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EVALUATION OF INSECTICIDES AGAINST THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* (THYSANOPTERA: THRIPIDAE), IN THE LABORATORY

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Abstract

To evaluate insecticide efficacy against the western flower thrips, *Frankliniella occidentalis* (Pergande), the first step was to select a host suitable for rearing sufficient numbers of this pest. The influence on the development and survival rates of this thrips of each of 3 selected leguminous hosts, *Canavalia gladiata* (Jacq.) DC, *Lablab purpureus* (L.) Sweet and *Phaseolus vulgaris* L., was examined and compared to the other in the laboratory. Results showed that the number of newly hatched larvae (543.20), the survival rates of 2nd to 4th instar (89.12%), and the eclosion (73.17%) on *C. gladiata* were significantly higher than on *L. purpureus* and *P. vulgaris*, and also the developmental time from egg to adult was the shortest on *C. gladiata* (10.15 d). Therefore, *C. gladiata* was selected as the best host among these legumes for rearing the thrips in the laboratory. Thirty-six insecticides commonly used in China to protect flowers and vegetables were chosen from 8 chemical classes for assay using a glass-vial method to evaluate their toxicities against thrips larvae in a laboratory. Based on LC_{50} values, and on the need to rotate and alternate the application of insecticides, 12 highly efficacious insecticides from different IRAC mode of action groups were evaluated against adult females. Although the ranking of toxicities to adults was slightly different from that to larvae, the results showed that the insecticides with high efficacy against larvae were also effective against adults. These findings will facilitate the selection of insecticides for effective control of western flower thrips and for developing insecticide resistance management strategies.

Key Words: *Frankliniella occidentalis*; host for rearing; insecticides; laboratory toxicity

Resumen

Para evaluar la eficacia de insecticidas contra el trips, *Frankliniella occidentalis* (Pergande), el primer paso fue seleccionar un hospedero adecuado para criar un número suficiente de esta plaga. El efecto de 3 plantas leguminosas hospederas, *Canavalia gladiata* (Jacq.) DC, *Lablab purpureus* (L.) Sweet y *Phaseolus vulgaris* L., sobre la tasa de desarrollo y la supervivencia de los trips fue examinado y comparado en el laboratorio. Los resultados mostraron que el número de larvas neonatas (543.20), la tasa de supervivencia desde el segundo hasta el cuarto estadio (89.12%), y la eclosión (73.17%) en *C. gladiata* fueron significativamente mayores que en *L. purpureus* y *P. vulgaris*; también, el tiempo de desarrollo de huevo a adulto fue más corto en *C. gladiata* (10.15 d). Por lo tanto, *C. gladiata* fue seleccionado como el mejor hospedero entre estas leguminosas para la cría de los trips en el laboratorio. Se analizaron 36 insecticidas de 8 clases químicas diferentes comúnmente usados para proteger flores y hortalizas. Se utilizó un bioensayo con viales de vidrio para evaluar su toxicidad contra larvas de trips en el laboratorio. Basadose en resultados de CL_{50}, 12 insecticidas altamente eficaces y de diferentes grupos (IRAC) de modo de acción fueron seleccionados para evaluar su toxicidad contra las hembras adultas. Aunque la clasificación de la toxicidad en los adultos fue ligeramente diferente a la de las larvas, los resultados mostraron que los insecticidas con una alta eficacia contra las larvas también fueron efectivos contra los adultos. Estos hallazgos ayudarán en la selección de insecticidas para el control efectivo de esta especie de trips y para desarrollar estrategias de manejo de resistencia a insecticidas.

The western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), invaded China in 2003 and became a major pest of ornamentals, such as roses (*Rosa* spp.; Rosales: Rosaceae), various vegetable crops, such as peppers (*Capsicum* spp.: Solanales: Solanaceae) and legumes including common beans (*Phaseolus vulgaris* L.; Fabales: Fabaceae). It was found first in Beijing in 2003 (Zhang et al. 2003), and then spread throughout Zhejiang, Yunnan, Shandong (Zheng et al. 2007) and Guizhong Provinces (Li et al. 2007). The western flower thrips is a highly polyphagous insect, attacking more than 240 species in 62 plant families (Lim et al. 2001). The insect's host range includes open-field ornamental, orchard, garden, and field crops, as well as other plants (Jensen 2000; Yudin et al. 1986). *Frankliniella occidentalis* directly damages plants by feeding and oviposition. The mechanical damage to plant cells caused by the thrips' feeding can result in the deformation of flowers, leaves, and shoots. Aside from the direct damage, it may also spread viral diseases (Allen & Broadbent 1986). The most serious indirectly induced damage of the insect is the transmission of *Tomato spotted wilt virus* and *Impatiens necrotic spot virus* (Riley & Pappu 2004).

Owing to particular biological characteristics of the western flower thrips, such as short generation time, small size, high polyphagy, and high fecundity, chemical control has been used as the primary strategy against this pest (Dai et al. 2005). Therefore, laboratory evaluation of available insecticides is a key step for successful control of this insect (Zhang et al. 2007). To achieve this, a suitable host must first be identified to obtain a sufficient number of insects for the evaluation of insecticides in the laboratory (Contreras et al. 2008). To this end we studied the effects of the jackbean (*Canavalia gladiata* (Jacq.) DC.), lablab bean (*Lablab purpureus* (L.) Sweet), and *Phaseolus vulgaris* L. - all members of Fabales: Fabaceae - on the development and survival rates of *F. occidentalis*. In addition, the toxicities of 36 commonly used insecticides in 8 chemical/IRAC mode of action classes were assayed by the glass-vial method in laboratory.

Materials and Methods

Insecticides

Thirty six technical-grade insecticides were used for bioassays representing 8 IRAC mode of action groups or subgroups with alphanumeric designations in parentheeses as follows; 7 acteylcholine inhibitors (1B) - organophosphates, 7 acteylcholine inhibitors (1A) - carbamates, 12 sodium channel modulators (3A) - pyrethroids, 6 nicotinic acetylcholine receptor agonists (4A) - neonicotinoids, 1 nicotinic acetyl choline receptor allosteric activator (5) - spinosyn, chloride channel activator (6) - avermectin, 1 oxidative phosphorylation uncoupler (13) -chlorfenpyr, and 1 GABA-gated chloride channel antagonist (2B) - phenylpyrazole (fiprol). Details of the insecticides are listed in Table 1.

Insects

Western flower thrips were provided by the Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences. This strain was collected from pepper in this Institute's greenhouse in 2003 and has been reared in the laboratory for 9 years without exposure to any insecticides or introduction of field thrips. The thrips were reared on Phaseolus vulgaris L. from 2003 to 2009 and subsequently on *C. gladiata.* The thrips were fed in glass containers (19 × 14 × 20 cm high) at 27 ± 1 °C, 50%-60% RH, and 16:8 h L: D. The desired developmental stages for the bioassays were the 2nd instar larvae and the adult females.

Selection of Host Plant for Rearing Western Flower Thrips

Three different types of bean-pods, *C. gladiata* (swordbean), *L. purpureus* (lablab) and *P. vulgaris* (Frenchbean) were bought at the supermarket. To remove insecticide residues, all bean-pods were soaked in an abluent solution at 0.5% sodium allyl sulfonate for 1 to 2 h, thoroughly washed with water, and air dried.

Forty adult females were introduced into a container with 2 fresh bean-pods. After a 2-d oviposition period, the adults were removed from the bean-pods, and the bean-pods with eggs were transferred to another container and checked twice daily (08:00 a.m. and 20:00 p.m.) for egg hatch. If newly hatched larvae were found, they were carefully transferred to scintillation vials together with the bean-pods. The number of newly hatched 1st instars, 2nd instars, pupae, and adults were recorded. The average development periods of the thrips on the different hosts were also observed and recorded. Five replicates were included for each kind of bean-pod and each replicate had two bean-pods. The rearing conditions were maintained as described above.

Bioassay

The glass-vial method modified from Zhao et al. (1995) was adopted in the current study. Insecticides were diluted with acetone into a series of concentrations. The glass scintillation vials (22 mL) were coated with 0.5 mL of the insecticide solution or acetone-only as a control, and rolled on the laminator (Model: C3 20, ICO Science & Technology Co., Ltd. Beijing, China) until the acetone had evaporated. Each dose-response bioassay normally included 5-7 insecticide doses and a control. Fifteen 2nd instars or ten adult females were transferred with a brush into each insecticide-treated vial. After 6 h, a small section (2 cm × 3 cm) of an untreated broccoli leaf was added to each vial as a food source. To prevent the thrips from escaping, the vials were sealed with a plastic

TABLE 1. PERCENT ACTIVE INGREDIENT, CHEMICAL AND IRAC GROUPS AND SUPPLIER OF EACH OF THE 36 INSECTICIDES EVALUATED AGAINST *FRANKLINIELLA OCCIDENTALIS*.

Insecticide	Technical grade (A.I.) (%)	Chemical group, IRAC group	Supplier
Acephate	98	Organophosphate, IB	Shandong Huayang Technology Co., Ltd.
Chlorpyrifos	96	Organophosphate, IB	Nanjing Redsun Co., Ltd.
Diazinon	96	Organophosphate, 1B	Jiangsu Nantong Jiangshan Agrochemical & Chemicals Co., Ltd.
Malathion	95	Organophosphate, 1B	Dezhou Hengdong Chemical Co., Ltd.
Profenofos	90.7	Organophosphate. 1B	Tianjin Pesticide Co., Ltd.
Phoxim	88	Organophosphate, 1B	Jiangsu Baoling Chemical Co., Ltd.
Triazophos	85	Organophosphate, 1B	Hubei Xianlong Chemical Co., Ltd.
Benfuracarb	90	Carbamate, 1A	Shanxi Sunger Road Bio-science Co., Ltd.
Carbosulfan	90	Carbamate, 1A	American FMC Co., Ltd.
Indoxacarb	94.95	Carbamate, 1A	Dupont Company
Isoprocarb	95	Carbamate, 1A	Jiangsu Changlong Chemical Co., Ltd.
Metolcarb	96	Carbamate, 1A	Jiangsu Changlong Chemical Co., Ltd.
Methomyl	97.5	Carbamate, 1A	Jiangsu Changlong Chemical Co., Ltd.
Thiodicarb	95	Carbamate, 1A	Shandong Libang Chemical Co., Ltd.
Beta-cyfluthrin	95	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Lambda-cyhalothrin	95	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Etofenprox	90	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Salifluofen	93.5	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Fenpropathrin	99.1	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Cycloprothrin	90	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Cyhalothrin	95.8	Pyrethroid, 3A	Jiangsu Yangnong Chemical Co., Ltd.
Bifenthrin	97	Pyrethroid, 3A	Nanjing Redsun Co., Ltd.
Deltamethrin	98	Pyrethroid, 3A	Nanjing Redsun Co., Ltd.
Fenvalerate	91	Pyrethroid, 3A	Nanjing Redsun Co., Ltd.
Beta-cypermethrin	93	Pyrethroid, 3A	Nanjing Redsun Co., Ltd.
Esfenvalerate	96	Pyrethroid, 3A	Nanjing Redsun Co., Ltd.
Imidacloprid	95.3	Neonicotinoid, 4A	Jiangsu Yangnong Chemical Co., Ltd.
Acetamiprid	96	Neonicotinoid, 4A	Nanjing Redsun Co., Ltd.
Thiamethoxam	97.7	Neonicotinoid, 4A	Syngenta Co., Ltd.
Nitenpyram	95	Neonicotinoid, 4A	Jiangsu Nantong Jiangshan Agrochemical & Chemicals Co., Ltd.
Imidaclothiz	95	Neonicotinoid, 4A	Jiangsu Nantong Jiangshan Agrochemical & Chemicals Co., Ltd.
Thiacloprid	97.5	Neonicotinoid, 4A	Tianjin Xingguang Pesticide Factory
Chlorfenapyr	95	Chlorfenapyr, 13	BASF-The Chemical Company
Spinosad	90	Spinosyn, 5	Dow Agrosciences Ltd.
Emamectin benzoate	92	Avermectin, 6	Hebei Veyong Biochemical Co., Ltd.
Butylene fipronil	90	Phenylpyrazole, 2B	Dalian Regar Pesticides Co., Ltd.

film. The vials were maintained under conditions described above. Each concentration was evaluated with 4 replicates of larvae and 3 replicates of adults. Mortality was determined after 24 h for the organophosphate, carbamate, pyrethroid, and neonicotinoid treatments. Mortality was recorded after 48 h for the phenylpyrazole, *p*-chlorophenylpyrrole, spinosad, and emamectin benzoate treatments. Larvae and adults were scored as dead if they did not respond to gentle probing with a pin.

Data Analysis

The biological data of the thrips feeding on different host plants were analyzed by SAS program (SAS Institute 1990). The Polo Plus software (LeOra Software 2002) was used for probit analysis of dosed response data. LC_{50} concentrations were calculated, and any two LC_{50} values compared were considered significantly different if their respective 95% fiducial limits (F.L.) did not overlap.

Results

Selection of Host Plant for Rearing Western Flower Thrips

Influences of the 3 bean host species, *C. gladiata* (swordbean), *L. purpureus* (lablab) and *P. vulgaris* (Frenchbean), on the development and survival rates of the western flower thrips were compared. The results showed that the number of newly hatched larvae (543.20), the survival rates of 2nd to 4th instars (89.12%), and adult eclosion (73.17%) on *C. gladiata* were significantly higher than those on *L. purpureus* and *P. vulgaris*. Also, the survival rate from egg to pupa on *C. gladiata* was highest (84.28%). In comparison, the survival rates of western flower thrips on *L. purpureus* (60.63%) and *P. vulgaris* (44.24%) were much lower than on *C. gladiata*. There was no significant difference in the survival rates of the 1st to 2nd instar, egg period, and the 2nd instar period between the 3 hosts. The development time from egg to adult was the shortest on *C. gladiata* (10.15 d) and the longest on *L. purpureus* (11.97 d) (Table 2). Therefore, *C. gladiata* is considered to be the best of the 3 legume species for rearing western flower thrips.

Toxicity of Insecticides to Larvae

The contact toxicities of the 36 insecticides against the larvae of western flower thrips were determined (Table 3) using the glass-vial testing method. Based on chemical amount used to achieve 50% mortality, the relative toxicities of the insecticides were ranked as follows: phoxim > methomyl > butylene fipronil> chlorpyrifos > spinosad > chlorfenapyr, profenofos > emamectin benzoate, malathion, benfuracarb > thiamethoxam, carbosulfan, triazophos > acetamiprid, nitenpyram, metolcarb, thiodicarb, diazinon, cyhalothrin, bifenthrin, acephate, imidacloprid, *beta*-cyfluthrin, lambda-cyhalothrin, isoprocarb > salifluofen (LC_{50}'s with overlapping confidence intervals were classified as the same rank). The first 7 insecticides (Table 3) had higher toxicities than the other insecticides. Their LC_{50} values were less than 1.0 mg/L. Seven insecticides had LC_{50} values ranging from 1.5 to 9.0 mg/L, and the LC_{50} values of another 7 insecticides had were between 10 to 100 mg/L. 9 insecticides, including indoxacarb, fenvalerate, deltamethrin, fenpropathrin, cycloprothrin, *beta*-cypermethrin, esfenvalerate, etofenprox, and thiacloprid, showed the lowest contact toxicity against western flower thrips. Even when the concentrations were increased to 10,000 mg/L, these 9 insecticides produced only 20% - 40% mortalities. An even layer on the inner surface of glass vials could not be formed when concentrations exceeded 10,000 mg/L. Therefore, the toxicities for the latter group of insecticides could not be exactly quantified. Instead, their LC_{50} values were designated as > 10,000 mg/L for low toxicity against western flower thrips (Table 3).

Table 2. Comparison of development and survival of various life stages of *Frankliniella occidentalis* on 3 different leguminous (Fabales: Fabaceae) host plant species.

Biology	*Canavalia gladiata*	*Lablab purpureus*	*Phaseolus vulgaris*
Number of eggs that hatched	543.20 ± 20.13 a	292.60 ± 33.63 b	85.00 ± 14.30 c
%Survival of 1st to 2nd instar	94.85 ± 0.75 a	91.52 ± 4.55 ab	89.40 ± 3.45 b
%Survival of 2nd to 4th instar	89.12 ± 1.75 a	66.66 ±7.00 b	49.14 ± 2.50 c
%Eclosion of adults	73.17 ± 1.11 a	56.59 ± 6.83 b	58.31 ± 1.75 b
Egg period (d)	3.12 ± 0.39 a	3.41 ± 0.21 a	2.90 ± 0.22 a
1st instar larva period (d)	1.72 ± 0.17 b	2.38 ± 0.28 a	1.99 ± 0.10 b
2nd instar larva period (d)	2.22 ± 0.11 a	2.41 ± 0.14 a	2.28 ± 0.09 a
Prepupa period (d)	1.00 ± 0.06 b	1.28 ± 0.13 a	1.21 ± 0.04 a
Pupa period (d)	2.10 ± 0.05 b	2.48 ± 0.09 a	2.20 ± 0.05 b
Immature period (d)	10.15 ± 0.47 b	11.97 ± 0.56 a	10.60 ± 0.24 b

SAS ANOVA program was used to analyze the data.
Mean values within the same column followed by different letters are significantly different ($P < 0.05$).
Five replicates were included for each kind of bean-pod and each replicate with 40 adult females.

TABLE 3. TOXICITIES OF 36 INSECTICIDES AGAINST LARVAE OF *FRANKLINIELLA OCCIDENTALIS* BY THE GLASS-VIAL BIOASSAY.

Insecticides	*n*[a]	Slope ± SE	LC_{50} (95% F.L.)[b] (mg/L)	χ^2
Phoxim	360	2.376 ± 0.308	0.003 (0.001 - 0.004)	4.532
Methomyl	420	1.636 ± 0.185	0.034 (0.015 - 0.064)	12.471
Butylene-fipronil	420	2.616 ± 0.274	0.088 (0.067 - 0.112)	4.275
Chlorpyrifos	360	3.910 ± 0.413	0.170 (0.152 - 0.188)	2.414
Spinosad	420	2.035 ± 0.239	0.456 (0.266 - 0.779)	9.966
Chlorfenapyr	360	2.562 ± 0.271	0.812 (0.678 - 0.959)	1.355
Profenofos	360	5.040 ± 0.628	0.869 (0.775 - 0.956)	2.870
Emamectin benzoate	420	2.005 ± 0.217	1.802 (1.253 - 2.405)	4.116
Malathion	360	1.847 ± 0.225	2.081 (1.329 - 3.037)	3.484
Benfuracarb	360	2.536 ± 0.289	2.422 (1.949 - 2.904)	0.776
Thiamethoxam	480	1.245 ± 0.138	4.803 (2.694 - 7.285)	6.452
Carbosulfan	360	2.835 ± 0.313	4.727 (3.986 - 5.536)	1.290
Triazophos	420	2.867 ± 0.294	4.443 (3.184 - 5.912)	6.710
Acetamiprid	420	1.080 ± 0.122	8.893 (6.213 - 12.771)	2.585
Nitenpyram	420	1.406 ± 0.156	17.148 (13.413 - 21.823)	0.074
Imidaclothiz	420	1.739 ± 0.186	17.882 (14.331 - 22.119)	2.926
Metolcarb	360	2.097 ± 0.243	18.767 (15.289 - 22.758)	1.769
Thiodicarb	420	0.955 ± 0.106	31.631 (20.847 - 45.851)	1.300
Diazinon	360	1.944 ± 0.230	35.764 (28.424 - 43.783)	1.269
Cyhalothrin	420	1.687 ± 0.206	38.110 (16.971 - 59.576)	6.676
Bifenthrin	420	1.620 ± 0.181	74.798 (58.977 - 94.058)	1.583
Acephate	480	0.974 ± 0.123	101.800 (66.163 - 42.475)	2.700
Imidacloprid	420	0.809 ± 0.109	139.458 (86.761 - 221.431)	1.296
Beta-cyfluthrin	420	1.860 ± 0.201	274.001 (203.355 - 374.908)	4.111
Lambda-cyhalothrin	420	2.179 ± 0.222	280.143 (197.413 - 379.592)	5.447
Isoprocarb	420	1.735 ± 0.199	480.111 (279.563 - 691.046)	4.937
Salifluofen	360	1.645 ± 0.216	959.127 (750.177 - 211.908)	2.174
Indoxacarb		—	>10000	—
Fenvalerate		—	>10000	—
Deltamethrin		—	>10000	—
Fenpropathrin		—	>10000	—
Cycloprothrin		—	>10000	—
Beta-cypermethrin		—	>10000	—
Esfenvalerate		—	>10000	—
Etofenprox		—	>10000	—
Thiacloprid		—	>40000	—

[a]number of insects tested.
[b]Non-overlapping 95% fiducial limits (F. L.) of LC_{50} values were used as the criterion to determine a significant difference among toxicities of insecticides.

Toxicity of Insecticides to Adults

To verify if the insecticides that had high efficacy against the larvae were also effective against adults of western flower thrips, 12 insecticides belonging to different chemical classes were chosen to evaluate their toxicities against the adult females using the glass-vial method in the laboratory. LC_{50}s for the 12 insecticides ranged from 0.014 to 1128.197 mg/L (Table 4). Their toxicities were ranked as follows: butylene fipronil > phoxim > chlorfenapyr, chlorpyrifos, spinosad > thiamethoxam, benfuracarb, acetamiprid > carbosulfan, cyhalothrin > bifenthrin > emamectin benzoate (Table 4). Only the toxicity of emamectin benzoate against adults was significantly lower than against larvae. For another 11 insecticides, although the order of toxicity against adults was slightly different from that against larvae, the results confirmed that the first 10 insecticides were highly effective against both larvae and adults.

DISCUSSION

Different host plants significantly affected the oviposition of western flower thrips (Chaisuekul & Riley 2005). This thrips species prefers feeding on flowers of leguminous vegetables in China. However, flowers cannot be kept fresh for long periods of time, which limits the rearing of this thrips on flowers of southern China or in greenhouses. Zhi et al. (2010) reported that the pods of *Phaseolus vulgaris* L. are more a suitable for growth medium of this thrips than the leaves. In several studies, western flower thrips were cultured on potted dwarf French bean (*P. vulgaris*) plants (Herron & James 2005, 2007; Thalavaisundaram et al. 2008; Broughton & Herron 2009). In order to confirm which is more suitable for rearing western flower thrips on leguminous vegetables, *C. gladiata*, *L. purpureus*, and *P. vulgaris*, we evaluated them as hosts, and the biological parameters of this thrips feeding on these 3 different bean species were ob-

TABLE 4. TOXICITIES OF 12 INSECTICIDES AGAINST ADULT FEMALES OF *FRANKLINIELLA OCCIDENTALIS* BY THE GLASS-VIAL BIOASSAY.

Insecticides	n[a]	Slope ± SE	LC_{50} (95% F.L.)[b] (mg/L)	χ^2
Butylene-fipronil	180	3.709 ± 0.636	0.014 (0.012 - 0.017)	1.695
Phoxim	180	2.238 ± 0.345	0.036 (0.027 - 0.046)	0.259
Chlorfenapyr	180	5.609 ± 1.107	0.246 (0.167 - 0.311)	3.352
Chlorpyrifos	210	4.221 ± 0.734	0.257 (0.145 - 0.343)	7.462
Spinosad	180	1.780 ± 0.326	0.541 (0.347 - 0.743)	0.690
Thiamethoxam	210	1.818 ± 0.262	2.291 (1.655 - 3.040)	2.413
Benfuracarb	180	1.794 ± 0.307	3.565 (2.489 - 4.808)	0.676
Acetamiprid	180	1.948 ± 0.337	5.913 (4.024 - 7.928)	0.390
Carbosulfan	180	1.949 ± 0.317	10.125 (7.371 - 13.422)	0.267
Cyhalothrin	210	1.466 ± 0.244	11.216 (7.039 - 15.915)	0.808
Bifenthrin	180	1.971 ± 0.338	88.296 (61.974 - 117.845)	0.970
Emamectin benzoate	210	1.354 ± 0.236	1128.197 (733.803 - 634.344)	1.701

[a]Number of insects tested.
[b]Non-overlapping 95% fiducial limits (F. L.) of LC_{50} values were used as the criterion to determine a significant difference among toxicities of insecticides.

served in this study. Performance criteria, including thrips longevity, feeding and oviposition levels, as well as growth and development, vary for different plant species (Brown et al. 2002). Faster developmental rates and higher fecundity of insects on a host plant indicate better suitability of that host (van Lenteren & Noldus 1990). In the current study, the results showed that *C. gladiata* is the best host for rearing *F. occidentalis* among the 3 bean species. The feeding preference of the thrips on the 3 bean species may be related to the physical characteristics of the different hosts. The pods of *C. gladiata* are long, wide and flat, and those of *L. purpureus* are similar, but they are only one-half as long. In contrast the pods of *P. vulgaris* are long, slender and have a circular cross section.

Insecticide resistance management is an important consideration, because chemical control continues to be a dominant approach in China for suppression of western flower thrips populations. To conserve existing insecticides and to delay the development of insecticide resistance, insecticide resistance management strategies (IRMS) require alternating or rotating insecticides from different mode of action groups (IRAC 2007). Therefore, insecticides with the highest toxicity in each mode of action group (i.e., phoxim, butylene fipronil, chlorpyrifos, spinosad, chlorfenapyr, benfuracarb, thiamethoxam, carbosulfan. acetamiprid and cyhalothrin) could be practical candidates for field trials. In our study, the pyrethroids had low toxicity against western flower thrips in the laboratory compared with other chemical classes. But pyrethroid resistance of western flower thrips has been shown to exist in other studies. Western flower thrips populations exhibited 18- to 273-fold resistance to cypermethrin (Zhao et al. 1995). In Australia, the insect had highest resistance to tau-fluvalinate with LC_{50} level resistance ranging from 167- to 1,300-fold comparing with a susceptible strain. The resistance to bifenthrin, deltamethrin, and esfenvalerate was also in the middle range (Thalavaisundaram et al. 2008). Whether the lower toxicities of pyrethriods found in this study are related to acquired resistance needs to be confirmed. Broughton and Herron (2009) reported that acetamiprid, chlorfenapyr, and thiamethoxam are effective against adults and can be incorporated into the Australian IRMS. Although methomyl, spinosad, and chlorfenapyr remain effective in the current study, resistance of adults to spinosad has been reported in Australia (Herron & James 2005) and southeastern Spain (Bielza et al. 2007). Methomyl and chlorpyrifos resistances were detected with low to moderate levels (Herron & James 2005). Thus, rotational use strategies must be developed to preserve and possibly restore the effectiveness of insecticides currently applied in China.

Control strategies should be developed based on the biological characteristics of western flower thrips and the characteristics of each effective insecticide.

All of the life cycle stages of western flower thrips are cryptic. Eggs are inserted into the plant tissue, the larvae and the adult feed in tight or protected areas, such as flower buds or foliage terminals, and the pupal stages are passed in the soil or leaf litter. These behaviors add difficulty to the control of western flower thrips with insecticides, and their population densities increase sharply after the plants start blooming (Zhi et al. 2006). Therefore, actions to control western flower thrips should be taken before the flowering stage of the plants. Among the 36 insecticides tested, phoxim is the most effective insecticide against the thrips. But, this chemical has a short half-life or residual activity due to rapid photolysis under UV light. To avoid this rapid dissipation of action, phoxim could be formulated as a microcapsule and used as the main insecticide for control before western flower thrips numbers reach high levels. Thiamethoxam has a strong systemic activity, so it could be coated onto the seed, applied as a granular formulation, or applied in the root zone in irrigation water. Some insecticides that kill insects by contact and ingestion, such as butylene fipronil, chlorpyrifos, chlorfenapyr, and benfuracarb could also be processed in smoke or aerosol formulations to control the western flower thrips in the greenhouse.

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