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Seasonal Abundance of *Liriomyza sativae* (Diptera: Agromyzidae) and its Parasitoids on Vegetables in Southern Vietnam

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The vegetable leafminer *Liriomyza sativae* is an economically important pest of a wide variety of vegetable and ornamental crops in tropical Asian countries, but information on the relative abundance of the leafminer and its parasitoids is still limited. Field surveys were conducted through the year (from June 2005 to June 2006) in three commercial vegetable fields in Ho Chi Minh City, southern Vietnam with the aim at monitoring the relative abundance of the leafminer and its parasitoids. Both adult and larva *L. sativae* were present in the vegetable fields throughout the year. The abundance of *L. sativae* on yardlong bean and kidney bean was relatively low in the beginning of growing seasons but the infestation became more serious in the end of the seasons. In contrast, the leafminer on cucumber and okra was highly abundant throughout the seasons. The abundance of parasitoids showed a similar tendency to that of the leafminer. The most frequent parasitoid species associating with *L. sativae* on yardlong bean, kidney bean and okra was *Asecodes delucchii*. *Neochrysocharis beasleyi* and *N. formosa* were common on garden cucumber and okra. The relative abundance of *L. sativae* and its associated parasitoids was influenced by seasonal climate, cropping schedules and pesticide applications. Hence, leafminer control strategies must be developed in a manner to conserve these parasitoid species by reducing the use of broad–spectrum insecticides and by applying some cultural control measures such as crop rotation and non–crop vegetation.

INTRODUCTION

Native to the North America, *Liriomyza sativae* (Blanchard) (Diptera: Agromyzidae) is widespread worldwide but mostly occurs in the temperature regions including South East Asian countries (Spencer, 1973; Murphy and LaSalle, 1999). Recently, *L. sativae* has been also recorded from China (Zhao and Kang, 2000) and Japan (Iwasaki *et al*., 2000). In Japan, *L. sativae* was found for the first time in 1999 in Kyoto and Yamaguchi Prefectures (Iwasaki *et al*., 2000). This species has quickly spread and become a serious pest of vegetable and ornamental crops in the fields and greenhouses. This rapid spread was mainly caused by transportation of plant materials for greenhouses and plastic tunnels. In northern areas beyond latitude 34°N in China, *L. sativae* can not overwinter in the outdoors (Zhao and Kang, 2000).

In Vietnam, *L. sativae* is an economically important pest of a wide variety of vegetable and ornamental crops in the open fields (Andersen *et al*., 2002; Tran *et al*., 2005a, b). Recent outbreaks of the leafminer were treated by a wide range of conventional insecticides, but control was unsatisfactory (Johansen *et al*., 2003; Tran and Takagi, 2005). Frequent applications of these broad spectrum insecticides can adversely affect parasitoid abundance in the vegetable agro–ecosystems (Saito *et al*., 1996; Johansen *et al*., 2003), can promote the development of pesticide resistance within fly populations (Keil *et al*., 1985, Johansen *et al*., 2003; Hofsvang *et al*., 2005) and frequently lead to an increase in leafminer density (Oatman and Kennedy, 1976; Murphy and LaSalle, 1999).

Agromyzid leafminers are known to have rich natural enemy communities. Eighteen species of hymenopteran parasitoids have been recovered from *Liriomyza* leafminers in central and southern Vietnam. Among them, *Neochrysocharis beasleyi* Fisher & LaSalle, *Neochrysocharis okazakii* Kamijo, *Neochrysocharis formosa* (Westwood) and *Asecodes delucchii* (Bouček) (Hymenoptera: Eulophidae) are numerically dominant species (Tran *et al*., 2006). They have played a very important role in leafminer suppression in natural ecosystems and cultivated areas with reduced insecticide use (Johnson *et al*., 1980; Murphy and LaSalle, 1999).

The objectives of this study were to survey damage caused by *L. sativae* in two important vegetable–growing areas of the Ho Chi Minh City, southern Vietnam, and to monitor the seasonal abundance of the leafminer and its parasitoids. In this paper, the seasonal occurrence of *L. sativae* in Vietnam and Japan was also discussed.

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MATERIALS AND METHODS

Surveys were carried out through the year (from June 2005 to June 2006) in the two commercial vegetable fields (F1 and F2) at Xuan Thoi Commune, Hoc Mon District and one field (F3) at Tan Thong Commune, Cu Chi District, Ho Chi Minh City, Vietnam. In generally, local varieties of vegetables were planted using standard local practices. The cropping schedules of these fields were in Table 2. In F1, yardlong bean (*Vigna unguiculata* (L.) Walp. spp.), kidney bean (*Phaseolus vulgaris* L.) and cultivated radish (*Raphanus sativirus* L.) were planted from May 2005 to February 2006. Okra (*Abelmoschus esculentus* L.), kidney bean (*Phaseolus vulgaris* L.) and cauliflower (*Brassica oleracea* var. *botrytis* (L.)) were planted from June 2005 to February 2006 in F2. There were no crops in F1 and F2 at the duration of March–May 2006. In F3, garden cucumber (*Cucumis sativus* L.), kidney bean, cultivated radish and yardlong bean were planted from May 2005 to May 2006. Growers applied pesticide treatments to control insect pests, including leafminers,

Table 1. Monthly temperature, relative humidity (RH) and rainfall in Ho Chi Minh City for the period April 2005–June 2006

Month 2005/2006	Temperature (°C)			RH (%)		Rainfall (mm)		
	Average	Max	Min	Average	Min	Total	Max	No. rainy days
April	29.8	35.8	27.2	70	38	10.0	10.0	1
May	29.7	38.2	24.0	74	42	143.6	33.1	17
June	28.9	34.8	26.1	77	45	269.0	114.0	17
July	27.4	33.0	25.2	81	51	228.0	64.0	22
August	28.4	33.8	25.8	78	50	146.0	29.0	18
September	27.9	32.9	25.6	80	48	184.0	56.0	20
October	27.6	33.1	25.3	82	54	389.0	73.0	24
November	27.5	33.5	25.0	79	46	265.0	64.0	17
December	26.2	34.7	19.8	77	49	105.4	22.5	17
January	27.2	32.4	24.6	73	36	0.0	0.0	0
February	28.2	32.9	25.3	68	40	73.0	66.0	6
March	28.6	34.2	25.9	71	26	9.0	5.0	3
April	29.5	35.1	26.8	73	40	212.0	148.4	9
May	28.9	34.8	26.1	77	47	269.0	102.4	19
June	28.4	33.7	25.8	81	51	139.0	18.2	24

Table 2. Insecticides applied to vegetable crops in surveyed fields (to be continued)

Field	Crop	Planting	Insecticides	
			Formulation	Trade name
F1	Yardlong bean	5/31/2005	Chlorfluazuron	Atabron 5EC
			Cyromazine	Trigard 75WP
			Fipronil	Regent 5SC
			Permethrin	Peran 10EC
			Pyridaphenthion	Ofunak 40EC
	Kidney bean	9/3/2005	Abamectin	Tapky 1.8 EC
			Fipronil	Regent 5SC
			Permethrin	Peran 10EC
			Phenthoate + Etofenprox	Vicidi–M 50ND
	White radish	11/19/2005	Abamectin	Tapky 1.8 EC
			Chlorfluazuron	Atabron 5EC
			Fenobucard + Phenthoate	Hopsan 75ND
			Fipronil	Regent 5SC
			Permethrin	Peran 10EC
			Phosalone + Cypermethrin	Shersol EC
F2	Okra	6/13/2005	Chlorfluazuron	Atabron 5EC
			Imidacloprid	Admire 50EC
			Imidacloprid	Confidor 100SL
			Permethrin	Peran 10EC
	Kidney bean	9/18/2005	Abamectin	Tapky 1.8 EC
			Chlorfluazuron	Atabron 5EC
			Fipronil	Regent 5SC
			Fipronil	Regent 5SC
			Permethrin	Peran 10EC
			Phenthoate	Vifel 50ND
			Phenthoate + Etofenprox	Vicidi–M 50ND

Table 2. Insecticides applied to vegetable crops in surveyed fields (continued)

Field	Crop	Planting	Insecticides	
			Formulation	Trade name
F2	Cauliflower	12/24/2005	Abamectin	Tapky 1.8 EC
			Chlorfluazuron	Atabron 5EC
			Fipronil	Regent 5SC
			Fipronil	Regent 5SC
			Permethrin	Peran 10EC
			Phenthoate	Vifel 50ND
			Phenthoate + Etofenprox	Vicidi–M 50ND
F3	Cucumber	6/22/2005	Indoxacarb	Ammate 150SC
			Imidacloprid	Confidor 100SL
	Kidney bean	8/27/2005	Abamectin	Vibamec 1.8EC
			Chlorpyrifos Ethyl	Pyrynex 20EC
			Fenitrothion + Trychlofon	Ofatox 400EC
			Fipronil	Regent 5SC
			Imidacloprid	Confidor 100SL
			Indoxacarb	Ammate 150SC
			Methamidophos	Minitor 50EC
			Methomyl	Lannate
			Nereistoxin + Imidacloprid	Dihet
			Thiamethoxam	Actatra 25WG
	White radish	12/17/2005	Fipronil	Regent 5SC
			Methomyl	Lannate
			Chlorfluazuron	Atabron 5EC
	Yardlong bean	3/1/2006	Dimethoate + Cypermethrin	Vifenva 20ND
			Acepphate	Binhmor 40EC
			Thiamethoxam	Actatra 25WG
			Indoxacarb	Ammate 150SC
			Methomyl	Lannate
			Ethofenprox	Trebon 20EC

thrips, hoppers and caterpillars (Table 2). The vegetable fields were monitored 2–4 times per month through the growing season by collecting 30 leafminer–infested leaves at random. Leaves were placed in plastic bags labeled with the name of location and date. Samples were placed in an ice chest and brought into the laboratory. Sampled leaves were examined under a microscope to count the number of mines, live and dead larvae present. Because parasitoid larvae are more difficult to detect reliably than leafminer larvae, we relied on adult emergence to estimate parasitoid numbers. Infested leaves were held individually in plastic containers (15 cm×25 cm) with (8 cm×12 cm) rectangular holes covering with fine mesh screen for air ventilation. Containers were lined with moist paper. Samples were maintained at room temperature and daily supplied with some drops of water for maintaining appropriate humidity in the containers. The infested leaves were checked daily for both leafminer and parasitoid emergence. Percentage parasitism was calculated as adult parasitoids emerged/ (live leafminer larvae+dead leafminer larvae)×100. This method gave a slight underestimate of percentage parasitism, as it did not take juvenile parasitoid mortality into account (Bjorksten *et al*., 2005).

Additionally, farmer surveys were carried out in the same fields to determine the frequency and kinds of pesticides used. Daily weather data were available during the study period from Tan Son Hoa weather station located at Ward No.1, Ho Chi Minh City (Table 1).

RESULTS

Insecticide application

The commercial fields sampled during 2005 and 2006 received multiple insecticide applications for control leafminers, thrips, leafhoppers and caterpillars (Table 2). The yardlong bean crop required 6 and 10 insecticide applications in F1 and F3, respectively. On kidney bean, insecticides were applied 5, 8 and 9 treatments in F1, F2 and F3, respectively. Although growing duration was short (approximately 2 months), cultivated radish and cauliflower required many insecticide applications (9–10 times) in these three fields. There were four insecticide sprays on okra crop in F2 and 6 applications on garden cucumber in F3 (Fig. 1, 2, 3).

Seasonal abundance of leafminer

Liriomyza sativae was present in the vegetable fields throughout the year. Infestations of *L. sativae* were serious during the dry season, and most severe were in the end of the growing seasons. The abundance of *L. sativae* on F1 and F2 was low at the beginning of the growing season in June 2005, then increased consistently over July and the beginning of August, and the number of mines, live larvae and emerged flies reached values of 230.6, 93.1 and 21.8, and 8.7, 2.4 and 2.2 per one infested leaf in F1 (yardlong bean) and F2 (okra), respectively (Fig 1A, B; Fig. 2A, B). Leafminer densities remained relatively high until the end of the growing season (the end of August). There was similar tendency

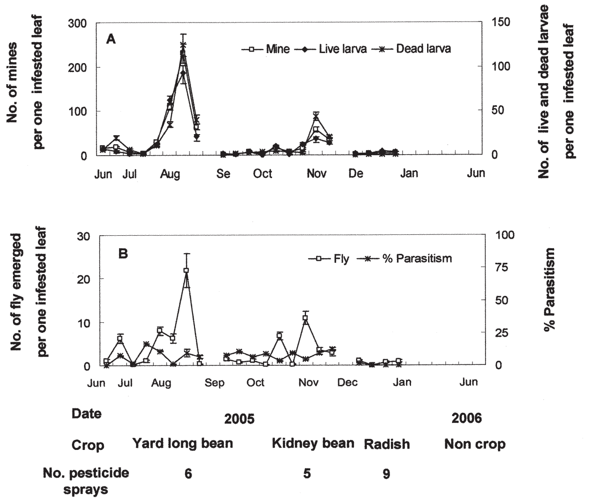

Fig. 1. Seasonal abundance of *L. sativae* and its parasitoids in the field 1 (F1). (A) mean±SE of mines, live and dead larvae; (B) emerged leafminer flies and percentage parasitism.

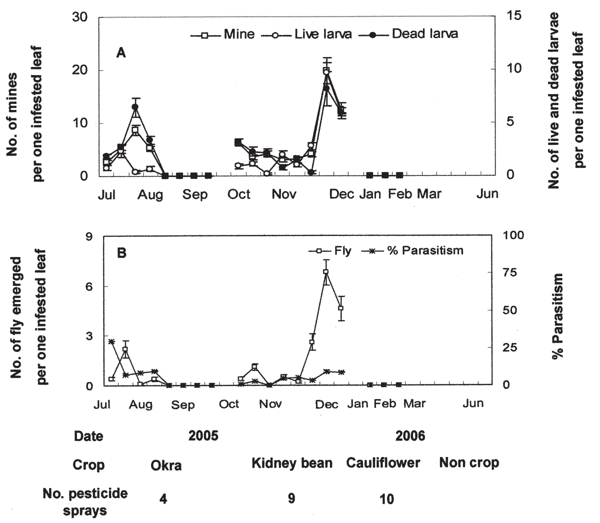

Fig. 2. Seasonal abundance of *L. sativae* and its parasitoids in the field 2 (F2). (A) mean±SE of mines, live and dead larvae; (B) emerged leafminer flies and percentage parasitism.

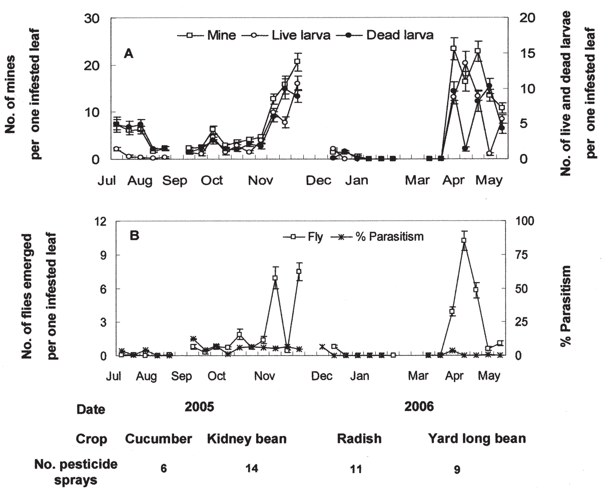

Fig. 3. Seasonal abundance of *L. sativae* and its parasitoids in the field 3 (F3). (A) mean±SE of mines, live and dead larvae; (B) emerged leafminer flies and percentage parasitism.

in leafminer population dynamics on the second crop (kidney bean) in F1 and F2. Beginning at 2 months after sowing, leafminer populations showed a slow increased with a peak at the end of November (58.5 mines, 18.2 live larvae and 10.9 emerged flies, and 19.8 mines, 9.7 live larvae and 6.8 emerged flies per one infested leaf collected from F1 and F2, respectively). Leafminer population was very low on the third crop (cultivated radish) in F1, and no leafminer was found on cauliflower in F2 (Fig 1A, B; Fig. 2A, B).

In contrast, the abundance of *L. sativae* on F3 was high at the beginning of the growing season (garden cucumber) in July 2005 and remained relatively high until late August after which population decreased until the last two sampling dates (Fig. 3A, B). On the second crop (kidney bean), leafminer dynamics showed a similar trend to F1 and F2 but the density did not decrease toward the end of the growing season. Leafminer population was very low on cultivated radish planted from December 2005 to February 2006. Yardlong bean was planted in F3 as an extensive crop in the dry season (March–May 2006). Leafminer population was remained relatively high during the season.

Seasonal abundance of parasitoids

In generally, the abundance of parasitoids was low throughout the growing seasons. In F1, percentage parasitism of *L. sativae* on yardlong bean reached a peak of 16.7% in the end of July, then maintained low (around 7–9%) for the two last samplings. On kidney bean, parasitoids were recorded in the beginning of the growing season, and parasitism was steady at a range from 4 to 12% throughout the season (Fig. 1B). In F2, percentage parasitism of *L. sativae* on okra was high in the first sampling (29.6%), decreased to about 7–9% for the next three samplings, then declined in the last four samplings. Parasitism was very low in the beginning of kidney bean growing season (0.8%), then increased and maintained high until the end of the season (around 9%) (Fig. 2B). In F3, parasitism was low on cucumber with a peak of 3.8% at the beginning of August. Percentage parasitism on kidney bean was high in the first sampling (12.2%), then decreased and maintained at a range from 2 to 7%. On yardlong bean, parasitism was very low and reached a peak of 3.4% in April 2006 (Fig. 3B). While some parasitoids were reared from infested leaves of radish in F3 (Fig. 3B), no parasitoids were collected from radish and cauliflower crops in F1 and F2 (Fig. 1B, 2B).

In three sampled fields, *A. delucchii* was the most dominant parasitoid emerged from *L. sativae* on yardlong bean (F1, 97.5%; F3, 85.7%), kidney bean (F1, 98.8%; F2, 100%; F3, 59.6%) and okra (F2, 43.9%). *Neochrysochris beasleyi* was an abundant species on garden cucumber (F2, 16.7%), and *N. formosa* was the second most abundant species on okra (F2, 22.8%) (Table 3).

Table 3. Relative abundance (%) of parasitoid species reared from leafminer–infested leaves of various vegetables in Ho Chi Minh City

Field	Plant	*A. delucchii*	*N. beasleyi*	*N. formosa*	Other species	Total no. of emerged adults
F1	Yard long bean	97.5	0.3	0.8	1.5	797
	Kidney bean	98.8	0.3	0.3	0.6	343
	Cultivated radish	0.0	0.0	100.0	0.0	1
F2	Okra	43.9	8.8	22.8	24.6	57
	Kidney bean	100.0	0.0	0.0	0.0	86
F3	Garden cucumber	0.0	16.7	0.0	83.3	6
	Kidney bean	59.6	6.4	6.4	25.5	47
	Cultivated radish	0.0	0.0	0.0	100.0	2
	Yard long bean	85.7	0.0	0.0	14.3	7

DISCUSSION

Currently, *L. sativae* has been well established on many vegetable crops throughout Vietnam and become one of the most important pests on garden cucumber, yardlong bean and kidney bean in Ho Chi Minh City (Andersen *et al.*, 2002; Tran *et al.*, 2005a, b, 2006). The occurrence and relative abundance of leafminers in relation to seasons and host plants may reflect the impacts of climate, their distinct preference for host plants, pesticide applications, and parasitoids (Parrella, 1987; Saito et al., 1996; Murphy and LaSalle, 1999; Johansen *et al.*, 2003).

In southern Vietnam, *L. sativae* can be present in the fields throughout the year. In general, the densities of *L. sativae* larvae were low in the rainy season and increased in the dry season. This result is consistent with our previous study indicating that the density of *L. sativae* on garden cucumber is very low in the rainy season and high in the dry season in Ho Chi Minh City (Tran *et al.*, 2005a). Previous survey on tomato in Indonesia has also shown that infestations of *L. hudobrensis* during the rainy season are generally low, and occur heavily in the end of the dry season (Rauf and Shepard, 1999). In Japan, in contrast, the occurrence of *L. satiave* in the fields is only from April to October (Fukuhara, pers. commun.). In winter, *L. sativae* can overwinter outdoors (Zhao and Kang, 2000). In the greenhouses, *L. sativae* can be present throughout the year, but the most abundant is from July to October (Sasaki and Nakamura, 2005). Therefore, the leafminer management must be focused on destroying leafminer sources from the last crops or overwinter by field sanitation or soil fumigation as well as by controlling the leafminer population in the fields and greenhouses.

Although the host range of *L. sativae* is extremely broad and diverse (Andersen *et al.*, 2002; Tran *et al.*, 2006), the leafminer exhibits host plant preference (Zhao and Kang, 2003; Tokumaru and Abe, 2005). Our field surveys indicated that *L. sativae* populations on yardlong bean and kidney bean were higher than those on garden cucumber and okra, and there were no *L. sativae* developing on cauliflower, and very low population of the leafminer on cultivated radish. These results are consistent with a previous study indicating that kidney bean, eggplant (*Solanum melongena* L.) and garland chrysanthemum (*Chrysanthemum coronarium* L.) were more suitable for *L. sativae* development than okra, tomato (*Lycopersicon esculentum* Mill.) and garden cucumber, no leafminer could develop on cultivated radish, and the leafminer preferably oviposited into the kidney bean (Tokumaru and Abe, 2005). Many factors affect the host plant preference of *Liriomyza* leafminers. The distribution and density of leaf trichomes, as well as the nutritional status of host plant, were found to be important in host selection (Fagoonee and Toory, 1983; Knodel–Montz *et al.*, 1985; Minkenberg and Ottenheim, 1990). More recently, Zhao and Kang (2003) determined that *L. sativae* antennae selectively responded to host plant odors. The most distinct responses were elicited by bean and tomato plants. If plant characteristics are dominant, then insects should maximize their fitness by ovipositing on plants on which larvae perform best (Gratton and Welter, 1998). It is considered that some cultural control measures (e.g. cropping rotation, trap crops, intercropping) are strategies for controlling the leafminer.

In three sampled fields, kidney bean was planted as a second crop of the cropping schedules. *Liriomyza sativae* populations were low in F1, but relatively higher in F2 and F3. It is unclear whether the different abundance of the leafminer is due to difference in pesticide usage or copping rotation. The use of crop rotation allows vegetable growers to diversify crop production and to reduce the likelihood of pest build–up due to continuous cropping. Plants belonging to the same or closely related taxonomic groups are likely to share the same pests. This may result in the year–round maintenance of the pest populations, but also the population of their natural enemies (Schroth *et al.*, 2000). The distribution of leafminer parasitoid species and their abundance are varied and strongly influenced by vegetable host plants (Johnson and Hara, 1987; Murphy and LaSalle, 1999). Our study shown that *A. delucchii* was the most abundant parasitoid species of *L. sativae* on yardlong bean and kidney bean. Thus, continuously planting kidney bean as a second crop in the cropping schedule of F1 could maintain these parasitoids from the last growing season (yardlong bean) that played an important role in suppressing the leafminer population.

Tran *et al.* (2006) reported 18 parasitoid species associated with *Liriomyza* leafminers on vegetable crops in central and southern Vietnam, including 9 species on yardlong bean and 6 species on French (kidney) bean. Seven parasitoid species were found associating with *L. sativae* on garden cucumber in Ho Chi Minh City (Tran *et al*., 2005a). The parasitoid species composition of *L. sativae* on each host plant was not investigated in this study, but the relative abundance of main species was determined (Table 3). *Asecodes delucchii* was the most abundant on yardlong bean and kidney bean. This species was a Palaearctic parasitoid found recently in Southeast Asia (Joshi, 2001), and was the most abundance parasitoid species of *Liriomyza* leafminers on kidney bean and the third most abundant parasitoid of the leafminers on yardlong bean (Tran *et al*., 2006). In Japan, *A. delucchii* was recorded associating with *L. trifollii* in bean (Arakaki and Kinjo, 1998). Thus, the plant species belonging to the family of Fabaceae may be preferred by *A. delucchii*. Our result suggests that this parasitoid can be nominated as a potential agent for biological control of *L. sativae* by augmentation or conservation on bean crops. It richly deserves further studies with respect to its biology and ecology.

Of the field practices investigated, pesticide application (e.g. type and frequency) was the most important factor affecting populations of the leafminer and its parasitoids. Conventional chemical insecticides including broad–spectrum synthetic insecticides, which were widely used in our fields, could kill insect pests, but also kill more natural enemies. Parasitoids were common in the beginning of the growing seasons of yardlong bean (F1) and okra (F2), but rare or absent on garden cucumber (F3). It seems likely that non insecticide application in the non–crop duration (March–May) was safely for parasitoids to maintain their populations in F1 and F2, and late insecticide treatments in the last crops of F3 prevented the establishment of parasitoid population on garden cucumber. Toxicological studies showed that most leafminer parasitoids are susceptible to broad–spectrum insecticides (Saito *et al*., 1996; Tran *et al*., 2004, 2005c). *Liriomyza sativae* is able to develop resistance to several insecticides (e.g. cypermethrin, fenvalerate, permethrin) (Mason *et al*., 1987; Johansen *et al*., 2003). Frequent applications of these insecticides can lead to an increase in leafminer density (Murphy and LaSalle, 1999). Hence, a leafminer control strategy must be to learn to conserve these parasitoid species by reducing the use of broad–spectrum insecticides.

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