Sublethal Effects of Insecticide Exposure on *Megacopta cribraria* (Fabricius) Nymphs: Key Biological Traits and Acetylcholinesterase Activity

**Jin Miao,1,2 Dominic D. Reisig,2,3 Guoping Li,1,2 and Yuqing Wu1**

1Institute of Plant Protection, Henan Academy of Agricultural Sciences, Zhengzhou 450002, P.R. China (miaojin1977@163.com), 2Department of Entomology, North Carolina State University, The Vernon James Research & Extension Center, 207 Research Station Road, Plymouth, NC 27962 and 3Corresponding author, e-mail: ddreisig@ncsu.edu

**Subject Editor:** Daniel Swale

**Received 24 June 2016; Accepted 11 August 2016**

**Abstract**

*Megacopta cribraria* F. (Hemiptera: Plataspidae), the kudzu bug, is an invasive insect pest of U.S. soybean. At present, insecticide application is the primary and most effective control option for *M. cribraria*. In this study, the potential effects of sublethal and low-lethal concentrations (LC10 and LC40) of three common insecticides on key biological traits and acetylcholinesterase (AChE) activity of the treated nymphal stage of insect were assessed. The results show that the sublethal concentration of imidacloprid significantly reduced adult emergence rate of *M. cribraria*. A low-lethal concentration of imidacloprid significantly increased nymphal development time, but significantly decreased adult emergence rate and adult longevity. Both sublethal and low-lethal concentrations of acephate caused an increase in nymphal development time and a reduction in adult emergence rate and adult longevity. Fecundity of females was significantly reduced only by exposure to low-lethal concentrations of acephate. Sublethal and low-lethal concentrations of bifenthrin increased nymphal development time, but significantly decreased adult emergence rate. In addition, we found that the AChE activity of *M. cribraria* was significantly increased only by LC40 imidacloprid, but strongly inhibited by acephate.

**Key words:** insecticide, nymphal developmental time, longevity, hormesis, fecundity

*Megacopta cribraria* F. (Hemiptera: Plataspidae), commonly referred to as kudzu bug, is a piercing–sucking insect that likely feeds on phloem in stems and foliage, intercepting nutrients and moisture from leguminous plants such as soybean, *Glycine max* Merrill and kudzu, *Pueraria montana* Loureiro (Zhang et al. 2012). *Megacopta cribraria* is known to be a pest of soybeans in its native range, with yield losses ranging from 10 to 50% in central and southern China (Xing et al. 2006, Eger et al. 2010). Although *M. cribraria* is native to Asia (Hosokawa et al. 2007, Eger et al. 2010), aggregations of this insect were discovered on kudzu in northeast Georgia during October 2009 (Suiter et al. 2010). This pest has spread quickly in the southeast and midsouth United States (Del Pozo-Valdivia and Reisig 2013); the infested acreage of soybeans in Virginia, North Carolina, Tennessee, and Alabama increased 24-fold, from 15,000 acres in 2011 to 366,600 acres in 2012 (Seiter et al. 2013). Two generations per year of this pest occur in the southeastern U.S. states (Eger et al. 2010, Suiter et al. 2010, Zhang et al. 2012, Gardener et al. 2013). In the spring, the overwintered adults fly to wild-legume hosts such as kudzu and wisteria to feed, mate, and oviposit. The first-generation nymphs develop on kudzu or early-planted soybean during May and June, and the first field-generation adults can re-invade later-planted soybeans during July (Zhang et al. 2012, Del Pozo-Valdivia and Reisig 2013, Seiter et al. 2013).

At present, insecticide application is the primary and most effective control option for *M. cribraria* in soybean fields. In China, up to 85% of *M. cribraria* in soybeans are controlled with pyrethroid and organophosphate class insecticides (Wang et al. 2004, Zhang and Yu 2005). Insecticide efficacy trials conducted during 2010–2012 in Georgia, South Carolina, and North Carolina have shown that several pyrethroids, organophosphates, and neonicotinoids provide excellent, but not total control. For example, many of these insecticides provided >90% control, defined as mortality, 6–14 days after being applied, alone or in tank-mixes (Greene, Reisig, and Roberts, unpublished data). Insects that survive exposure to insecticides can be behaviorally or physiologically modified, as a result (Desneux et al. 2007). The specific sublethal effects can include changes in life span, developmental rates, fecundity, changes in behavior, and changes in enzymatic activity (Stark and Banks 2003, Desneux et al. 2007, Miao et al. 2014).
The enzyme acetylcholinesterase (AChE, EC 3.1.1.7) hydrolyzes the neurotransmitter acetylcholine (Ach) to generate post-synaptic potentials. Within the field of ecotoxicology, AChE is used as a biochemical marker, since AChE is the primary target of inhibition by organophosphate and carbamate pesticides. Insects can be killed by these pesticides, because when AChE is inhibited, the post-synaptic neuron will continue to be stimulated. Studies using aquatic organisms have tested the inhibition of AChE activity by various toxicants and have found changes in behavior, feeding rate, and emergence of larvae (Domingues et al. 2007).

Our main objective of this study was to assess the sublethal effect of a single insecticide in each of three insecticide classes, a neonicotinoid (imidacloprid), a pyrethroid (bifenthrin), and an organophosphate (acephate), on M. cribraria nymphs. Biological traits and AChE activity of M. cribraria were observed under laboratory conditions. The results of this study can inform growers concerning the most effective products to control M. cribraria.

Materials and Methods

Insecticides. Commercial formulations were tested of the following insecticides registered for the use on soybean in the southeastern United States: imidacloprid (Admire Pro 42WPS, Bayer CropScience, Research Triangle Park, NC), bifenthrin (Brigade 25 EC, FMC Corporation, Philadelphia, PA), and acephate (Orthene CropScience, Research Triangle Park, NC), bifenthrin (Brigade 25 EC, FMC Corporation, Philadelphia, PA), and acephate (Orthene CropScience, Research Triangle Park, NC). Distilled water was used as untreated control in all treatments.

Insects and experimental conditions. Soybean seedlings were grown in 5 by 10 cm plastic cups with a soil mixture, and in a greenhouse for 27 ± 1°C, 70 ± 5% RH, and a photoperiod of 16:8 (L:D) h. Second-instar nymphs of M. cribraria were obtained from wild-kudzu plants in Plymouth, NC. These nymphs were maintained on soybean plants to allow them to develop to the third instar. Third-instar nymphs were used for all bioassay experiments. Environmental conditions in all experiments were 25 ± 1°C, 60 ± 10% RH, and a photoperiod of 16:8 (L:D) h.

Concentration–mortality response. Preliminary experiments using leaf dip bioassays were carried out to determine the range of concentrations to be tested for each insecticide considered in the study. Concentrations tested resulted in 0–100% mortality. Preliminary experiments were conducted to select five concentrations of each insecticide so that concentration–mortality regression lines could be calculated. All assays were performed in 30 ml plastic cups (RT32W, Bio-Serv, Flemington, NJ). Seven-day-old greenhouse-grown soybean plants were cut at the soil line and placed in the appropriate insecticide concentration for a time period of 5 s. Controls were treated with water only. Treated soybean plants were dried in ambient laboratory conditions, then placed upright on paper lids. For all bioassays, three replicates were conducted. All treatments were placed in a growth chamber at 25 ± 1°C, 70 ± 5% RH, and a photoperiod of 16:8 (L:D) h. Mortality was assessed after 24 h. A nymph was recorded as moribund if there was no coordinated movement when touched with a fine-haired paintbrush.

Sublethal and low-lethal effects on the biological traits. We exposed M. cribraria nymphs to sublethal and low-lethal concentrations of the three insecticides using the leaf dip bioassay protocol described above. Concentrations were chosen at the LD10 and LD40 values, which were determined in the previously described section. For each treatment and control, 100 third-instar M. cribraria nymphs were exposed to imidacloprid, bifenthrin, and acephate. After exposure 24 h, the survivors were placed into the plastic assay cups containing insecticide-free soybean plants as food. Five nymphs were placed in each plastic cup sealed with a paper lid. The assay cups were placed into growth chambers (same conditions as before) and were checked daily to record mortality and to replace old soybean plants with new ones. The duration of nymph to adult and adult emergence rate was determined by daily recording the stadia present in each treatment. Adults that completed development were then removed from the previous assay and placed as mating pairs (one male and one female) into new plastic cups covered with a paper top and containing insecticide-free soybean plants (provided as food and as oviposition substrate). These assay cups were placed into growth chambers (same conditions as before) and were checked daily to record mortality, eggs and to replace old soybean leaves with new ones.

Sublethal and low-lethal effects on AChE activity. Twenty third-instar M. cribraria nymphs were exposed to LC10 and LC40 concentrations of imidacloprid, bifenthrin, and acephate for 24 h following the method of above. The AChE activity of the survivors was tested using an enzyme-linked immunosorbent assay kit (Sigma-Aldrich Corporation, St. Louis, MO). A single nymph was homogenized for each replicate, and three replications were performed. Nymph homogenates were placed in 100 μl ice-cold 1× PBS buffer (Sigma-Aldrich Corporation). The homogenates were centrifuged at 4°C, 10,000g (Eppendorf centrifuge 5417R, Hamburg, Germany) for 30 min, and the supernatant was used for the AChE activity assay. Following the instructions of the AChE activity assay kit, 200 μl water and 200 μl calibrator were pipetted into wells of a 96-well plate. Homogenate samples were added in 10 μl aliquots to separate wells; directly following this, 190 μl of working reagent was added to all sample wells, and the plate was lightly and briefly tapped to facilitate mixing. Reads were conducted at OD412 nm for 2 min and for 10 min in a plate reader (Spectra-max Plus 384, Molecular Devices, Sunnyvale, CA). AChE activity was calculated using the equation:

$$AChE\ \text{activity} = \frac{OD_{10} - OD_{2}}{OD_{CAL} - OD_{H2O}} \times n \times 200 (U/L)$$

where OD10 and OD2 are the OD412nm values of the sample at 10 and 2 min, respectively. OD_{CAL} and OD_{H2O} are the OD412nm values of the calibrator and water at 10 min and n is the dilution factor (n = 1). The number “200” is the equivalent activity of the calibrator under the assay conditions.

Data analysis. The median lethal concentration (LC50) and the concentration–mortality response for third-instar M. cribraria nymphs were estimated using probit analysis (POLO-PC; LeOra Software 1987). One-way analysis of variance models were used to test the effects of the sublethal and low-lethal concentrations of three insecticides on the biological traits and AChE activity of M. cribraria, and means were separated using Tukey’s honestly significant difference (HSD) test (P < 0.05). The SPSS 10.0 (SPSS, Chicago, IL) software was used for all statistical analyses.

Results

Determination of the LC10 and the LC40 insecticides. The mortality of M. cribraria increased with increasing concentrations of each insecticide. The LC50 and LC40 values for different insecticides against M. cribraria at 24 h after exposure are listed in Table 1. Toxicities varied among insecticides, with the highest acute toxicity measured...
for bifenthrin, moderate toxicity measured for imidacloprid, and the least toxicity measured for acephate. The LC10 values for imidaclorpid, bifenthrin, and acephate were 1.86 (0.41–2.29) ppm, 0.027 (0.024–0.032) ppm, and 32.36 (27.53–38.22) ppm, respectively; and the LC40 values were 6.31 (5.16–7.74) ppm, 0.065 (0.059–0.078) ppm, and 89.13 (71.22–105.63) ppm, respectively.

Sublethal and low-lethal effects on the biological traits. The developmental time of nymphs varied significantly among treatments (Fig. 1; imidacloprid, \( F_{2,223} = 3.27, P = 0.043 \); bifenthrin, \( F_{2,235} = 4.02, P = 0.035 \); acephate, \( F_{2,206} = 4.65, P = 0.022 \) ). The development time of nymphs exposed to the LC40 concentration of imidacloprid, the LC10 and LC40 concentrations of bifenthrin, and the LC10 and LC40 concentrations of acephate were significantly longer than those in the control group.

Adult \( M. \) cribraria emergence rate was significantly reduced when nymphs were exposed to the LC10 and LC40 concentration of imidacloprid (\( F_{2,223} = 4.16, P = 0.032 \)), bifenthrin (\( F_{2,235} = 3.93, P = 0.038 \)), and acephate (\( F_{2,206} = 4.59, P = 0.026 \) ). Furthermore, the exposure to the LC40 concentration of imidacloprid (\( F_{2,235} = 3.02, P = 0.045 \) ) and the LC10 and LC40 concentration of acephate (\( F_{2,206} = 5.13, P = 0.017 \) ) significantly reduced adult longevity. However, no significant difference was observed after exposure to bifenthrin (\( F_{2,235} = 0.92, P = 0.36 \) ). Finally, fecundity of females (as measured by the number of eggs laid per female) was significantly reduced by exposure to the LC40 concentration of acephate, whereas there was no significant impact of other treatments on fecundity (Fig. 4).

Sublethal and low-lethal effects on AchE activity. The AchE activity of \( M. \) cribraria was significantly influenced by imidacloprid and acephate compared with their respective controls (Fig. 5; imidacloprid, \( F_{2,8} = 6.23, P = 0.034 \); acephate, \( F_{2,8} = 20.386, P = 0.002 \) ). AchE activity was increased significantly (28.57%) by LC40 imidacloprid, compared with the control (Fig. 5A). The AchE activity of \( M. \) cribraria exposed to the LC10 and LC40 concentration of acephate significantly decreased by 34.19 and 55.48%, respectively, compared with the control, (Fig. 5C). However, no significant difference was found in the AchE activity of \( M. \) cribraria exposed to the LC10 and LC40 concentration of bifenthrin compared with the control (Fig. 5B; \( F_{2,8} = 0.181, P = 0.739 \) ).

Discussion

This study in demographic toxicity (Akcakaya and Stark 2008) can serve to provide a baseline for management of \( M. \) cribraria in the United States. In addition to direct mortality, low or sublethal concentrations of insecticides may also affect population dynamics of insects through altering the behavioral and physiological traits, such as life span, development rates, fertility, and fecundity (Tan et al. 2012, He et al. 2013, Miao et al. 2014, Xiao et al. 2015). Therefore, characterization and assessment of sublethal effects could be crucial for understanding the global effects of insecticides on the pest and non-target organisms, and then optimizing its management in the crops (He et al. 2013, Pan et al. 2014).

We demonstrated that imidacloprid and bifenthrin were more lethal than acephate for \( M. \) cribraria. Moreover, based on our results evaluating development, fecundity, and AchE activity, negative sublethal effects of these insecticides on \( M. \) cribraria were observed.
Exposure to LC40 of imidacloprid significantly extended the development time of nymphs and reduced the emergence rate and longevity of adults, but an LC10 concentration of imidacloprid only reduced the emergence of adults. Furthermore, the fecundity of females was unaffected by exposure to either the LC10 or the LC40 concentration of imidacloprid. The differences in sublethal effects observed among insecticides and within insecticides by concentration should be expected, as it is known that these effects of insecticides on pests depend on the particular insecticide and its concentration, the pest species, and the pest stage (Holland and Chapman 1993, Pan et al. 2014). Similar results have been reported by Tan et al. (2012), where a sublethal concentration (LD25) of imidacloprid reduced the longevity of *Apolysis lucorum* males, but the LD5 and LD40 did not influence the longevity. Furthermore, He et al. (2011) did not find sublethal effects on fecundity of *B. tabaci* adults when they were exposed to LC20 and LC40 concentrations of imidacloprid for 24 h.

A number of studies have been conducted on the toxicity of acephate for different organisms (Rao et al. 2006). The results obtained from our study indicate that acephate had lower toxicity to *M. cribraria* than bifenthrin and imidacloprid, but the sublethal (LC10) and low-lethal (LC40) concentrations of acephate had a significant inhibitory effect on population development of *M. cribraria*. Similar effects were also observed in studies of greenhouse whitefly, *Trialeurodes vaporariorum* (Omer and Leigh 1995) and cotton aphid, *Aphis gossypii* (Kerns and Stewart 2000).

Because of their rapid action and excellent contact toxicity against a broad-spectrum of arthropod pests, the pyrethroid bifenthrin is widely used against many insect and mite pests (Herron et al. 2001, Zhang et al. 2012). The effects of lethal and sublethal concentrations of some pyrethroid insecticides can induce resurgence of the pest populations; for example, increased fecundity can be observed for *A. gossypii* following bifenthrin treatments (Kerns and Stewart 2000; hormoligosis in this case). Furthermore, bifenthrin can reduce *Apis mellifera* Linnaeus fecundity and decrease the developmental rate of *Tetranychus urticae* Koch (Dai et al. 2010, Wang et al. 2014). Our current results indicate that the effects of bifenthrin on population development of *M. cribraria* are concentration-dependent. Both the LC10 and LC40 concentrations of bifenthrin significantly increased developmental time of the nymph, and significantly decreased adult emergence rate.

Our results demonstrate that the AChE activity of *M. cribraria* is significantly reduced after exposure to the LC10 and LC40 concentrations of acephate. Previous studies involving the effect of various
organophosphate insecticides on AChE activity in *Micromus tasma-
nae* (Hodge et al. 2000), *Helicoverpa armigera* (Liu et al. 2003), and
*Rhopalosiphum padi* (Booth et al. 2007) have demonstrated similar
effects. While the results also show that the AChE activity of *M. cri-
braria* was significantly increased by LC40 imidacloprid. Despite the
fact that AChE is not a target for imidacloprid, our studies corrobo-
rated the finding that the AChE activity can be used as a biomarker of
imidacloprid sensitivity (Jemec et al. 2007), adding to the growing
body of literature with similar findings. For example, in one study,
the AChE activity of *M. cr
ibraria* was not affected after exposure to
the LC10 and LC40 concentrations of bifenthrin. Consequently, a low
concentration of imidacloprid, bifenthrin, and acephate can induce
some negative effects on biological traits of *M. cr
ibraria*. These results
suggest that these three insecticides can be used as tools in pest man-
agement programs of *M. cr
ibraria* in the field. Further experiments
are warranted to link these findings to field settings, both involving in-
secticide choice and resistance management.

**Acknowledgments**

The research was supported by the USDA National Institute of Food and
Agriculture HATCH project, under accession number 1004698. We would
like to acknowledge the help of Emily Goldsworthy for assistance in the lab-
atory and the research staff at the Vernon James Center in Plymouth for
assisting with greenhouse rearing of the soybean plants.
References Cited

Akçakaya, H., and J. D. Stark. 2008. Demographic toxicity: assessing the population-level impacts of contaminants, pp. 3–19. In H. Akçakaya, J. D. Stark, and T. Bridges (eds.), Demographic toxicity: methods in ecological risk assessment. Oxford University Press, Oxford, UK.

Azevedo-Pereira, H.M.V.S., M.F.L. Lemos, and A.M.V.M. Soares. 2011. Effects of imidacloprid exposure on Chronomus riparius Megen larvae: linking acetylcholinesterase activity to behaviour. Ecotoxicol. Environ. Saf. 74: 1210–1215.

Azevedo-Pereira, H.M.V.S., M.F.L. Lemos, and A.M.V.M. Soares. 2011. Effects of imidacloprid exposure on Chronomus riparius Megen larvae: linking acetylcholinesterase activity to behaviour. Ecotoxicol. Environ. Saf. 74: 1210–1215.

Dai, P. L., Q. Wang, J. H. Sun, and T. Zhou. 2010. Effects of sublethal concentrations of bifenthrin and deltamethrin on fecundity, growth, and development of honeybee Apis mellifera acariformer. A biomarker to detect deltamethrin exposure. Ecotoxicol. Environ. Saf. 69: 246–253.

Booth, L. H., S. D. Wratten, and P. Kehrli. 2007. Effects of reduced rates of two insecticides on enzyme activity and mortality of an aphid and its lacewing predator. J. Econ. Entomol. 100: 11–19.

Dai, P. L., Q. Wang, J. H. Sun, and T. Zhou. 2010. Effects of sublethal concentrations of bifenthrin and deltamethrin on fecundity, growth, and development of honeybee Apis mellifera acariformer. A biomarker to detect deltamethrin exposure. Ecotoxicol. Environ. Saf. 69: 246–253.

Del Pozo-Valdivia, A. I., and D. D. Resig. 2013. First-generation Megacopta cribraria (Hemiptera: Plataspidae) can develop on soybeans. J. Econ. Entomol. 106: 533–535.

Dai, P. L., Q. Wang, J. H. Sun, and T. Zhou. 2010. Effects of sublethal concentrations of bifenthrin and deltamethrin on fecundity, growth, and development of honeybee Apis mellifera acariformer. A biomarker to detect deltamethrin exposure. Ecotoxicol. Environ. Saf. 69: 246–253.

Booth, L. H., S. D. Wratten, and P. Kehrli. 2007. Effects of reduced rates of two insecticides on enzyme activity and mortality of an aphid and its lacing predator. J. Econ. Entomol. 100: 11–19.

Dai, P. L., Q. Wang, J. H. Sun, and T. Zhou. 2010. Effects of sublethal concentrations of bifenthrin and deltamethrin on fecundity, growth, and development of honeybee Apis mellifera acariformer. A biomarker to detect deltamethrin exposure. Ecotoxicol. Environ. Saf. 69: 246–253.

Dai, P. L., Q. Wang, J. H. Sun, and T. Zhou. 2010. Effects of sublethal concentrations of bifenthrin and deltamethrin on fecundity, growth, and development of honeybee Apis mellifera acariformer. A biomarker to detect deltamethrin exposure. Ecotoxicol. Environ. Saf. 69: 246–253.

Domingues, I., L. Guilhermino, A. M. Soares, and A. J. Nogueira. 2007. Assessing dimethoate contamination in temperate and tropical climates: potential use of biomarkers in biosassays with two chironomid species. Chemosphere. 69: 145–54.

Eger, J. E., L. M. Ames Jr., D. R. Suiter, T. M. Jenkins, D. A. Rider, and S. E. Halbert. 2010. Occurrence of the old world bug Megacopta cribraria (Fabricius) (Heteroptera: Plataspidae) in Georgia: a serious home invader and potential legume pest. Insecta Mundi. 121: 1–11.

Gardner, W. A., H. B. Peeler, J. LaForest, P. M. Roberts, A. N. Sparks, Jr., J. K. Greene, D. Reisig, D. R. Suiter, J. S. Bachelier, K. Kidd et al. 2013. Confirmed distribution and occurrence of Megacopta cribraria (F.) (Hemiptera: Plataspidae) in the Southeastern United States. J. Entomol. Sci. 48: 118–127.

He, Y. X., J. W. Zhao, Y. Zheng, Q. Y. Weng A. Biondi, N. Desneux, and K. M. Wu. 2013. Assessment of potential sublethal effects of various insecticides on key biological traits of the tobacco whitefly, Bemisia tabaci. Inter. J. Biolo. Sci. 9: 246–255.

Herron, G. A., K. Powis, and J. Rophail. 2001. Biotic involved in pest status of host insect. Proc. R. Soc. 274: 1979–1984.

Hocking, S. M., M. Longley, L. Booth, V. Heppelthwaite, and K. O’Halloran. 2002. Acetylcholinesterase activity in the Tasmanian lacewing as a biomarker for sublethal effects of dimethoate. J. Econ. Entomol. 106: 1676–1683.

Omer, A. D., and T. F. Leigh. 1995. Sublethal effects of acephate and biphate on fecundity, longevity, and egg viability in greenhouse whitefly (Horn., Aleyrodidae). J. Appl. Entomol. 119: 119–122.

Pan, H. S., Y. Q. Liu, B. Liu, Y. H. Lu, X. Y. Xu, X. H. Qian, K. M. Wu, and N. Desneux. 2014. Lethal and sublethal effects of cyfluthrin, a novel cis-nicotine-derived insecticide, on the mirid bug Apolygus lucorum. J. Pest Sci. 87: 731–738.

Seiter, N. J., J. K. Greene, and F. P. Ray-Jones. 2013. Reduction of soybean seed components by Megacopta cribraria (Hemiptera: Plataspidae). J. Econ. Entomol. 106: 1676–1683.

Stark, J. D., and J. E. Banks. 2003. Population-level effects of pesticides and other toxicants on arthropods. Ann. Rev. Entomol. 48: 505–519.

Xia, T., D. T. Yang, N. Desneux, and X. W. Gao. 2012. Assessment of physiologic sublethal effects of imidacloprid on the mirid bug Apolygus lucorum (Meyer-Dür). Ecotoxicology 21: 1989–1997.

Wang, H. S., C. S. Zhang, and D. P. Yu. 2004. Preliminary studies on occurrence and control technology of Megacopta cribraria (Fabricius). China Plant Protect. 24: 45–46 [in Chinese, abstract in English].

Wang, S. L., X. F. Tang, L. Wang, and W. Xie. 2014. Effects of sublethal concentrations of bifenthrin on the two-spotted spider mite, Tetanychus urticae (Acari: Tetranychidae). Syst. Appl. Acarol. 19: 481–490.

Xiao, D., T. Yang, N. Desneux, and X. W. Gao. 2015. Assessment of sublethal and transgenerational effects of pirimicarb on the wheat aphids Rhopalosiphum padi and Sitobion avenae. Plant Protect. 33: 53–54 [in Chinese, abstract in English].

Zeng, C. X., and J. J. Wang. 2007. Time and dose effects of sublethal imidacloprid concentrations on acetylcholinesterase in Myzus persicae. Plant Protect. 33: 50–54 [in Chinese, abstract in English].

Zhang, C. S., and D. P. Yu. 2005. Occurrence and control of Megacopta cribraria (Fabricius), Chinese Countryside Well-off Technol. 1: 35–36 [in Chinese].

Zhang, Y. Z., J. L. Hanula, and H. Scott. 2012. The biology and preliminary host range of Megacopta cribraria (Heteroptera: Plataspidae) and its impact on kudzu growth. Environ. Entomol. 41: 40–50.