An Entomopathogenic Strain of *Beauveria bassiana* against *Frankliniella occidentalis* with no Detrimental Effect on the Predatory Mite *Neoseiulus barkeri*: Evidence from Laboratory Bioassay and Scanning Electron Microscopic Observation

Shengyong Wu, Yulin Gao, Yaping Zhang, Endong Wang, Xuenong Xu, Zhongren Lei*

State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China

**Abstract**

Among 28 isolates of *Beauveria bassiana* tested for virulence against *F. occidentalis* in laboratory bioassays, we found strain SZ-26 as the most potent, causing 96% mortality in adults at $1 \times 10^7$ mL$^{-1}$ conidia after 4 days. The effect of the strain SZ-26 on survival, longevity and fecundity of the predatory mite *Neoseiulus (Amblyseius) barkeri* (Hughes) was studied under laboratory conditions. The bioassay results showed that the corrected mortalities were less than 4 and 8% at 10 days following inoculation of the adult and the larvae of the predator, respectively, with $1 \times 10^7$ conidia mL$^{-1}$ of SZ-26. Furthermore, no fungal hyphae were found in dead predators. The oviposition and postoviposition durations, longevity, and fecundity displayed no significant differences after inoculation with SZ-26 using first-instar larvae of *F. occidentalis* as prey in comparison with untreated predator. In contrast, the preoviposition durations were significantly longer. Observations with a scanning electron microscope, revealed that many conidia were attached to the cuticles of *F. occidentalis* at 2 h after treatment with germ tubes oriented toward cuticle at 24 h, penetration of the insect cuticle at 36 h, and finally, fungal colonization of the whole insect body at 60 h. In contrast, we never observed penetration of the predator’s cuticle and conidia were shed gradually from the body, further demonstrating that *B. bassiana* strain SZ-26 show high toxicity against *F. occidentalis* but no pathogenicity to predatory mite.

**Citation:** Wu S, Gao Y, Zhang Y, Wang E, Xu X, et al. (2014) An Entomopathogenic Strain of *Beauveria bassiana* against *Frankliniella occidentalis* with no Detrimental Effect on the Predatory Mite *Neoseiulus barkeri*: Evidence from Laboratory Bioassay and Scanning Electron Microscopic Observation. PLoS ONE 9(1): e84732. doi:10.1371/journal.pone.0084732

**Editor:** Guy Smagghe, Ghent University, Belgium

**Received** August 20, 2013; **Accepted** November 19, 2013; **Published** January 14, 2014

**Copyright:** © 2014 Wu et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Funding:** This research was supported by the National Special Fund for the Commonwealth Agricultural Research (200903032), National Modern Agricultural Science and Technology City Industry of Beijing (212110001212006) and the National Key Basic Research Program (973 Projects Grant 2009CB119004). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Competing Interests:** The authors have declared that no competing interests exist.

* E-mail: zrlei@ippcaas.cn

**Introduction**

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is regarded as an important economic pest of a wide range of agricultural and horticultural crops worldwide [1–4]. Because *F. occidentalis* has developed a high level of resistance to many chemical pesticides [5–7], it is essential to adopt a biological control program for this pest. The predatory mite *Neoseiulus (Amblyseius) barkeri* (Hughes) (Acarina: Phytoseiidae) and the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin have been shown to be potential biological control agents of *F. occidentalis* [7,8–11].

*N. barkeri* has been successfully employed for reducing populations of *F. occidentalis* in crops, such as strawberries and cucumbers [12,13]. However, the control efficiency for thrips is limited because the mite prefers to prey only on larval stages of thrips [14,15]. The application of the entomopathogenic fungus *B. bassiana* against *F. occidentalis* results in high rates of mortality in laboratory screenings and greenhouse conditions [16–18]. In order to obtain the highest efficiency in controlling *F. occidentalis*, it is suggested that *B. bassiana* should be applied along with the releases of predatory mites under field conditions [9,18]. Therefore, evaluating the compatibility of applying *B. bassiana* and predators to control *F. occidentalis* is a critical issue for the implementation of IPM programs. A better understanding of the factors that minimize undesirable effects of insect pathogens on natural enemies could improve their integrated utilization against pest insects [19].

Most previous research has been designed to evaluate the effects of pathogens on predators directly by exposing predators to pathogen residues or by topical application, and then studying factors such as predator mortality and behavior, or indirectly by allowing predation on fungal-infected preys, or assessing predator-prey abundance in experimental crops. [9,20–22]. Recent studies have focused on effects on fecundity of predators [23,24]. We determined the compatible utilisation of *B. bassiana* strain SZ-26 and *N. barkeri* by studying the effect on the longevity and fecundity of predatory mites when offered first-instar thrips as prey. Furthermore, there are no reports for the micromorphological observations of fungal conidial inoculation processes on this
Results

Screening fungal isolates

Of the 28 strains of *B. bassiana* (Table 1) tested at 1 x 10^7 conidia mL\(^{-1}\) in the laboratory, the SDLZ-12 strain caused only 43% mortality after 4 days, while strain SZ-26 killed the highest percentages with 96% mortality (F = 11.212, p < 0.001) (Fig 1). Strain SZ-26 was identified as the most virulent strain and was selected for further evaluation on the predatory mite, *N. barkeri*.

The corrected mortalities of *N. barkeri* were maintained below 4 and 8% at 10 days following inoculation of the adult and larvae, respectively. These mortalities for *N. barkeri* were significantly lower than those of *F. occidentalis*, whose corrected mortalities reached 100% and 66%, respectively, (Adult: t = 82.186, p < 0.001; First instar: t = 57.531, p < 0.001) (Fig 2 and Fig 3). No penetration of germ tube or formation of hyphal bodies was observed from dead predators as viewed under an optical microscope.

Effect of *B. bassiana* strain SZ-26 on the predator longevity and oviposition

When inoculated by *B. bassiana* strain SZ-26, preoviposition duration of predators was significantly longer as compared to the controls. There were no differences in other life table parameters, such as oviposition, postoviposition duration, female longevity and daily fecundity compared to the controls (Table 2).

Scanning electron microscopic observation

When treated with 1 x 10^7 conidia mL\(^{-1}\) of *B. bassiana* strain SZ-26, many conidia adhered to the cuticle of adult *F. occidentalis* after 2 h (Fig 4 A). Germ tubes of conidia oriented toward cuticle after 24 h (Fig 4 B). Germ tubes penetrated the cuticle after 36 h (Fig 4 C). Many conidia germinated and fungal hyphae were produced after 48 h (Fig 4 D). Mycelium colonized the whole body after 60 h (Fig 4 E). Conidia emerged from dead adults after 72 h (Fig 4 F).

When *N. barkeri* were treated with 1 x 10^7 conidia mL\(^{-1}\) of *B. bassiana* strain SZ-26, the conidia could adhere to the cuticle of adults after 2 h (Fig 5 A). Secretions on the interface of conidia emerged after 12 h (Fig 5 B). Conidia germinated after 24 h, but were not observed to penetrate the cuticle within 36 h (Fig 5 C). Conidia were shed gradually from the body, leaving the secretions on the surface of the cuticle. Several conidia were observed to have shriveled after 48 h (Fig 5 D). Few conidia were detected on the body after 48 h.

Discussion

Risk evaluation and compatibility research on pathogens and predators have always drawn scientists’ attention. Furtado et al. [30] reported that a strain of the fungal pathogen, *Neozygites acaricida* was pathogenic to a phytoseiid mite, *Euseius citrillus*, while other studies have shown other fungal pathogens displayed no pathogenicity to predatory mites [9,18,23]. Our study used a novel strain of *B. bassiana* strain SZ-26 that is highly virulent to *F. occidentalis*, but proved not to be detrimental to both adult and larval *N. barkeri*. Although first instar thrips are considered the most susceptible life stage to entomopathogenic fungi compared to the other life stages [31], our results showed that adult thrips were more susceptible to *B. bassiana* strain SZ-26. This differential mortality may be because fungal conidia are shed with the exuvium following ecdysis decreasing pathogenicity to immature stages. These results are supported by the studies of Vestergaard et al. [32] and Maniania et al. [33] who also demonstrated that the mortality of entomopathogenic fungus on adult *F. occidentalis* were displayed much higher than for larvae.

There has been increasing interest in evaluating the sub-lethal effects of pathogens on predators. Shaw et al. [34] reported that the fecundity of the predatory mites *Euseius hibisci*, *Amblyseius limonineus* and *Typhlodromus occidentalis* are not affected by feeding on virus-infected citrus red mites, *Panonychus citri*. *Neozygites floridana* does not affect the oviposition of *Phytoseiulus longipes* when fed with *N. floridana* infected *Tetranychus evansi* and *Tetranychus urticae*. [23].

While the longevity and fecundity of predatory mites *Phytoseius persimilis* were displayed lower when fed on *B. bassiana* treated spider mite, *Tetranychus urticae* for 24–72 h [35]. We observed *N. barkeri* could not only feed on *B. bassiana*-infected larval *F. occidentalis*, but also feed *B. bassiana* strain SZ-26 conidial suspension directly (unpublished). In this study, the sub-lethal effects on *N. barkeri* when directly exposed to *B. bassiana* strain SZ-26 conidial suspension were evaluated. we observed that *N. barkeri*...
groomed conidia from their bodies so that few conidia remained on *N. barkeri* 48 h after treatment with *B. bassiana* strain SZ-26 (unpublished). One function of grooming in arthropods is the removal of foreign bodies such as fungal or mite parasites [36].

Wekesa et al [23] reported that the predatory mite, *Phytoseiulus longipes*, was efficient in removing most capilliconidia of the fungal pathogen *N. floridana* through self-grooming behavior.

In order to avoid being influenced by other factors, we supplied Table 1.

Table 1. Origin of *Beauveria bassiana* isolates screened against the western flower thrips, *Frankliniella occidentalis*.

| Fungal isolates | Host or source of origin | Site origin (Collected date) |
|-----------------|---------------------------|-----------------------------|
| SZ-26           | *Ostrinia nubilalis* (Lepidoptera: Pyralidae) | Suizhong, Liaoning (2011) |
| HNL-58          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Luoyang, Henan (2010) |
| HNL-63          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Luoyang, Henan (2010) |
| HNL-70          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Luoyang, Henan (2010) |
| HNL-72          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Luoyang, Henan (2010) |
| GZL-8           | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Gong Zhuling, Jilin (2011) |
| GZL-16          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Gong Zhuling, Jilin (2011) |
| GZL-21          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Gong Zhuling, Jilin (2011) |
| FSYQ-1          | *Trialeurodes vaporariorum* (Westwood) | Yongqing, Hebei (2011) |
| FSYQ-2          | *Trialeurodes vaporariorum* (Westwood) | Yongqing, Hebei (2011) |
| FSYQ-3          | *Trialeurodes vaporariorum* (Westwood) | Yongqing, Hebei (2011) |
| FSYQ-4          | *Trialeurodes vaporariorum* (Westwood) | Yongqing, Hebei (2011) |
| SCWJ-1          | *Ostrinia nubilalis* (Lepidoptera: Pyralidae) | Wenjiang, Sichuang (2011) |
| SDJN-2          | *Ostrinia nubilalis* (Lepidoptera: Pyralidae) | Jinan, Shandong (2011) |
| SDJN-6          | *Ostrinia nubilalis* (Lepidoptera: Pyralidae) | Jinan, Shandong (2011) |
| SDLZ-12         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Laizhou, Shandong (2010) |
| SDLZ-19         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Laizhou, Shandong (2010) |
| SDLZ-20         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Laizhou, Shandong (2010) |
| SDLZ-25         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Laizhou, Shandong (2010) |
| GZGY-2          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Guiyang Guizhou (2010) |
| GZGY-3          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Guiyang Guizhou (2010) |
| GZGY-5          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Guiyang Guizhou (2010) |
| DZDC-9          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Decheng, Dezhou (2012) |
| DZDC-12         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Decheng, Dezhou (2012) |
| WLMQ-8          | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Urumqi, Xinjiang (2012) |
| WLMQ-31         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Urumqi, Xinjiang (2012) |
| WLMQ-32         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Urumqi, Xinjiang (2012) |
| WLMQ-26         | *Ostrinia furnacalis* (Lepidoptera: Pyralidae) | Urumqi, Xinjiang (2012) |

DOI:10.1371/journal.pone.0084732.t001

We used *B. bassiana* strain SZ-26 for the experiments. After 10 days following inoculation as first instars with $1 \times 10^7$ conidia mL$^{-1}$ of *B. bassiana* strain SZ-26, surviving *F. occidentalis* had reached the pupal stage and surviving *N. barkeri* had reached the adult stage.
untreated larval *F. occidentalis* to predators as food, because *B. bassiana* infection could make the larval thrips deficient in certain essential nutrients [37] that may reduce fecundity of female predator, or create a buildup of fungal toxins or metabolites that may shorten adult predator longevity [38]. Whether feeding infected larvae of *F. occidentalis* to *N. barkeri* will affect life table parameters of the predator still needs to be demonstrated. From our recent results, this exposure did lengthen the preoviposition period of adult females. However, this likely reflects time spent by all treated mites grooming off conidia and not a physiological effect on females. Overall, both direct bioassay and sub-lethal effects on *N. barkeri* indicated that *B. bassiana* strain SZ-26 poses a negligible risk to *N. barkeri*.

From our SEM observations, *B. bassiana* strain SZ-26 conidia penetrated *F. occidentalis* cuticle soon after germination. The results agree with those of Vestergaard et al. [32] and Wang et al. [39] in their studies with most fungus germlings producing appressoria within 24–48 h post-inoculation on *F. occidentalis*. In contrast, despite being able to attach to *N. bakeri*, it was displayed that no pathogenicity of *B. bassiana* strain SZ-26 to *N. bakeri*. No penetration of germ tube or formation of hyphal bodies was observed on dead *N. bakeri* further supporting the SEM results. The pathogenicity of entomopathogenic fungi is the result of mechanism pressure and proteinases which are associated with cuticle degradation [40–44]. This raises questions regarding the capacity of *N. bakeri* to avoid infection by fungi. Although many studies indicate that entomopathogenic fungi are highly

### Table 2. Length of reproductive durations, longevity (days ± SE) and fecundity (eggs ± SE) of *N. barkeri* when treated with *B. bassiana* strain SZ-26.

|                      | Preoviposition | Oviposition | Postoviposition | Female Longevity | Daily fecundity |
|----------------------|---------------|------------|----------------|-----------------|-----------------|
| Untreated            | 2.48±0.12a    | 26.58±3.28a| 7.12±0.47a     | 36.19±0.90a     | 1.90±0.05a      |
| Treated              | 3.35±0.17b    | 25.00±3.03a| 6.00±0.38a     | 34.32±0.56a     | 1.79±0.03a      |
| df                   | 45            | 49         | 49             | 41              | 49              |
| t                    | −4.036        | 1.783      | 1.843          | 1.763           | 1.911           |
| p                    | <0.001        | 0.081      | 0.071          | 0.085           | 0.062           |

Note: The same small letters in the same column represented no significant difference at 0.05 levels by T-test.

doi:10.1371/journal.pone.0084732.t002

Figure 4. Germination and infection of *B. bassiana* strain SZ-26 conidia on the cuticle of *F. occidentalis*. (A) conidia adhering to the cuticle of *F. occidentalis*; (B) germ tube of conidia oriented toward cuticle; (C) germ tube penetrating the cuticle; (D) fungal hyphae growing on the cuticle; (E) mycelium colonized the whole body; (F) conidia emerging from the dead adult.

doi:10.1371/journal.pone.0084732.g004
pathogenic against targeted insect pests while showing no detrimental effects on predators in laboratory bioassays and field investigations [9,27], it is unclear how entomopathogenic fungi identify and infect host species. In our study, most conidia was removed by self-grooming off the N. bakeri body within 48 h, reducing the infection possibility. Moreover, although conidia could germinate, they were not observed to penetrate the N. bakeri cuticle, we speculate that the different cuticle structures or proteinase targets between F. occidentalis and N. bakeri influence the fungi pathogenicity. The proteinaceous outer integument of predatory mites probably forms an effective barrier against B. bassiana strain SZ-26. In addition, few shriveled conidia were detected on the cuticle of N. barkeri after 48 h, possibly because the germinated conidia which were remaining on N. bakeri could not be glued on the susceptible host, the few shriveled conidia probably lost their viability. These observations and speculations may aid in explaining why N. bakeri is not infected by B. bassiana strain SZ-26. The results also enhance our understanding of the interactions between pathogen and predators. To better understand the interactions, the defense mechanisms of predators need to be further explored.

Materials and Methods

Subheading Ethics Statement

No specific permissions were required for these locations/activities.

None of the species used in this study are endangered or protected.

Beauveria bassiana

The origin and source of the twenty-eight fungal isolates are shown in Table 1. All isolates were maintained and conidia were produced on Sabouraud Dextrose Agar (SDA) at 26±1°C under continuous darkness. Conidial concentrations were determined with a hemocytometer and adjusted with sterile water containing Tween-80 at 0.05% (v/v). The viability of the conidia was confirmed on SDA medium [25] and was >90% for all strains.

Mite colony

N. barkeri and the prey Tyrophagus putrescentiae were obtained from colonies maintained in the laboratory of insect natural enemies, Institute of Plant Protection, Chinese Academy of Agricultural Sciences. N. barkeri are reared in sterilized wheat bran-T. putrescentiae mixture and fed on T. putrescentiae in plastic boxes (15 cm×15 cm×10 cm) with lips and a circular moist sponge (10 cm diameter) at the edge of boxes for preventing escape. A hole (12 cm diameter) was cut in the lid and covered with fine mesh to allow for ventilation. Culture boxes were kept at 25±1°C, 60–70% RH and L16:D8 photoperiod in a climate controlled chamber. Cotton silk was placed on the surface of the leaves for oviposition, eggs were collected and transferred to a new plastic box using a fine paintbrush after 6 hours and allowing the emergent larvae to develop in synchrony. The newly emerged larvae and adults were obtained for experimental use.

Western flower thrips colony

A colony of western flower thrips, F. occidentalis was maintained as described by Liang et al [26]. Briefly, thrips colonies were continuously reared on sterilized kidney beans (Phaseolus vulgaris L.) in 0.5 L tube-shaped glass jars with snap-on lids. A hole (10 cm diameter) was cut in the lid and covered with fine mesh to allow for ventilation. Rearing jars were kept at 26±2°C, 60–70% RH and L13:D11 photoperiod in a climate controlled chamber. Thrips at similar stages of development were obtained by incubating adults on fresh, healthy plants for oviposition, removing the thrips after 3 days and allowing the different stage of thrips to develop in
synchrony. The first instars and adults were obtained for experimental use.

Screening of 28 new fungal isolates
The effect of the fungal isolates on adult *F. occidentalis* survival was evaluated by treating thrips with concentrations of 1×10³ mL⁻¹ conidia, which is the concentration commonly used for spray application for control of western flower thrips in greenhouses in China [27]. A control consisted of sterile water containing Tween-80 at 0.05% (v/v). Individual newly eclosed *F. occidentalis* adults were collected from the laboratory rearing colony and dipped for 5 s in the conidial suspension. Adults were allowed to dry on filter paper and transferred to Petri dishes (diameter 7 cm) lined with bean leaves and covered with plastic film which were pricked for ventilation. The Petri dishes were stored in a climate controlled chamber (26±2°C, RH 60–70% and 13 L: 11D photoperiod). The effects against the *F. occidentalis* adults were scored at day 5 after treatment. The presence of fungal mycelia was used as an indication of mycosis. Each replicate consisted of 20 adults; treatments were randomized and the experiment was replicated 3 times using different insect lots over time.

Efficacy against *F. occidentalis* and *N. barkeri* with the SZ-26 strain
Based on the screening of the 28 new strains as reported above, strain SZ-26 was re-evaluated against *F. occidentalis* and *N. barkeri* using the same conditions listed above. The first instar larval and newly eclosed adult stages of *F. occidentalis* were inoculated by immersion for 5 s in 2 ml conidial suspension of *B. bassiana* strain SZ-26 and using a fine paintbrush carefully transferred to petri dish (3.5 cm diameter) lined with freshly excised bean leaf, which was placed on the surface of the water—saturated filter paper, the root vein of leaf was wrapped by moist cotton wool to slow leaf desiccation. The dish was then sealed with polyvinyl chloride (PVC) cling film and incubated at 25±1°C, 60–70% RH and L16:D8 photoperiod in a climate controlled chamber. The status of individuals was determined 10 days after treatment. Mortality was recorded daily. Each stage of thrips consisted of 8 replicates with 20 insects per replicate. The presence of fungal mycelia was used as an indication of mycosis. Controls consisted of thrips treated with 0.05% Tween-80 in sterile H₂O. Bioassays for adult and larval *N. barkeri* were repeated as described above. Ample *T. putrescentiae* immatures were needed to supply as food, the dead *N. barkeri* were picked and placed on SDA at 26±1°C under continuous darkness, then examined under optical microscope for the presence of *B. bassiana* strain SZ-26 conidia or hyphal bodies. Each replicate consisted of 20 adult *N. barkeri*, treatments were randomized and the experiment was replicated 8 times using different insect lots over time.

Effect of SZ-26 strain on the predator longevity and oviposition
The experimental units were designed with two pieces of uniform organic glass (6 cm×5 cm×4 mm), the water—saturated filter paper was placed on one piece, the freshly excised leaf of kidney beans was upside down on the surface of the filter paper, a hole (2.5 cm diameter) was punched in another piece and pressed on the leaf. A chamber was formed between two pieces of organic glass which served as the experimental platform. The newly molted female adults were inoculated by immersion for 5 s in 2 ml conidial suspension of *B. bassiana* strain SZ-26 and placed individually in each chamber and about 20 first-instar larval *F. occidentalis* were supplied as food. A male was added to each chamber for 1 d to allow mating and then the male was removed. The successfully mated females started to lay eggs, the daily fecundity of each was recorded until the females died, predators were transferred into new chambers and supplied daily with first instars as food. The excised leaves were changed every 4–5 days and the predators were transferred into new chambers. The oviposition period and female longevity were also estimated. Controls were set up only with untreated females. For treatment and control, a total of 30 synchronized female predators were tested.

Scanning electron microscope observations (SEM)
For SEM observation, the predatory mites and thrips were collected and inoculated by immersion for 5 s in 2 ml conidial suspension of the SZ-26 strain, then transferred into the chamber (10/species in each chamber). Ample *T. putrescentiae* immatures were supplied to predators as food. After 1, 2, 12, 24, 36, 48, 60 and 72 h, the SZ-26-treated samples were fixed in 70% ethyl alcohol for 24 h, then dehydrated in a ascending series of ethyl alcohol (75, 80, 90, 95 and 100%, 6 min each), left to air dry for a few seconds and mounted on SEM stubs with double-sided carbon tape. Dried samples were sputtered with gold and observed with the SEM under Quanta 200 FEG at high-vacuum mode.

Statistical analysis
All statistical analyses were carried out using SPSS software [28]. Data of mortality were corrected for control mortality [29] and were normalised using arcsine transformation. Differences of mortality between two species were evaluated using a T-test procedure at a = 0.05 to determine significance. Differences of longevity and oviposition between treatment and control were also compared by T-test after log transformation of the data. Data will be available from the corresponding author upon request.

Acknowledgments
We are grateful to Mark Goettel and Guy Smaghe for helpful comments on a previous version of the manuscript.

Author Contributions
Conceived and designed the experiments: SW YG ZL. Performed the experiments: SW YZ YG. Analyzed the data: SW YG ZL. Wrote the paper: SW YG XX EW ZL.

References
1. Yulin LS, Cho, JJ, Mitchell WC (1986) Host range of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), with special reference to *Lewana glauca*. Environmental Entomology 15: 1292-1295.
2. Shipp JL, Birns MR, Hao X, Wang K (1998) Economic injury levels for western flower thrips, *F. occidentalis* (Thysanoptera: Thripidae), with special reference to *Leucaena glauca* flower thrips, *Frankliniella occidentalis*. Environmental Entomology 15: 1292–1295.
3. Bielza P (2008) Insecticide resistance management strategies against the western flower thrips, *Frankliniella occidentalis*. Pest Management Science 64:1131–1138.
4. Morse JG, Hoddle MS (2006) Invasion Biology of Thrips. Annual Review of Entomology 51: 67–89.
5. Broadbent AR, Ffree DJ (1997) Resistance to insecticides in populations of *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) from greenhouses in the Niagara region of Ontario. Canadian Entomologist 129:907–913.
7. Gao YL, Lei ZR, Reitz SR (2012) Western flower thrips resistance to insecticides: detection, mechanisms and management strategies. Pest Management Science 68: 1111–21.
8. Gillespie DR (1989) Biological control of thrips (Thysanoptera:Thripidae) on greenhouse cucumber by Amblyseius cucumeris. Entomophaga 34: 183–192.
9. Jacobson RJ, Chandler D, Fenlon J, Russell KM (2001) Compatibility of Beauveria bassiana (Balsamo) Vuillerm with Amblyseius cucumeris Oudemans (Acarina: Phytoseiidae) to control Frankliniella occidentalis Pergande (Thysanoptera: Thripidae) on cucumber plants. Biocontrol Science and Technology 11: 391–400.
10. Rodrigo-Reina JM, Garcia-Mari F, Ferragut F (1992) Predator activity of phytophagous mites on different developmental stages of the Western flower thrips Frankliniella occidentalis. Boletín de Sanidad Vegetal, Plagas 1: 253–263.
11. Shipp L, Zhang Y, Hunt D, Ferguson G (2002) Influence of greenhouse microclimate on the efficacy of Beauveria bassiana (Balsamo) Vuillerm for control of greenhouse pests. IOBC/WPRS Bulletin 27: 237–240.
12. Gonzalez-Zamora JE, Garcia-Mari F, Benages E, Royo S (1992) Biological control of the Western flower thrips Frankliniella occidentalis in strawberries. Boletín de Sanidad Vegetal, Plagas 1: 263–268.
13. Jarosik V, Priesie J (1995) Assessment of Amblyseius barkeri (Acarina: Phytoseiidae) as a control agent for thrips on greenhouse cucumbers. Acta Societatis Zoologicae Bohmicae 3(4): 177–186.
14. Broodgaard HF (1989) Frankliniella occidentalis (Thysanoptera: Thripidae) — a new pest in Danish glasshouses, a review. Tidskr Plantekend 93: 83–91.
15. Van der Hoeven WAD, van Rijts PCJ (1990) Factors affecting the attack success of predatory mites on thrips larvae. Proceedings of the Section Experimental and Applied Entomology of the Netherlands Entomological Society.(NEV Amsterdam) 1: 25–30.
16. Yuan SY, Zhang HR, Kong Q, Wang P, Sun SQ, et al. (2011) Detection on the virulence of Beauveria bassiana MZ0060112 against Frankliniella occidentalis. Journal of Huazhong Agricultural University 2: 177–199.
17. Boaria A, Rossignolo L, Pozzebon A, Duso C (2011) Effects of Beauveria bassiana on Frankliniella occidentalis (Thysanoptera: Thripidae) through different routes of exposure. IOBC/WPRS Bulletin 66: 245–248.
18. Wang J, Lei ZR, Xu HF, Gao YL, Wang HH (2011) Virulence of Beauveria bassiana isolates against the first instar nymphs of Frankliniella occidentalis and effects on natural enemy Amblyseius barkeri. Chinese Journal of Biological Control 27: 479–484.
19. Lacey LA, Mesquita ALM (2002) Interaction of entomopathogenic fungi, insect parasites and their hosts. Proceeding of the VIIth International Colloquium on Invertebrate Pathology and Microbial Control pp: 31–35.
20. Roy HE, Pell JK, Clark SJ, Alderson PG (1998) Implications of predator foraging on aphid pathogen dynamics. Journal of Invertebrate Pathology 71: 230–247.
21. Poprawski TJ, Legaspi JC, Fealon J, Russell KM (2001) Compatibility of Beauveria bassiana (Balsamo) Vuillerm with Amblyseius cucumeris Oudemans (Acarina: Phytotseidae) to control Frankliniella occidentalis Pergande (Thysanoptera: Thripidae) on cucumber plants. Biocontrol Science and Technology 11: 391–400.
22. Pozzebon A, Duso C (2009) Pesticide Side-Effects on Predatory Mites: The Role of Beauveria bassiana isolates against the first instar nymphs of Frankliniella occidentalis. Boletin de Sanidad Vegetal, Plagas 1: 253–263.
23. Zhao ZF, Chen XQ, Liu Y, Wang J, Yang W, et al. (2011) Effects of Beauveria bassiana on the prey of the Western flower thrips Frankliniella occidentalis and the predatory mite Phytoseius persimilis. Biocontrol Science and Technology 8: 873–882.
24. Wen JZ, Lei ZR, Tan ZH, Wang Y, Fu W, et al. (2003) Pathogenicity of Five Beauveria bassiana Strains Against Locusta migratoria. Plant Protection 29: 50–52.
25. Liang XH, Lei ZR, Wen JZ, Zhu ML (2010) The Diurnal Flight Activity and Influential Factors of Frankliniella occidentalis in the Greenhouse. Insect Science 17: 535–541.
26. Roy HE, Pell JK, Clark SJ, Alderson PG (1998) Implications of predator foraging on aphid pathogen dynamics. Journal of Invertebrate Pathology 71: 230–247.