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Population densities, spatial pattern and development of the pea leafminer (Diptera: Agromyzidae) on cucumber, swisschard and bean

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SUMMARY

Liriomyza huidobrensis, the pea leafminer, is a recently identified pest on vegetables in Lebanon. The objectives of this study were to survey the leafminer infestation, to study its dispersion and its development on cucumber, swisschard and bean. In general, the infestation level was found to be higher in the middle coastal sites than in the other sites during the period of the study 1994–95. In the former sites, the pest was found to thrive on swisschard in October and November, in presence of cucumber under greenhouses, while it was encountered in significantly higher numbers on cucumber during the spring season, in absence of swisschard. Pairwise comparisons of Taylor's and Iwao's regression slope for *L. huidobrensis* larval mines indicated a contagious dispersion on leaves of cucumber and bean, while the pattern was random to slightly aggregated on swisschard. There was a significantly higher number of larval mines on the lower plant stratum compared to the middle and upper strata of cucumber through the cropping season. There was a significant difference in the overall development duration (19·6–22·3 days) of the insect among the three hosts. The larval development duration was significantly shorter on bean compared to swisschard and cucumber consecutively. However, there was no significant difference in egg or pupa duration among the three hosts. Results of this study provide bases for appropriate management of the pest, taking into consideration its infestation level, spatial pattern, and development duration on the mentioned hosts.

INTRODUCTION

The pea leafminer, *Liriomyza huidobrensis* (Blanchard), as identified during this study by the Centre for Agriculture and Bioscience (CAB) – International Institute of Entomology (IIE) in London, is a non-indigenous species to Lebanon and was most probably introduced on imported material. *L. huidobrensis* is considered to be a nearctic or neotropical species (Spencer 1973). This new species has quickly become a pest on a large number of economic crops. The introduction of *L. huidobrensis* was not an isolated incident but was related to the invasion of the same pest in other countries like Syria and Israel (Weintraub 1995). This was preceded in the late '80s by the invasion of this pest to European countries such as the UK, France, Italy, Belgium and the Netherlands (Sunderlands *et al*. 1992). *L. huidobrensis* was reported in Israel as an extremely proliferous insect pest, difficult to control and more damaging than the previously introduced *Liriomyza trifolii* (Burgess) (Weintraub 1995).

The economic impact of *Liriomyza* leafminers has been considerable throughout the world. The movement of *L. huidobrensis* along with *L. trifolii* within infested plant material has caused a worldwide problem (Parrella 1987). *L. huidobrensis* that had a relatively limited distribution can now be considered a cosmopolitan and major pest on numerous ornamental and vegetable crops almost everywhere (Parrella 1987). The host plant can be of great influence on the population growth of leafminers. *L. huidobrensis* is found to attack different plant families in different subclasses (Spencer 1990). This pest has a wider host range than its closely related species *L. trifolii*; it feeds on eggplant, cucumber, endive, lettuce, celery and tomato as well as on *Chrysanthemum*, *Carthamum*, *Exacum*, *Gypsophila* and many weeds (Sunderlands *et al*. 1992).

Several characteristics associated with *L. huidobrensis* suggest that it may be the most serious

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leafmining pest. Its larvae feed within lower mesophyll layers and hence have a greater impact on leaf photosynthesis than mining in the upper mesophyll layers (Parrella *et al.* 1985). Its mines are normally associated with the midribs of mature trifoliates and with mature petioles; vegetative products with aesthetically unacceptable mines represent a direct yield loss to leafy vegetables (Spencer 1981).

The purpose of this study is to determine the level of infestation of the pest, its spatial pattern, and its development on the economic edible crops: cucumber, swisschard and bean.

MATERIALS AND METHODS

Determination of leafminer status and its spatial pattern

Eighteen farms from the coastal and inland (Beqaa) regions of Lebanon were selected, to document the occurrence of *L. huidobrensis*, its infestation level and its within-canopy spatial pattern.

Study sites

Farms from each of the middle, north and south coastal areas, central Beqaa, and north Beqaa were selected. Surveyed crops included cucumber *Cucumis sativus* L. in greenhouses, swisschard *Beta vulgaris* var. *Cicla*, and bean *Phaseolus vulgaris* L. in the field. The extensive type of sampling (Buntin 1994; Southwood 1978) was followed; two to three visits per season were made to each farm for sampling the larval stage of the pest. The study covered two cropping seasons for cucumber, autumn (September–December 1994) and spring (March–June 1995), in 12 coastal sites. However, the study covered only one cropping season (September–December 1994) for cucumber in central and north Beqaa (three sites in each area), as it is the main season for cucumber in this region. Field swisschard was sampled during the cropping season (September 1994–January 1995) from three sites in each of the middle and south coastal areas only, as this crop is not suitable for growing in the semi-arid climate of the inland region. Field bean sampling was performed at three sites in each of the middle and south coastal areas, and north Beqaa during the autumn (September–December 1994).

Greenhouse cucumber sampling

Leaf sampling was divided into two types according to the age of the crop. Plants with six true leaves, during the first month of each cropping season, were sampled by taking one leaf every one metre within a row and every other row; a total of 90 leaves were collected from each greenhouse ($50 \times 9 \times 4$ m) at one sampling date. Plants with more than six leaves were sampled by taking one leaf from each of the following plant strata: low (0–60 cm), middle (60–100 cm), and upper (> 100 cm); 90 leaves were sampled from each stratum at one sampling date. Samples were put in plastic bags in a cooler and were taken to the laboratory for further study.

Bean and swisschard field sampling

Plots of 500 m^2 were selected for sampling from each farm. Leaf sampling was performed by walking diagonally in each plot and removing one leaf (swisschard) or trifoliate (bean) every one metre. Sixty-four leaves were collected from each farm at one sampling date. Samples were put in plastic bags in a cooler and were transported to the laboratory for further study.

Data collection

Cucumber, swisschard and bean leaves were checked directly after sampling for larval mines using a $20\times$ hand lens. Total number of mines on each leaf was recorded from both upper and lower leaf surfaces. Larval mines were classified in three categories: large (> 2·5 cm length), medium (1–2·5 cm), and small (< 1 cm) mines. Mines containing larvae as well as empty mines were counted for the three categories.

Statistical analysis

Data were analysed using the MSTAT package (MSTATC 1991). Population density of the leafminer was represented by the sample mean for total number of mines per leaf of each crop. Data were transformed into $\log(x+1)$, x is number of mines per cucumber or bean leaf. Analysis of variance (ANOVA) was performed over the two factors: site and sampling date, to compare the level of infestation on cucumber or bean over different sites of the country at different periods of the year. ANOVA-1 was performed over the factor, plant stratum, to determine the distribution of the leafminer within cucumber canopy, during September–November 1994 from 18 sites in the coastal and inland regions. All means were separated by Fisher's (1949) least significant difference (LSD) test if significant F values were obtained (Gomez & Gomez 1984).

The inherent variability, represented by the variance (s^2), in a set of samples was used to provide important information on the spatial distribution or dispersion of the leafminer population within the plant. The low variability in sample counts from a regularly dispersed population results in a sample variance that is smaller than the sample mean. The mean would be equal to the variance in a randomly dispersed population, while in an aggregated population the sample variance exceeds the mean (Taylor 1961; Taylor *et al.* 1978). Taylor's power law relates variance to mean density such that:

$$\log s^2 = b \log \bar{x} + \log a$$

where the slope (b) is an index of aggregation and a is a computing factor related to sample size (Taylor 1961, 1984).

Mean crowding (Lloyd 1967) is another index that can be used to indicate the possible effects of mutual interference or competition (Davis 1994) within the pea leafminer population. Mean crowding (x^*) is highly dependent upon both the degree of clumping and population density and is calculated as follows:

$$x^* = \bar{x} + \frac{s^2}{\bar{x}} - 1$$

The index of patchiness (Lloyd 1967) expressed as the ratio of mean crowding to the mean was also calculated to describe the leafminer's spatial pattern; the latter might be regular if the ratio is less than one, random if the ratio is equal to one or aggregated if the ratio is greater than one. Regression relationship between Lloyd's mean crowding parameter and mean density was analysed according to Iwao's (1968) method. Taylor's power law (Taylor 1984) and Iwao's mean crowding-mean regression (Iwao 1968) were used to model the variance to mean relationships and to evaluate dispersion of the leafminer larval mines within the canopy of each crop. The Student's *t*-test was further used to test the null hypothesis that slopes of the regression equations from the two models were equal to 1; where a slope of 1 indicates a random distribution and a slope > 1 indicates aggregation (Steel & Torrie 1960).

Leafminer development experiment

Insect and plant material

A leafminer colony was established for approximately five months before initiation of the biological study, from collected infested field swisschard leaves. The study was performed in a glasshouse compartment, under controlled conditions of 28 ± 3 °C, 70 ± 20 % relative humidity and a photoperiod of 14:10 (L:D) h on swisschard, cucumber and bean plants. Varieties that were used in the experiment included a local variety of swisschard 'Baladi', bean variety 'Primo' (local supplier, Debbane Freres; source: Ferry-Morse, USA) and cucumber variety 'Fatima' (local supplier, Amalia Ltd.; source: AgrEvo, Holland). Seeds were planted in a potting soil mixture (sand: peatmoss:soil, 1:1:1). Seedlings were transplanted to pots (12 cm diameter) and were placed in insect-proof cylindrical plastic cages (30×20 cm diameter). Aeration of the cage was provided by cutting a disk (17 cm diameter) out of the cage lid and replacing it with a plastic net of 270×770 microns mesh size. Bean and cucumber plants with three true leaves and swisschard plants with two true leaves were selected at the initiation of this study. Cotyledonary leaves were trimmed on bean and cucumber plants.

Data collection

Thirty-eight plants were individually exposed to one adult female leafminer. Each adult was aspirated from the colony and was transferred to a cylindrical plastic cage, in which it was allowed 12 h to oviposit. Data on the development of the immature stages on the three hosts were collected by monitoring one mine on each plant. Larval duration was considered as the period from egg eclosion to emergence from leaves for pupation. Each plant was checked for egg hatch, larva and pupa development every 24 h during the experiment.

Statistical analysis

Data was analysed by the MSTAT package (MSTATC 1991). The experiment was laid out as a completely randomized design. ANOVA-1 for each of the egg, larva, and pupa duration was performed over the host plant as a factor. Means were separated by Fisher's (1949) LSD test if significant *F* values were obtained (Gomez & Gomez 1984).

RESULTS AND DISCUSSION

Liriomyza huidobrensis was the only leafminer species documented from the different regions on cucumber, swisschard and bean as well as on other crops like tomato, squash, pepper and eggplant that were occasionally sampled during the study.

Cucumber stratification sampling effect

Data analysis for cucumber in the autumn cropping season indicated that significant differences were observed in the number of leafminer larval mines per leaf among the different leaf strata ($P < 0{\cdot}01$). Larval mines were encountered in significantly higher numbers at the lower stratum than at the middle and upper ones. However, there was no significant difference in number of mines per leaf between the middle and upper strata (Table 1). Similarly, Lynch & Johnson (1987) found significantly greater densities of *Liriomyza sativae* Blanchard and *L. trifolii* larvae at the plant base of watermelon as compared with the distal end of the vine, in a study to evaluate the accuracy of random compared to stratified sampling of watermelon foliage. Hanna *et al.* (1987) also reported the mean number of 8·2, 6·8 and 4·9 mines per leaf of snap bean at the low, middle and upper leaf zones respectively. Thus, results of the stratification sampling experiment have led to the incorporation of data on the low plant stratum only for determination of the population density and the spatial pattern of the leafminer on cucumber.

Population densities

Analysis of data collected from cucumber planted in greenhouses of the coastal and inland regions during the fall season indicated a significant difference in number of mines per leaf among studied areas ($P < 0{\cdot}05$). The highest infested sites were in the

Table 1. *Distribution of* Liriomyza huidobrensis *within cucumber canopy in greenhouses* (*number of mines per leaf** ± S.E.)

Sampling date	Plant strata† Lower	Middle	Upper
September 1994	8·27 ± 1·77[a]	0·18 ± 0·07[b]	0·01 ± 0·07[b]
October 1994	8·75 ± 3·48[a]	0·26 ± 0·07[b]	0·03 ± 0·02[b]
November 1994	12·41 ± 3·09[a]	0·39 ± 0·19[b]	0·05 ± 0·03[b]

* Values represent the means at each sampling date and their standard errors (51 D.F.). Means followed by the same letter within a row are not significantly different (LSD, $P > 0·01$).
† Plant strata with corresponding distance from plant base (cm): lower (0–60), middle (60–100), and upper (> 100).

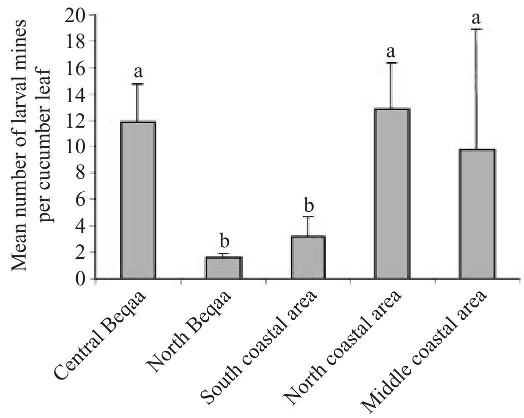

Fig. 1. Survey of *Liriomyza huidobrensis* on greenhouse cucumber at 18 sites of the coastal and inland regions in Lebanon during the autumn season (September, October and November 1994). Means designated by a common letter do not differ significantly (error D.F. = 39; LSD, $P > 0·05$).

middle and north coastal areas, and central Beqaa (Fig. 1). The middle coastal area was further found to be more infested in the spring season than during the autumn season ($P < 0·05$) (Fig. 2). This could be explained by the availability of swisschard extensively during the autumn season, in which it was found to be highly infested by the leafminer followed by greenhouse cucumber and bean consecutively (Table 2);

Table 2. *Survey of* Liriomyza huidobrensis *on greenhouse cucumber, field swisschard and bean in the middle coastal area* (*intensive agricultural area*) *of Lebanon during September and October 1994* (*mean number of mines per leaf* ± S.E.)

Crop	September 1994	October 1994
Cucumber	8·00 ± 9·45	18·0 ± 3·32
Swisschard	25·0 ± 15·2	45·0 ± 8·72
Beans	15·0 ± 6·73	10·0 ± 1·52

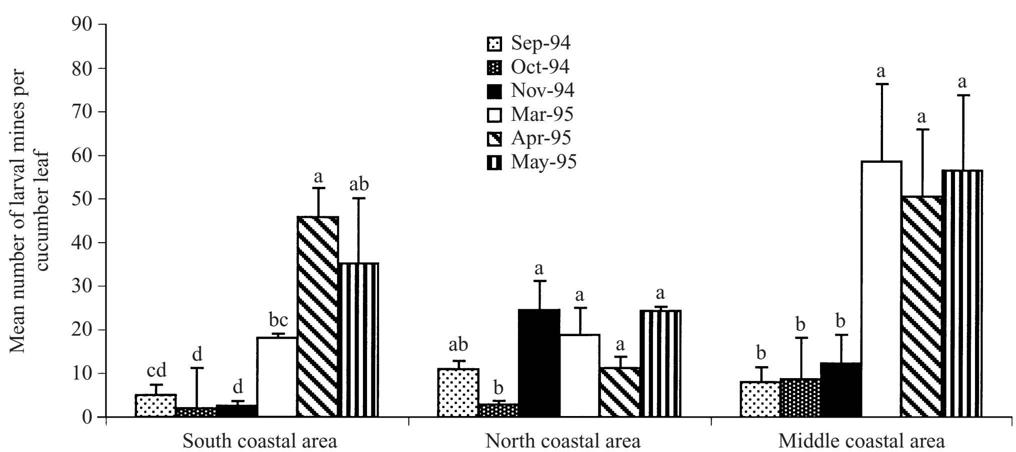

Fig. 2. Survey of *Liriomyza huidobrensis* on greenhouse cucumber at 12 coastal sites in Lebanon during a period of 6 months in 1994–95. Means designated by a common letter within each area do not differ significantly (error D.F. = 54; LSD, $P > 0·05$). The six different patched boxes represent sampling dates in September, October, November 1994, March, April and May 1995.

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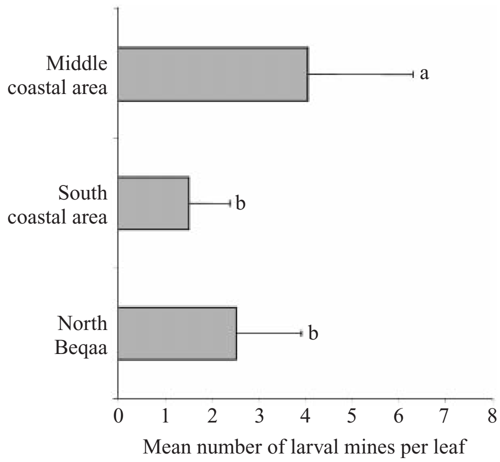

Fig. 3. Survey of *Liriomyza huidobrensis* on beans at nine sites of the coastal and inland regions in Lebanon during autumn 1994. Means designated by a common letter are not significantly different (error D.F. = 12; LSD, $P > 0{\cdot}05$).

though the predominantly warm and sheltered greenhouse environment and the abundant high-quality food supply can lead to a rapid increase in leafminer populations. The general reduction in population density of the leafminer on cucumber in September and October 1994 (Fig. 2) could be related to the high average maximum daily temperatures that were found to be 31·2 and 29·7 °C, respectively. While the temperature was 19·4, 26·6 and 27·7 °C for March, April and May 1995, respectively (Faculty of Engineering and Architecture (FEA) – Weather Station (WS), American University of Beirut (AUB)). Temperature was found to have a direct effect on the growth rate of the leafminer population. Minkenburgh & van Lenteren (1986) reported reductions in population levels of *Liriomyza bryoniae* (Kaltenbach) and *L. trifolii* when the maximum daily temperature rose to 40 °C. However, the maximum daily temperature in the present study did not exceed 31·2 °C and still a reduction in the population of the pea leafminer was observed as the temperature of the weather increased.

Bean planted in the middle coastal area was also significantly higher in infestation than the comparable south coastal area and north Beqaa ($P < 0{\cdot}01$) during autumn 1994 (Fig. 3). Furthermore, the infestation was found not to be significantly different ($P > 0{\cdot}01$) between September and October 1994; 15 and 10 larval mines per leaf, respectively. Similarly, Hanna *et al.* (1987) encountered 5·9–7·7 leafmines per trifoliate of snap bean, depending on cultivar.

Spatial pattern

Results of Iwao's and Taylor's methods indicated that the slopes of each regression was significantly > 1 revealing that leaf mines have clumped distributions in most of the sampling dates for the three crops (Table 3). Whenever the slope is not significantly different from 1 but > 1, this indicates that there is random distribution to slightly contagious pattern of leaf mines.

Iwao's patchiness regression method showed a significant correlation between the mean and the variance ($r^2 \geqslant 0{\cdot}81$) in all sites for the three crops (Table 3). Similarly, Taylor's regression method significantly accounted for variation in total number of mines on different dates for each crop ($r^2 \geqslant 0{\cdot}87$). The correlation coefficient (r^2) values were so high for both models that either model can suffice for the practical purpose of describing the variance-mean relationship although Taylor's power law does this more directly. Analysis of the regression slopes indicated that aggregation was similar among cucumber and bean leaves (Table 3). There were consistent (b) values in field samples of the leafminer for each crop using Taylor's power law compared to Iwao's method. The frequent recurrence of the same b value in field samples might facilitate efficient sampling programmes (Taylor *et al.* 1988, 1998) for this pest. Studies utilizing Taylor's power law dispersion analysis for *L. trifolii* reported b (regression slope) values of 1·51 and 1·19 for infestation on celery (Beck *et al.* 1981) and cut chrysanthemum (Jones & Parrella 1986), respectively. Heinz & Chaney (1995) reported that the regression slope derived for *L. huidobrensis* larval mines with Taylor's power law is within the range of previously reported values for *L. sativae* and *L. trifolii.*

The significance of the regression slopes was not similar among swisschard leaves at different sampling dates, when the two methods were compared. Moreover, analyses of regression slopes showed that aggregation was not similar between swisschard and the two crops: cucumber and bean (Table 3). This could be probably related to low number of points in the swisschard regression. However, analysis of the regression slopes indicated a trend of random to slightly contagious distribution on swisschard, while the spatial pattern was contagious on cucumber and bean. Similarly, Henna *et al.* (1987) reported, with *L. sativae* on snap beans, slopes of Iwao's patchiness regression equations to be consistently > 1·0, but not significantly > 1·0, indicating a random to slightly aggregated dispersion. One explanation for the difference in distribution of the pest on the hosts may be due to the leaf size (Minkenburgh *et al.* 1993) of swisschard which is bigger than that of cucumber and bean or due to the different leaf arrangement for each host plant. However, the latter issues need to be further investigated. Insect distributions in nature are likely to be determined by complicated processes involving many factors. Kuno (1991) suggested that Taylor's model might be used best as a descriptive

Table 3. *Regression statistics from dispersion analysis of* Liriomyza huidobrensis *larval mine counts on different crops*

		Iwao's patchiness regression					Taylor's power law				
Crop/sampling date	D.F.*	Intercept	Slope (β)	r^2	t value†	P	Intercept	Slope (b)	r^2	t value	P
Cucumber											
Sep 1994	16	4·19	2·32	0·95	6·67	< 0·01	0·40	1·89	0·98	10·66	< 0·01
Oct 1994	16	−1·02	2·28	0·99	13·9	< 0·01	0·38	1·66	0·95	5·03	< 0·01
Nov 1994	16	1·96	2·31	0·99	8·87	< 0·01	0·64	1·64	0·95	4·99	< 0·01
March 1995	10	19·32	1·16	0·99	2·54	< 0·01	0·77	1·42	0·99	5·84	< 0·01
April 1995	10	21·0	1·43	0·97	3·69	< 0·01	0·69	1·57	0·99	7·20	< 0·01
May 1995	10	34·1	1·34	0·93	2·05	> 0·01	0·84	1·52	0·97	4·49	< 0·01
Swisschard											
Sep 1994	4	6·43	2·17	0·81	1·5	> 0·01	0·29	1·89	0·87	1·16	> 0·01
Oct 1994	4	17·29	1·59	0·96	2·57	> 0·01	0·59	1·66	0·98	4·34	< 0·01
Nov 1994	4	1·96	2·31	0·99	8·87	< 0·01	0·60	1·63	0·98	4·31	< 0·01
Bean											
Sep 1994	7	−5·85	5·22	0·98	10·2	< 0·01	0·70	1·74	0·95	3·60	< 0·01
Oct 1994	7	1·71	2·31	0·98	7·06	< 0·01	0·67	1·41	0·96	2·70	< 0·01

* D.F. corresponds to number of sampled sites per date per crop.
† Student's t-test (Steel & Torrie 1960), $t = (b \text{ or } \beta - 1)/\text{standard error of } b \text{ or } \beta$.

Table 4. *Development of* Liriomyza huidobrensis *on different host plants*

		Development duration (days)* ± S.E.			
Crop	n†	Egg	Larvae	Pupae	Total
Cucumber	38	$2·90 \pm 0·04^a$	$10·2 \pm 0·27^c$	$9·20 \pm 0·10^a$	$22·3 \pm 0·28^c$
Swisschard	38	$2·80 \pm 0·05^a$	$9·40 \pm 0·18^b$	$9·20 \pm 0·13^a$	$21·5 \pm 0·22^b$
Bean	38	$2·90 \pm 0·04^a$	$7·70 \pm 0·22^a$	$8·90 \pm 0·05^a$	$19·6 \pm 0·25^a$

* Values represent the means of development duration of the insect instars on each host and their standard errors (113 D.F.). Means within a column followed by the same letter do not differ significantly (LSD, $P > 0·05$).
† Number of plants infested with leafminers followed up during this experiment.

model over a wide range of means without extrapolation. In contrast, Iwao's model can be used as an analytical tool in intensive population studies, with limited specified ranges of density.

Leafminer development

The suitability of the host can be determined by the growth, survival, oviposition or feeding of the insect on the host plants. In this study, there was no significant difference in egg or pupa duration of the insect among the three hosts: cucumber, swisschard, and bean ($P > 0·05$) (Table 4). However, the larval development time duration was significantly shorter on bean as compared to cucumber and swisschard ($P < 0·05$) (Table 4). Similarly, Parella & Bethke (1984) studied the development time of *L. huidobrensis* under constant laboratory conditions on chrysanthemum, aster and peas; they found that shorter larval development time occurred on peas than aster and chrysanthemum with no significant differences in egg or pupa duration on the three hosts. Zuniga *et al.* (1991) studied, in laboratory experiments at 22·67 ± 1·1 °C and 89·74 ± 5·45% RH, the feeding and oviposition preferences as well as egg, larva and pupa development of *L. huidobrensis* on potatoes, celery and certain weed species associated with these crops. Most preferred hosts for feeding of the leafminer were potatoes and the weed *Galinsoga ciliata*. Most viable eggs were laid on *G. ciliata* but egg development was shorter on the weed *Bidens pilosa*. There was no significant difference in the development time of the larvae and pupae among the different plant species. Based on our comparative data, the suitability of bean compared to swisschard and cucumber as a host for *L. huidobrensis* might be expected as the first infestation report of this pest was on pea (Blanchard

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1929), a crop in the same family of bean. However, other physiological factors are involved in the leafminer–host plant interaction.

Parella (1987) showed that the egg, larva and pupa development for *L. huidobrensis* varied with temperature and host plant. In this study, the egg duration was found to be 2·8, 2·9 and 2·9 days at 28 ± 3 °C, 70 ± 20% RH, and 14 h photophase on swisschard, cucumber and bean, respectively (Table 4). Similarly, Parrella & Bethke (1984) reported the egg duration to be 2·9, 3·0 and 3·0 days on peas, chrysanthemum and aster, respectively at 26·7 °C, 60 to 70% RH, and 14·5 h photophase at 5380 lux within an environmental chamber. However, Hincapié *et al*. (1993) reported 1·5 days as the egg duration at 24·7 °C and 64·3% RH on bulb onion. In this study, the larval duration was found to be 7·7, 9·4 and 10·2 days on bean, swisschard and cucumber, respectively (Table 4). However, other studies have reported shorter larval development periods at different temperatures and on other hosts. Parrella & Bethke (1984) reported a larval duration of 3·6, 4·7 and 4·9 days on peas, chrysanthemum and aster, respectively. Similarly, Hincapié *et al*. (1993) reported a short larval duration of 5·54 days on bulb onion. Pupation is considered optimum at relative humidity between 30 and 70% (Parrella 1987). In this study, the development duration for the pupa was found to be 8·9, 9·2 and 9·2 days on bean, cucumber and swisschard, respectively. Similarly, 8·9, 9·1 and 9·3 days were the reported period for the development of pupae on peas, aster and chrysanthemum, respectively (Parrella & Bethke 1984). However, Hincapié *et al*. (1993) reported the pupa duration on bulb onion as 8·14 days.

In general, many biotic and abiotic factors would act in combination to establish leafminer populations on a host plant. The significance of each factor might vary with location, season or spatial pattern determined on each host. Hanna *et al*. (1987) found that populations of *L. sativae* were higher in 1984 than in 1983 and were different in infestation level on two cultivars of snap bean. Therrien & McNeil (1985) found that early removal of the alfalfa canopy reduced the population density of *Agromyza frontella* (Rond.) by eliminating the partially developed larvae and influencing pupa survival through decreased moisture associated with canopy removal. In the present study, the contagious distribution of the pea leafminer on lower leaves of cucumber in greenhouses allows recommending removal of these leaves as a simple cultural practice. However, further studies are needed to investigate the effect of removing the lower stratum of cucumber canopy on economic yield and its correlation to the pea leafminer population. The high infestation of the pea leafminer on swisschard in presence of cucumber in greenhouses permits recommending the use of swisschard as a trap crop for this leafminer in areas where the latter is a low-value crop. Furthermore, the short development period of the pea leafminer on bean compared to cucumber and swisschard might suggest other studies for host preference of this pest. Thus, results of this study contribute to the management of the pea leafminer on vegetables taking into consideration its infestation level at different seasons, its spatial pattern within the canopy, and its variable development duration on each host plant.

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REFERENCES

Beck, H. W., Musgrave, C. A., Strandberg, J. O. & Genung, W. G. (1981). Spatial dispersion pattern of *Liriomyza* spp. on celery. In *Proceedings of the Second Institute Food Agricultural Science* (*IFAS*) *– Industry Conference. Biology and Control of Liriomyza Leafminers* (Ed. D. J. Schuster), pp. 129–140. University of Florida, Gainsville, USA: IFAS.

Blanchard, E. (1929). A dipterous leafminer on *Cinearia*, new to science. *Revista Sociedad de Entomologia Argentina* **1**, 10–11.

Buntin, G. D. (1994). Developing a primary sampling programme. In *Handbook of Sampling Methods for Arthropods in Agriculture* (Eds L. P. Pedigo & G. D. Buntin), pp. 101. Boca Raton, Fl: CRC Press.

Davis, M. P. (1994). Statistics for describing populations. In *Handbook of Sampling Methods for Arthropods in Agriculture* (Eds L. P. Pedigo & G. D. Buntin), pp. 34–53. Boca Raton, FL: CRC Press.

Fisher, R. A. (1949). *The Design of Experiments*. Edinburgh: Oliver and Boyd.

Gomez, K. A. & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*. New York: John Wiley.

Hanna, H. Y., Story, R. N. & Adams, A. J. (1987). Influence of cultivar, nitrogen, and frequency of insecticide application on vegetable leafminer (Diptera: Agromyzidae) population density and dispersion on snap beans. *Journal of Economic Entomology* **80**, 107–110.

Heinz, K. M. & Chaney, W. E. (1995). Sampling for *Liriomyza huidobrensis* (Diptera: Agromyzidae) larvae and damage in celery. *Environmental Entomology* **24**, 204–211.

Hincapié, C. M., Saaverda, H. M. E. & Trochez, P. A. L.

(1993). Life cycle, behaviour and natural enemies of *Liriomyza huidobrensis* (Blanchard) on bulb onion (*Allium cepa* L.). *Revista Colombiana de Entomologia* **19**, 51–57.

Iwao, S. (1968). A new regression method for analyzing the aggregation pattern of animal populations. *Researches on Population Ecology* **10**, 1–20.

Jones, V. P. & Parrella, M. P. (1986). Development of sampling strategies for larvae of *Liriomyza trifolii* (Diptera: Agromyzidae) in chrysanthemum. *Environmental Entomology* **15**, 268–273.

Kuno, E. (1991). Sampling and analysis of insect populations. *Annual Review of Entomology* **36**, 285–304.

Lloyd, M. (1967). Mean crowding. *Journal of Animal Ecology* **36**, 1–30.

Lynch, J. A. & Johnson, M. W. (1987). Stratified sampling of *Liriomyza* spp. (Diptera: Agromyzidae) and associated hymenopterous parasites on watermelon. *Journal of Economic Entomology* **80**, 1254–1261.

Minkenburgh, O. J. P. M., Byrne, D. N. & Palumbo, J. C. (1993). *Insect Pest Management for Vegetables 1993*. University of Arizona Cooperative Extension Service No. 192034.

Minkenburgh, O. J. P. M. & van Lenteren, J. C. (1986). The leafminers *Liriomyza trifolii* and *L. bryoniae* (Diptera: Agromyzidae), their parasites and host plants: a review. *Agriculture University of Wageningen Papers* **86**, 1–50.

MSTATC (1991). *MSTATC User's Guide*. East Lansing, Michigan, USA: Michigan State University.

Parrella, M. P. (1987). Biology of *Liriomyza*. *Annual Review of Entomology* **32**, 201–224.

Parrella, M. P. & Bethke, J. A. (1984). Biological studies of *Liriomyza huidobrensis* (Diptera: Agromyzidae) on chrysanthemum, aster, and pea. *Journal of Economic Entomology* **77**, 342–345.

Parrella, M. P., Jones, V. P., Youngman, R. R. & Lebeck, L. M. (1985). Effect of leaf mining and leaf stippling of *Lyriomyza* spp. on photosynthetic rates of chrysanthemum. *Annals of the Entomological Society of America* **78**, 90–93.

Southwood, T. R. E. (1978). *Ecological Methods*. London: Chapman & Hall.

Spencer, K. A. (1973). Agromyzidae (Diptera) of economic importance. *Series Entomologica* **9**, 1–418.

Spencer, K. A. (1981). *A Revisionary Study of the Leaf Mining Flies* (*Agromyzidae*) *of California*. University of California, Division of Agricultural Sciences Special Publications No. 3273. 489 pp.

Spencer, K. A. (1990). *Host Specialization in the World Agromyzidae* (*Diptera*). The Netherlands: Kluwer Academic Publishers.

Steel, R. G. D. & Torrie, J. H. (1960). *Principles and Procedures of Statistics*. New York: McGraw Hill.

Sunderlands, K. D., Chambers, R. J., Heyler, N. L. & Sopp, P. I. (1992). IPM of greenhouse crops in Northern Europe. *Horticultural Reviews* **13**, 4–46.

Taylor, L. R. (1961). Aggregation, variance and the mean. *Nature* **189**, 732–735.

Taylor, L. R. (1984). Assessing and interpreting the spatial distributions of insect populations. *Annual Review of Entomology* **29**, 321–357.

Taylor, L. R., Woiwod, I. P. & Perry, N. J. (1978). The density-dependence of spatial behaviour and the rarity of randomness. *Journal of Animal Ecology* **47**, 383–406.

Taylor, L. R., Perry, N. J., Woiwod, I. P. & Taylor, R. A. J. (1988). Specificity of the spatial power-law exponent in ecology and agriculture. *Nature* **332**, 721–722.

Taylor, R. A. J., Lindquist, R. K. & Shipp, J. L. (1998). Variation and consistency in spatial distribution as measured by Taylor's power law. *Environmental Entomology* **27**, 191–201.

Therrien, P. & McNeil, J. (1985). Effects of removing the plant canopy on pupal survival and adult emergence of the alfalfa blotch leafminer, *Agromyza frontella* (Diptera: Agromyzidae). *Canadian Entomologist* **117**, 167–170.

Weintraub, P. G. (1995). The newest leafminer pest in Israel, *Liriomyza huidobrensis*. *Phytoparasitica* **23**, 177–184.

Zuniga, H., Zoebisch, T. & Carballo, M. (1991). Life cycle and feeding preference of *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae) on potato, celery, and five important weeds in Cartago, Costa Rica. *Manejo Integrado de Plagas* **22**, 1–4.