/aez.2000.565

Nakashima, Y., & Hirose, Y. (2003). Sex differences in foraging behaviour and oviposition site preference in an insect predator, *Orius sauteri*. *Entomologia Experimentalis et Applicata*, *106*, 79–86. doi:10.1046/j.1570-7458.2003.00002.x

Nakata, T. (1995a). Effect of rearing temperature on the development of *Orius sauteri* (Poppius) (Heteroptera: Anthocoridae). *Appllied Entomology and Zoology*, *30*, 145–151.

Nakata, T. (1995b). Population fluctuations of aphids and their natural enemies on potato in Hokkaido. *Appllied Entomology and Zoology*, *30*, 129–138.

Nisha, D., & Gupta, P. R. (2010). Anthocorid bugs encountered on cultivated crops and ornamentals, and an attempt to rear *Orius niger* Wolff under laboratory conditions. *Pest Management and Economic Zoology*, *18*, 19–21.

Richards, P. C., & Schmidt, J. M. (1996). The suitability of some natural and artificial substrates as oviposition sites for the insidious flower bug, *Orius insidiosus*. *Entomologia Experimentalis et Applicata*, *80*, 325–333. doi:10.1111/j.1570-7458.1996.tb00945.x

Ruberson, J. R., Bush, L., & Kring T. J. (1997). Photoperiodic effect on dispause induction and development in the predator *Orius insidiosus* (Hemiptera: Anthocoridae). *Environmental Entomology*, *20*, 171–176.
Schmidt, J. M., Richards, P. C., Nadel, H., & Ferguson, G. (1995). A rearing method for the production of large numbers of the insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae). *The Canadian Entomologist*, *127*, 445–447. doi:10.4039/Ent127445-3
Shapiro, J. P., & Ferkovich, S. M. (2006). Oviposition and isolation of viable eggs from *Orius insidiosus* in a parafilm and water substrate: Comparison with green beans and use in enzyme-linked immunosorbent assay. *Annals Entomological Society America*, *99*, 596–601.
Simmons, A. M. (1994). Oviposition on vegetables by *Bemisia tabaci* (Homoptera: Aleyrodidae): Temporal and leaf surface factors. *Environmental Entomology*, *23*, 381–389.
Stone, T. B., Pitre, H. N., & Thompson, A. C. (1984). Relationship of cotton phenology, leaf soluble protein, extrafloral nectar carbohydrate and fatty acid concentrations with popultions of five predator species. *Journal of the Geogia Entomological Society*, *19*, 204–212.
Tan, X. L., Wang, S., & Zhang, F. (2013). Optimization an optimal artificial diet for the predatory bug *Orius sauteri* (Hemiptera: Anthocoridae). *PLoS One*, *8*(4), e61129. doi:10.1371/journal.pone.0061129
Vancante, V., Cocuzza, G. E., De Clercq, P., Van der Veire, M., & Tirry, L. (1997). Development and survival of *Orius albidipennis* and *O. laevigatus* (Het.: Anthocoridae) on various diets. *Entomophaga*, *42*, 493–498. doi:10.1007/BF02769809
Yano, E. (1996). Biology of *Orius sauteri* (Poppius) and its potential as a biocontrol agent for *Thrips palmi*. *IOBC/WPRS Bulletin*, *19*, 203–206.
Yano, E. (2004). Recent development of biological control and IPM in greenhouse in Japan. *Journal of Asia-Pacific Entomology*, *7*, 5–11. doi:10.1016/S1226-8615(08)60195-8
Yano, E., Jiang, N., Hemerik, L., Mochizuki, M., Mitsunaga, T., & Shimoda, T. (2005). Time allocation of *Orius sauteri* in attacking *Thrips palmi* on eggplant leaf. *Entomologia Experimentalis et Applicata*, *117*, 177–184. doi:10.1111/j.1570-7458.2005.00347.x
Yano, E., Watanabe, K., & Yara, K. (2002). Life history parameters of *Orius sauteri* (Poppius) (Het., Anthocoridae) reared on *Ephestia kuehniella* eggs and the minimum amount of the diet for rearing individuals. *Journal of Applied Entomology*, *126*, 389–394. doi:10.1046/j.1439-0418.2002.00598.x
Zhang, G., Lü, Z. C., Wan, F. H., & Lövei, G. L. (2007). Real-time PCR quantification of Bemisia tabaci (Homoptera: Aleyrodidae) B-biotype remains in predator guts. *Molecular Ecology Notes*, *7*, 947–954. doi:10.1111/j.1471-8286.2007.01819.x
Zhou, W. R., & Wang, R. (1989). Rearing of *Orius sauteri* (Hem: Anthocoridae) with natural and artificial diets. *Chinese Journal of Biological Control*, *5*, 9–12. (In Chinese).
Zhou, W. R., Wang, R., & Qiu, L. (1991). Use of soybean sprouts as the oviposition material in mass rearing of *Orius sauteri* (Hem: Anthocoridae). *Chinese Journal of Biological Control*, *7*, 7–9. (In Chinese).