Host Selection Behavior and the Fecundity of *Plutella xylostella* (Lepidoptera: Plutellidae) on Multiple Host Plants

Bin Huang,1,2,3 Zhanghong Shi,1,2,3 and Youming Hou1,2,3,4

1College of Plant Protection, Fujian Agriculture and Forestry University, Fuzhou, Fujian 350002, China
2Key Laboratory of Integrated Pest Management for Fujian-Taiwan Crops, Ministry of Agriculture, Fuzhou, Fujian 350002, China
3Key Laboratory of Insect Ecology in Fujian, Fuzhou, Fujian 350002, China
4Corresponding author, e-mail: ymhou@fafu.edu.cn

Subject Editor: Steve Lapointe

J. Insect Sci. 14(251): 2014; DOI: 10.1093/jisesa/ieu113

**ABSTRACT.** Insect herbivores often have higher densities on host plants grown in monocultures than those in diverse environments. The underlying mechanisms are thought to be that polyphagous insects have difficulty in selecting food or oviposition sites when multiple host plants exist. However, this hypothesis needs to be extensively investigated. Our field experiments revealed that the population of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), significantly decreased in a mixed cropping field compared with a monoculture. To determine the reasons for the reduction in population in the mixed cropping field, the takeoff behavior and fecundity of females in no-choice and free-choice laboratory environments were compared by video recordings of host selection by *P. xylostella*. Adults displayed a significantly higher takeoff frequency in free-choice environments than those in no-choice treatments and preferred landing on *Brassica campestris* (L.) or *Brassica juncea* (Coss) plants in contrast with *Brassica oleracea* (L.). Female adults in the free-choice environment also laid fewer eggs compared with the monoculture. Olfaction experiments demonstrated orientation by *P. xylostella* to host volatiles when presented with a choice between plant odors and clean air, but females showed no preference when odors from three *Brassicaceae* species were presented simultaneously. We conclude that mixed cropping alters the host-finding behavior of *P. xylostella* resulting in reduced oviposition.

**Key Words:** multiple host plant, insect behavior, fecundity, cruciferous vegetable

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is one of the worldwide destructive pest species for cruciferous vegetables (Talekar and Shelton 1993). It has caused huge economic losses in a large number of countries, including China, Japan, United States, Mexico, Australia, India, the Russian Federation, Indonesia, Thailand, and Vietnam, as well as European countries such as Germany (Centre Agriculture Bioscience International (CABI) Compendium, www.ipmcenters.org/cabi). Many factors have been reported to affect the infestation extent of *P. xylostella*. For example, cruciferous host plant species could dramatically affect the genetic differentiation of *P. xylostella* (Luo et al. 2011). The competition among *P. xylostella* and other *P. xylostella* other species were presented simultaneously. We conclude that mixed cropping alters the host-finding behavior of *P. xylostella* resulting in reduced oviposition.

Materials and Methods

**Insects and Plants.** *P. xylostella* was collected from cruciferous vegetables on the campus of Fujian Agriculture and Forest University (Fuzhou, Fujian, China) and was maintained for several generations on *Brassica rapa* (L.) Chinensis Group (Chinese white cabbage, Fuzhou Gaoda Seed Industry Co. Ltd., Fuzhou, China) in an environmental chamber at 27 ± 1°C, 70 ± 10% relative humidity (RH), and illumination 1,200–1,400 lux (10:14 L:D h).
Only large and healthy pupae were selected for adult emergence (the weight of the pupae was about 3.9 mg). Five hours after mating, the female individuals were randomly assigned to experimental treatments.

To remove the potential effects of Br. rapa on the behavioral response of P. xylostella in our experiments, three other species of cruciferous vegetables, Brassica campestris (L.) (green chili sum 50 d, Fuzhou Wing Rong Seed Co. Ltd., Fuzhou, China), Brassica juncea (Coss) (Fuzhou wide red mustard, Fuzhou Wing Rong Seed Co. Ltd., Fuzhou, China), and Brassica oleracea (L.) (Snow Lotus 65, The Fuzhou Bud Force Agricultural Science and Technology Co. Ltd., Fuzhou, China) were used. Plants were transplanted into 15-cm diameter plastic pots for experiments when six to seven leaves had been developed. Fertilizer (26:10:15 N:P:K, Stanley Fertilizer Co. Ltd., Sunner Group, Biological Engineering Co., Ltd., Nanping City, China) was applied at 40 g/m² before sowing. Soil surfaces were covered with plaster for all experiments. All plants were grown in comparable soil mixtures collected from suburban farm lands near Fuzhou city, Fujian province and watered equally every day.

Field Experiment. Field experiments were conducted during the summer (May–June 2011) at an island on Jianxi river of Jian’ou City, Fujian Province, China. A field (≈3,335 m²) was divided into 10 plots. Plots were separated by 1-m vegetational-free borders. The experimental land was separated from other fields by bamboo.

The experiments were arranged in a randomized complete block design, and each treatment was replicated three times for Br. juncea and mixed cropping and four times for Br. campestris, and the layout of the plot design is shown in Fig. 1. In the monoculture, 26 g seeds were sowed in each plot. In the mixed cropping plot, 13 g Br. campestris and 13 g Br. juncea seeds were mixed thoroughly before sowing. Three thousand kilogram per hectare of organic fertilizer (Lu Tun, Fujian Sunner Group, Biological Engineering Co., Ltd., Nanping City, China) was applied in the experimental field without the use of any pesticides.

Twenty days after sowing, six investigations were sampled every 2 d. The spatial distribution pattern of P. xylostella was obtained by six investigations on each plot was used to reveal the effects of the mix cropping on the infestation of this pest by statistical analysis.

Behavioral Experiment. Experiments were conducted in an acrylic cage (60 by 60 by 60 cm) with sufficient room for P. xylostella flight. A 15-cm diameter hole was present at the top of the cage and was covered by fine gauze. The cage was placed on a stainless steel platform that had small holes radially arranged from the center to the edge of the platform to ensure airflow to avoid mixing of olfactory cues as far as possible and prevent condensation. The cage was washed with soap solution and then rinsed with clean water between trials to remove any residues from the earlier experiment.

Each experiment consisted of four environments, including three no-choice environments and one free-choice environment. Br. campestris, Br. juncea, or Br. oleracea was used alone in the no-choice environments. In each environment, nine plants were arranged in an equilateral triangle that had three plants on each side. The free-choice environment was composed of three Brassica species, and each Brassica was with three plants. The three species of vegetables were arranged in every 40-cm-lengthened side of an even-sided triangle inside the cage, respectively (Fig. 2). All experiments were repeated three times.

In the behavioral studies, a female just after copulation completed was immediately introduced into the center of the cage for laying eggs. Two cameras were placed on each side of the cage, one facing up and one facing down. The observation began immediately after the female was released and lasted for 48 h. The experiments were conducted at 28 ± 1°C, 70 ± 10% RH, and illumination 1,200 lux (10:14 L:D h). In each treatment, only one female was used to investigate behavior in order to prevent interruption from among the different individuals.

The behavioral response of P. xylostella was recorded by DVR. The video of P. xylostella’s live behavioral response was transferred to a personal computer and watched to determine parameters such as takeoff frequency. When the moth landed on a vegetable leaf or the inner surface of an apparatus after being released, we defined this behavior as flying for one time. Insects have almost no response to wavelengths of light greater than 650 nm (infrared light; Langer et al. 1979, White 1985). Therefore, in these experiments, 850-nm infrared light was used as lighting throughout the 24-h period.

Female Fecundity. The same basic experimental layout as in the behavioral experiment was used. The number of newly mated female moths was subsequently increased to 3. Because most eggs were laid within 5 d after emergence (Ko and Fang 1980), the female adults were released and allowed to oviposit for 5 d. Thereafter, the number of eggs laid in each environment was compared to determine the effect of host selection on fecundity. The experiment was repeated 10 times for choice and no-choice experiments.

Olfaction Experiment. The olfaction bioassays were conducted in a pentagonal acrylic apparatus (Fig. 3). A release room (2-cm diameter) was located in the center. Three doors are set up along the wall of release room. To let the released moth quiet before moving into the activity room (diameter 10 cm) which is around the release room, a

![Fig. 2. The schematic of plant arrangement in the behavioral experiment and female fecundity experiment (in the free-choice environment, Brassica campestris, Brassica juncea, or Brassica oleracea, respectively, was arranged on one side A, B, or C of triangle; in the no-choice environment, three sides of triangle were arranged nine plants by B. campestris, B. juncea, or B. oleracea alone).](image-url)
valve is set inside the release room. Three option arms (width 4.7 cm) are evenly distributed around the pentagon, and a trap at the top of the option arm is used to catch the moth. The three traps were connected with three different glass bell jars where we placed the host plant. Activated carbon apparatus was used to filter the air flowing into the glass bell jar. The top of release room was connected to an air pump.

These experiments were divided into two treatments. In treatment A, one of the three glass bell jars contained Br. campestris and the others were blank (fresh air). In treatment B, three glass bell jars contained Br. campestris, Br. juncea, and Br. oleracea, respectively.

In this study, a female which completed copulation in 5 h after emergence was immediately released into the olfactometer. No-choice experiment was repeated 11 times and choice experiment was repeated 13 times. The experiments were conducted at 28 ± 1°C and 70 ± 10% RH.

Statistical Analyses. In the field experiment and female fecundity experiments, one-way analysis of variance (ANOVA) was used to analyze the differences in P. xylostella population and number of eggs laid from various treatments. Percentages of laid eggs on plants were arcsine square-root transformed for analyses. Duncan’s multiple range test was employed to complete multiple means comparisons. The Kruskal–Wallis one-way ANOVA with all pairwise multiple comparisons was used to detect the takeoff frequencies of P. xylostella on different host plants and the chi-square test was used to detect the selection behavior under different odor sources. All data analyses were conducted using IBM SPSS Statistics version 20 (IBM Corp., New York City, USA) with α = 0.05 significance level.

Results

Field Experiment. Field investigations uncovered that the mean (±SD) population density of P. xylostella in the mixed cropping land was 27.7 ± 6.1 individuals per 20 plants, while those in the monoculture land with Br. campestris or Br. juncea was 33.0 ± 7.8 and 45.7 ± 7.0 individuals per 20 plants, respectively. Statistical analyses revealed that the P. xylostella populations from the mixed cropping field were smaller than those from the monoculture lands (F2,7 = 11.094, P < 0.05; Fig. 4). No significant difference (P = 0.229) was detected between P. xylostella populations in the two monoculture fields.

Behavioral Experiment. When females were released into the mixed cropping environment, mean (±SD) takeoff frequency was 315.0 ± 108.5 flights per 24 h (Fig. 5). In the monoculture environment with Br. campestris, Br. juncea, and Br. oleracea, takeoff frequency of females was 103.0 ± 17.3, 108.0 ± 8.8, and 210.0 ± 16.3 flights per 24 h, respectively. The present result demonstrated significant differences in the behavioral responses of the moths to the mixed cropping and the monoculture treatments with Br. campestris and Br. juncea (χ² = 8.453, df = 3, P < 0.05). However, no difference in the moth behavior was observed between the mixed cropping and Br. oleracea monocultured treatment. This result indicated that female P. xylostella in the mixed cropping environment had much more tests during the location of its suitable host plant than in the monoculture environment of Br. campestris and Br. juncea, respectively.

Female Fecundity. During the 5-d period, females laid 112.0 ± 9.9 (n = 27) eggs in the mixed cropping treatment, but those in the treatment only being supplied with Br. campestris, Br. juncea, and Br. oleracea produced 176.3 ± 14.0 (n = 30), 133.3 ± 10.3 (n = 30), and 114.7 ± 8.7 (n = 30) eggs per female in average, respectively. Duncan’s multiple range test revealed that mean number of eggs laid in
the mixed cropping treatment was significantly fewer than that in *Br. campestris* and *Br. juncea* monoculture, but not different from the *Br. oleracea* monoculture (*F*3,113 = 218.7, *P* < 0.05; Fig. 6). Moreover, we also found that eggs were not evenly distributed on the leaves of different vegetable species in the mixed cropping treatment, and the majority of eggs were laid on *Br. campestris* (41.2 ± 12.0%) or *Br. juncea* (40.9 ± 10.0%), but less on *Br. oleracea* (17.9 ± 6.1%) (*F*2,78 = 51.481, *P* < 0.05; Fig. 7). These results suggested that the fecundity of females was significantly decreased by mixed cropping and they obviously preferred the *Br. campestris*, followed by *Br. juncea* and *Br. oleracea*.

**Olfaction Experiment.** In treatment A, 72.7% of females located the *Br. campestris*, while 27.3% moved into the blank glass jars. This result indicated that the volatiles from *Br. campestris* could attract *P. xylostella* and this effect was significant (*n* = 2, *χ*² = 7.682, df = 1, *P* < 0.05). In treatment B, when three tested species of vegetables were presented simultaneously, 38.5% of females landed on the leaves of *Br. oleracea*, 38.5% on *Br. campestris*, and the remaining ones (23.1%) on *Br. juncea*. It suggested that females could not discriminate the three species of cruciferous vegetables (*Br. campestris*, *Br. juncea*, and *Br. oleracea*) (*n* = 3, *χ*² = 0.615, df = 2, *P* > 0.05; Fig. 8) when they were presented at once.

**Discussion**

In this study, our field experiments demonstrated that mixed cropping decreased the population size of *P. xylostella* (Fig. 4). Furthermore, *P. xylostella* showed different behavioral responses to the chosen vegetable species. For instance, when the *Br. campestris*, *Br. juncea*, and *Br. oleracea* were supplied alone in the no-choice experiment, *P. xylostella* had the lowest takeoff frequency on the *Br. campestris* and laid the largest number of eggs, followed by *Br. juncea* and *Br. oleracea* (Figs. 3 and 4). When the three *Brassica* species were presented together, more eggs were oviposited on *Br. campestris* and *Br. juncea*, compared with *Br. oleracea*. It suggested that *P. xylostella* females were able to respond differently to the host plants with various preference whether in the monoculture or in the polyculture of different cruciferous species. In the two treatments, *Br. campestris* was always the highest rank host species for oviposition. Previous evidence also showed that *P. xylostella* preferred to lay more eggs on leaves of Chinese cabbage and mustard than other *Brassica* species, which suggested that they might be a good candidate for use as a trap crop to control *P. xylostella* (Badenes-Perez et al. 2004, 2006;
Shelton and Badenes-Perez 2006; Satpathy et al. 2010). Furthermore, our experiments revealed that *P. xylostella* in the free-choice environment laid significantly less eggs than in the no-choice environment. This was consistent with the previous report that mixed cropping a whitefly-susceptible cassava cultivar with a whitefly-resistant cassava cultivar results in a 60% overall reduction in abundance of the whitefly *T. variabilis* (Gold et al. 1990). This result indicated that the polycultural agroecosystem, being composed of three *Brassica* species with different preference for *P. xylostella*, also significantly affected their host-selecting behavior and reduced their fecundity. However, our results were contrary to the conclusion from Badenes-Perez et al. (2004), which presented that total oviposition of *P. xylostella* in the cage plots containing yellow rocket, *Barbarea vulgaris* (R. Br.) variety *arcuata*, was far higher than in the plots only with cabbage. We thought that it resulted from the differences in the oviposition preference of *P. xylostella* to the two vegetable species in the mix-cropping tests. For instance, when *B. tabaci* was released into the mixed cropping environment with high-rank and low-rank hosts, it showed a distinctive behavioral preference for the highest rank host cucumber, which suggested that *B. tabaci* tends to select a high-ranking host as soon as possible and deposit all or most of its eggs on the preferred host species (Bird and Krüger 2006). In our experiments, both *Br. campestris* and *Br. juncea* are the preferred host for *P. xylostella*. In contrast, *Ba. vulgaris* was much more attractive to *P. xylostella* than cabbage (Badenes-Perez et al. 2004). Therefore, the similar host preference in our tests might lead to more behavioral confusions when *P. xylostella* located its preferred host plant.

Although many studies have documented the mixed cropping-mediated effects on the population size of other insect pests, the major question that needed to be elucidated was “how do insect pests respond to polycultures compared with monocultures.” To the best of our knowledge, there is no consensus on the underlying mechanism of the mixed cropping-mediated drop in insect pests. It is generally accepted that the behavioral response of insect pests in polycultures is directed either by chemical cues or by visual signals (Finch and Collier 2012). However, no robust evidence in the literature indicated that plant chemicals can attract insects beyond 5 m (Finch and Skinner 1982). The trap crops serve as a sink for insects or the pathogens they vector (Shelton and Badenes-Perez 2006). Meanwhile, we could not find evidence indicating that insects were repelled from landing on nonhost plants. Here, our analysis on the behavior video of *P. xylostella* revealed that their takeoff frequency in the free-choice experiment was remarkably higher than that in the no-choice treatment. This result suggested that they could not discriminate their superior host plants from the inferior ones in the free-choice environment prior to landing. In other words, *P. xylostella* in our study landed randomly on the supplied plants and then evaluated whether it was the preferable host through other stimulus such as leaf physical characteristics and so on. If the landing host was not suitable, *P. xylostella* left to search the preferable host again. Similar behavioral responses were also documented on the extremely polyphagous whitefly *B. tabaci* B-biotype when *B. tabaci* was placed in choice and no-choice environments in the laboratory (Bird and Krüger 2006).

Crop diversification has been demonstrated extensively to retard the occurrence of insect pests and other plant diseases (Finch and Collier 2012). However, the mechanism for this effect was still unknown. Several lines of literature reported that simultaneous exposure to more than one food item involves tradeoff between host location and other physiological processes including immune defense and reproduction (Janz and Nylin 1997, Bernays 2001). Janz and Nylin (1997) proposed that such tradeoffs are caused by behavioral responses rather than physiological costs in nature. According to the information-processing hypothesis, females of polyphagous insects costly discriminate and evaluate a larger number of plant species, e.g., by eventually using less or nonacceptable plants (Nylin et al. 2000, Bernays 2001). Combined with these relative reports, our results suggested that the changes in the behavioral responses of insect pests such as the increase of takeoff frequency of *P. xylostella* could explain the documented intercropping-mediated effects. Here, we determined that they laid fewer eggs in the free-choice treatment as well. It appears that in the free-choice environment, there is a tradeoff between the egg production of *P. xylostella* and the evaluation of the preferred hosts. However, this hypothesis should be further investigated through comparative researches on the oviposition preference for *P. xylostella* from the above distinct treatments.

In our bioassays, host plant volatiles were shown to guide the females to locate their host plants. However, when three *Brassicaceae* species were presented simultaneously, the number of females on the vegetable leaves was similar. It suggested that females could not discriminate between the three tested vegetable species because they emitted similar volatiles. Current evidence has demonstrated that other cues such as gustation and plant surface characteristics could guide herbivores to suitable hosts after landing (Schoonhoven et al. 2005). In the behavioral experiments, *P. xylostella* females released into a mixed cropping environment returned to flight more frequently compared with those in a monoculture. These differences in *P. xylostella* behavior may be led by the similar volatiles from three cruciferous vegetables in this study. In the mixed cropping environment, females were lured to land on one species of vegetable. After landing, *P. xylostella* further evaluated the host by other stimulus from the vegetable species. If it was not suitable, they flew off the plant to locate the host again. Therefore, these results revealed that mixed cropping with different vegetable species could dramatically alter the host location behavior of females.

Our experiments demonstrated that mixed cropping with the different-rank host species could reduce the infestation intensity of *P. xylostella* in the field. Additionally, we recorded and analyzed the live behavioral response of *P. xylostella* when they were released into the monoculture and multiculture treatments and determined that the decline in oviposition was the major factor for the decrease of *P. xylostella* population. This study provided further insights into the possible underlying mechanisms that control herbivore population size in polyculture versus monoculture systems.

Acknowledgments

We thank Prof. Xiaojun Gu to provide constructive comments to improve our manuscript. The project was supported by the Key Program of the National Natural Science Foundation of China (31230061), Special Fund for Agro-scientific Research in the Public Interest (201103021), The 12th Five-Year National Science and technology plan project in rural areas (2012BAD19B06), and Fujian Provincial Department of Education Project (JA11081).

References Cited

Andow, D. A. 1990. Population dynamics of an insect herbivore in simple and diverse habitats. Ecology 71: 1006–1017.

Badenes-Perez, F. R., A. M. Shelton, and B. A. Nault. 2004. Evaluating trap crops for diamondback moth, *Plutella xylostella* (*Lepidoptera: Plutellidae*). J. Econ. Entomol. 97: 1365–1372.

Badenes-Perez, F. R., B. A. Nault, and A. M. Shelton. 2006. Dynamics of diamondback moth oviposition in the presence of a highly preferred non-suitable host. Entomol. Exp. Appl. 120: 23–31.

Bernays, E. A. 1996. Selective attention and host-plant specialization. Entomol. Exp. Appl. 80: 125–131.

Bernays, E. A. 1999. When host choice is a problem for a generalist herbivore, experiments with the whitefly *Bemisia tabaci*. Ecol. Entomol. 24: 260–267.

Bernays, E. A. 2001. Neural limitations in phytophagous insects: implications for diet breadth and evolution of host affiliation. Annu. Rev. Entomol. 46: 703–727.

Bird, T. L., and K. Krüger. 2006. Response of the polyphagous whitefly *Bemisia tabaci* B-biotype (*Hemiptera: Aleyrodidae*) to crop diversification— influence of multiple sensory stimuli on activity and fecundity. Bull. Entomol. Res. 96: 15–23.

Costello, M. J., 1994. Broccoli growth, yield and level of aphid infestation in leguminous living mulches. Biol. Agric. Horticult. 10: 207–222.
Courtney, S. P. 1983. Models of host-plant location by butterflies: the effect of search images and searching efficiency. Oecologia 59: 317–321.

Couty, A., H. Emden, J. Perry, J. Hardie, J. A. Pickett, and L. J. Wadham. 2006. The roles of olfaction and vision in host-plant finding by the diamondback moth, Plutella xylostella. Physiol. Entomol. 59: 134–145.

Finch, S., and R. H. Collier. 2012. The influence of host and non-host companion plants on the behaviour of pest insects in field crops. Entomol. Exp. Appl. 142: 87–96.

Finch, S., and G. Skinner. 1982. Upwind flight by the cabbage root fly, Delia radicum. Physiol. Entomol. 7: 387–399.

Fox, C. W., and R. G. Lalonde. 1993. Host confusion and the evolution of insect diet breadths. Oikos 67: 577–581.

Futuyama, D. J. 1983. Selective factors in the evolution of host choice by phytophagous insects, pp. 227–244. In S. Ahmad (ed.), Herbivorous insects: host-seeking behavior and mechanisms. Academic Press, New York.

Gold, C. S., M. A. Altieri, and A. C. Bellotti. 1990. Direct and residual effects of short duration intercrops on the cassava whiteflies Aleurotrachelus socialis and Trialeurodes varibalis (Homoptera: Aleyrodidae) in Colombia. Agr. Ecosyst. Environ. 32: 57–67.

Hooks, C.R.R., H. R. Valenzuela, and J. Defrank. 1998. Incidence of pests and arthropod natural enemies in zucchini grown with living mulches. Agr. Ecosyst. Environ. 69: 217–231.

Janz, N., and S. Nylin. 1997. The role of female search behaviour in determining host plant range in plant feeding insects: a test of the information processing hypothesis. Proc. R. Soc. B Biol. Sci. 264: 701–707.

Ko, L. T., and J. L. Fang. 1990. Studies on the biology of the diamondback moth: observations on behaviour. Chin. J. Plant Prot. 7: 139–143.

Langer, H., B. Hamann, and C. C. Meinecke. 1979. Tetra chromatic visual system in the moth Spodoptera exempta (Insecta: Noctuidae). J. Comp. Physiol. 129: 235–239.

Larsson, S., and B. Ekbom. 1995. Oviposition mistakes in herbivorous insects: confusion or a step towards a new host plant. Oikos 72: 155–160.

Letourneau, D. K. 1986. Associational resistance in squash monocultures and polycultures in tropical Mexico. Environ. Entomol. 15: 285–292.

Liu, S. S., Y. H. Li, and Y. G. Lou. 2006. Non-host plant extracts reduce oviposition of Plutella xylostella (Lepidoptera: Plutellidae) and enhance parasitism by its parasitoid Cotesia plutellae (Hymenoptera: Braconidae). Bull. Entomol. Res. 96: 373–378.

Luo, D., B. Huang, and Y. M. Hou. 2011. Analysis of diamondback moth populations under host plants stress by RAPD. Chin. J. Appl. Entomol. 48: 273–279.

Nylin, S., A. Bergström, and N. Janz. 2000. Butterfly host plant choice in the face of the possible confusion. J. Insect Behav. 13: 469–482.

Pan, B. P., L. Xin, Z. P. Wang, Y. Q. Ren, and H. M. Yan. 1999. Diamondback spatial distribution pattern and sampling technique. Chinese J. Inner Mongolia Agr. Sci. Technol 6: 12–14.

Rämer, B., and B. Ekbom. 1996. Intercropping as a management strategy against carrot rust fly (Diptera: Psilidae): a test of enemies and resource concentration hypothesis. Environ. Entomol. 25: 1092–1100.

Sarfraz, M., L. M. Dosdall, and B. A. Keddie. 2006. Diamondback moth-host plant interactions: implications for pest management. Crop Prot. 25: 625–639.

Satpaty, S., T. Shivalingaswamy, A. Kumar, A. Rai, and M. Rai. 2010. Potentiality of Chinese cabbage (Brassica rapa subsp. Pekinensis) as a trap crop for diamondback moth (Plutella xylostella) management in cabbage. Indian J. Agr. Sci. 80: 238–241.

Schoonhoven, L. M., J.J.A. van Loon, and M. Dicke. 2005. Insect-plant biology: from physiology to evolution. Oxford University Press, Oxford, United Kingdom.

Shelton, A. M., and F. R. Badenes-Perez. 2006. Concepts and applications of trap cropping in pest management. Annu. Rev. Entomol. 51: 285–308.

Talekar, N. S., and A. M. Shelton. 1993. Biology, ecology, and management of the diamondback moth. Annu. Rev. Entomol. 38: 275–301.

White, R. H. 1985. Insect visual pigments and color vision, pp. 431–493. In G. A. Kerkut and L. I. Gilbert (eds.), Comprehensive insect physiology, vol. 6. Pergamon Press, Oxford, United Kingdom.

Zhang, E. N., B. Huang, and Y. M. Hou. 2011. The effect of competition by Phytophthora striata on the feeding and growth of Plutella xylostella. Chinese J. Appl. Entomol. 48: 267–272.

Received 14 August 2013; accepted 1 April 2014.