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A review on management of leafminer in horticultural crops

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Abstract

The leafminers of genus Liriomyza (Agromyzidae: Diptera) is a polyphagous pest capable of infesting a wide variety of horticultural crops. Formerly, they were categorized as a pest of minor importance. But now, it invades many regions of the world due to inadequate quarantine procedures. Owing to its extended host range, presently it becomes an economic pest of native as well as invaded regions of the world. Moreover, the development of insecticide resistance also attributed to the rise in pest status. The most commonly observed reason for the outbreak of leafminers is inappropriate use or exploitation of insecticides and their impact on natural enemies. This indicates that there is an imperative need to made further improvement in pest management tactics. The management of Liriomyza is still continued to be the topic of extensive research and study. In order to develop a prompt management tactics, the basic information such as species composition, host range, distribution, seasonal abundance and biology of the pest has to be acquired. The cultural practices such as mulching and use of vermicompost were more appropriate regarding sustainable management. The use of yellow sticky traps attracted more number of leafminer individuals when compared to other traps. Regarding natural enemies, there were about 41 species of parasitoid under four families reported in Asia and about 140 species of parasitoid have been reported over the world. Among that about 23 species have been successfully used in biological control programme. In case of chemical control, both synthetic as well as natural insecticides (Botanicals) have been extensively researched and commonly used by the farmers but the effectiveness of these insecticides has been reduced due to their indiscriminate use. Thus IPM strategy is a comprehensive technique seeks to provide an economical and effective control measures. In this article, a gist of information of the pest leafminer and various management techniques for leafminer management recorded were discussed.

Keywords: leafminers, management, insecticides, natural enemies, pest

Introduction

Leaf miners of genus Liriomyza belongs to the family Agromyzidae and order Diptera are considered as important pest in most of the vegetables, ornamentals, and their associated weeds all over the world [1]. The family Agromyzidae composed of about 1800 species and 75% of them produce mines on leaves [2]. The genus includes twenty-three economically significant species causing damage to a good vary of agricultural, horticultural crops and ornamental plants [3, 4]. Six economically important species noticed on crop plants were, *L. sativae* (Blanchard), *L. trifolii* (Burgess), *L.* (Blanchard), *L. bryoniae* (Kaltenbach), *L. strigata* (Meigen), and *L. longei* (Frick) and all of them occur world-wide [1, 5-7]. Liriomyza species will develop host plant specialization, which could be explained by pre-imaginal adult expertise or the presence of inexplicable species [8, 9]. Parrella (1987) [10] described that this pest group can influence crops in six different ways: as a disease vector, sabotaging young seedlings, causing yield loss, “sunburning” of the fruit, reducing the value of ornamental plants, and causing plant quarantine issues.

Historically, Liriomyza species were categorized as a pest of minor importance, however within the early 1980s, the pest populations multiplied swiftly; some species, such as *L. trifolii* and *L. sativae*, developed insecticide resistance and menaced the chrysanthemum and celery industries in North America [11, 5]. *L. trifolii* and *L. sativae* have high reproductive potential because the adults are highly mobile that give rise to rapidly maturing immature growing in protected plant tissue followed by pupation in the soil [10]; these factors contribute to their pestiferous capabilities. In UK, about 41 species of Liriomyza were found including *L. bryoniae,* which has established as a major pest of glass grew tomatoes in England, and is

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found in Europe and Asia, as well as parts of North Africa. To date, *L. sativae* has not been found in Europe, although it has been introduced to both Israel and Turkey. Both *L. huidobrensis* and *L. trifolii* are now established in parts of the European continent and are widespread in some countries, especially in countries with a suitable climate. Over the past three decades, there have been a number of outbreaks of *L. huidobrensis* and *L. trifolii* which attacked crops under protected cultivation in England, but these have always been eradicated [12].

The agromyzid fly, *L. huidobrensis* was reported by Blanchard of Argentina in 1926 and has now reached its potential which is native to many crops, including potatoes. Among the economically important species *L. sativae*, *L. trifolii* and *L. huidobrensis* has the most cosmopolitan distribution [13]. The agromyzid fly, *L. huidobrensis* was first reported by Blanchard from Argentina in 1926 and has reached a peak of maximum infestation [14]. It developed rapidly in Europe and Asia since 1980s. It can now be seen as a cosmopolitan species. *L. huidobrensis* is an important pest of flowers and vegetables in many parts of the world, sometimes leading to complete cop loss [1, 3].

Damage Symptoms

The damage caused by Liriomyza spp. is divided into 2 classes (direct and indirect)

- The foremost serious damage is caused by larval feeding. The mining activity of larvae can scale back the photosynthetic capacity of the plant. Serious infestation will cause desiccation and premature fall of leaves. In (sub) tropical areas this may result in sunburning of fruits, e.g., melons and tomatoes [15]. Feeding punctures created by the adult females may also cause damage. Total destruction of seedlings and young plants has been reported.
- The adult females also cause damage by creating feeding punctures. The seedlings and young plants will lead to total destruction. The fungi and bacteria can invade the feeding punctures. Price and Harbaugh (1981) [16] ascertained a rise of microorganism leaf spot disease, probably Pseudomonas cichorii (Swing) Stapp, in chrysanthemum infested by L. trifolii, that aggravated the conditions of the mined leaves remarkably.

Host Range

Species	Hosts	Reference
L. brassicae	*L. brassicae* was detected from sixteen genera within the Cruciferae, Capparaceae, resedaceae and nasturtium family.	[1]
	Seldom found within the legume family and *Lathyrus odoratus*	[17]
	Thirteen genera of Cruciferae, a pair of genera of Capparaceae, one genus of tropaeolaceae and 2 genera of legume family were recorded in detailed field studies in Australia	[18, 17, 19]
L. bryoniae	L. bryoniae was first reported on Bryonia (Cucurbitaceae), but it has been rarely reported on that host.	[20]
	It is a highly polyphagous species and infests several hosts of economic importance including, lettuces, tomatoes, watermelons, cabbages, courgettes and melons.	[21] Bragard *et al.*, 2020
	This pest possibly spread to any areas where Asteraceae, Brassicaceae, Cucurbitaceae or Solanaceae are grown under glass	[22]
L. sativa	Reported in 9 plant families, though its preferred hosts are usually within the family Cucurbitaceae, legume family and family Solanaceae	[23, 1]
L. trifolii	Recorded from 25 families and was an extremely polyphagous pest. The foremost important plants infected are beans, celery, chrysanthemums, cucumbers, gerberas, gypsophila, lettuce, onions, potatoes and tomatoes	[24]
L. huidobrensis	It is extremely polyphagous and has been known by 365 host plant species in forty-nine plant families worldwide	[25]
	The foremost infected plants are beans, peas, beets, spinach, potatoes, tomatoes and cut flowers	[24]

Distribution

Species	Distribution
L. brassicae	The serpentine miner is the most cosmopolitan species known in the Agromyzidae and, although not found in the United Kingdom and parts of northern Europe, it is widespread in the Pacific, including regions of Australia, Hawaii, the East and Ethiopia and found locally in Canada and is abundant in California, Florida and other southern states. It was first recorded on Oahu in 1952 and is now common across the state [26, 23].
L. bryoniae	*L. bryoniae* is commonly found in Europe and northern Africa east to East Asia. It is actually native to southern Europe; in northern Europe, it is found mainly in greenhouses [27, 1].
L. trifolii	Since October 1979, a new polyphagous agricultural pest, the serpentine miner *L. trifoli*i (Diptera: Agromyzidae), has invaded Mauritius. It was probably accidentally imported from a nearby island in La Reunion where it was first recorded the previous year [28]. Its existence was first reported in France and Kenya in 1977, but is certainly of North American origin [1]. and exists in South America, the Caribbean Islands, the Bahamas, Malta and Europe.
L. sativae	*L. sativae* Blanchard, a vegetable leaf miner, is commonly found in Florida, California, Hawaii, and most of Latin America in the southern United States. Originally limited to the New World (Western Hemisphere), it can now be seen again. It is shipped with plant material in many parts of Asia and in Middle East, so it may be reported in colder regions. In cold regions it can survive only in greenhouses. This has been shown to be a small complex of obscure species [29].
L. huidobrensis	*L. huidobrensis* seems to have originated in cooler, predominantly mountainous regions of Latin America [20]. In South America, it is known from Argentina, Brazil, Chile, Juan Fernandez, Colombia, Peru and Venezuela. North America: California [23]; Hawaii; Europe: Belgium, Netherlands, UK; Middle East: Israel; Central America: Panama, El Salvador, Guatemala, Honduras, Costa Rica, Nicaragua, Belize. Caribbean: Dominican Republic, Guadeloupe.

Biology of Liriomyza Species

Species	**EP (in days)**	**LP (in days)**	**PP (in days)**	**AL (in days)**		**TL (in days)**		**OP (in days)**	**F (Numbers /Female)**	**HP (Percentage)**	**Reference**
				M	**FM**	**M**	**FM**				
L. trifolii	3	2-3	9 - 10	5	6	21	23	2-3	102 - 136	90- 95	[30]
	2-5	2-3	9-15	8-11	9-13	-	-	2-4	13-23	84.21 - 100	[31]
	3	2-4	9	-	-	17		3-6	200-400	-	[32]
	-	4-7	-	-	-	-	-	-	-	-	[33]
	-	12-54	-	-	-	-	-	-	-	-	[34]
	-	-	-	8	19	13-53		3-7	204-340	-	[35]
L. sativa	3	-	7-9	-		-	-	-	600-700	-	[36]
	6-13		7-15	-	-	-	-	-	-	-	[37]
	4-7	-	-	-	-	-	-	-	-	-	[33]
			7-14	-	-	-	-	-	-		[34]
	-	-	-	9	28	13-59		8-10	640-1000	-	[35]
L. huidobrensis	3	3-5	8-9	12-14		17-30 (S) 50-65(W)		4-8	-	-	[38]
	3	5	9	6	-	22		-	-	-	[25]
	3-4	8-11	12-18	2-6	3-28	-		-	117 (W), 161 (Sp)	-	[39]
L. bryoniae	3-6	5-13	9-24	7-14		17-41		4-5	92-163	-	[40]
	-	-	-	5	9	19-52		2-3	91-190	-	[35]

Note: EP-Egg Period, LP-Larval Period, PP-Pupal Period, AL- Adult Longevity, TL- Total Life span, OP-Oviposition Period, F- Fecundity, HP-Hatching Percentage, S- Summer, W- Winter, Sp- Spring.

Seasonal Incidence

The seasonal activity of the leafminer and its parasitoid was monitored on potato, scallions, and broccoli at Indonesia. The population of *L.huidobrensis* was abundant on potato during the wet season of March, 1996 (1700 adults) and in the dry season (June ± August 1996), the population of the leafminer and its parasitoid was low in scallion. In broccoli, the leafminer population was always higher during early to mid March and low during the dry season (July± August) (Sheppard *et al.*, 1998).

Weintraub (2001) studied the population dynamics of adults of *L. huidobrensis* in Israeli potato fields during the spring seasons for consecutive years. Throughout the years of monitoring, one notable observation was the first major peak of adult activity, which always occurred during the first 2 weeks of April followed by two smaller peaks. In 1995, the peak population of leafminer occurred in the second week of April. According to 1996 data, the activity of the adult was small at the beginning of March and much smaller peak in the first week of April followed by one subsequent peak. In 1997, a slight peak was observed during March and a smaller peak first and second week of April. In 1998 due to unusual weather (Heat wave), less number of leafminers was caught from the middle of May until the middle of June.

Population dynamics of leafminer adults of *L. huidobrensis* on seven processing varieties of potato were monitored using yellow sticky traps at Balcarce during 2002 and 2003.The leaf miner population was peek during the period from 2nd – 3rd week of January (806 specimens/ trap/week) to 3rd week of February (3947 specimens/ trap/ week). Within this period the population density steadily increased from the 4th week of January, which coincides with flowering period (Lopez *et al.*, 2010).

Li *et al.* (2012) observed the population density of L.trifolii and its parasitoid *O. dissitus* at three snap bean sites in South Florida from 2010-2011. *L. trifolii* population was abundant during Dec 2010(17.9 ± 1.5 adults per 5 leaves) and Jan 2011(30.3 ± 2.7 adults per 5 leaves) and its parasitoid also showed similar population density during December 2010 (4.5 ± 0.45 adults per 5 leaves) and January 2011 (5.4 ± 0.73 adults per 5 leaves).

Management Techniques

Host plant Resistance

1.	Host monogenic resistance of leaf miner, *L. trifolii* in melons has been studied. Antibiosis type of resistance is conferred by the line Nantais Oblong, a Charentais type melon, against *L. trifolii.*	Dogimont *et al.*, 1999
2.	Genetic resistance in some chrysanthemum cultivars like *Chrysanthemum pacificurn* IVT 78 173 and *C. morifolium* 'Penny Lane' has been reported.	De Jong and Van De Vrie, 1987
3.	Antibiotic and antibiotic resistance have been identified in Apium species, *Apium leptophyllum* and *A. prostratum* has been reported	Trumble *et al.*, 1997

Cultural Control

1.	Exclusion of leafminers from greenhouse growing areas by physical barrier (mesh protection)	Schuster, 1994
2.	Elimination of host weeds in the crop environment	Price and Harbaugh, 1981
3.	The use of gravel as a substrate in the greenhouse to reduce leafminer survival	Oetting, 1985
4.	Leafminer population was higher in tomatoes grown with plastic mulches or when they were tied to stakes and this was due to the lower activity of parasitoids.	Price and Poe, 1976
5.	Introducing trap crops such as shallots and cucumbers reduced the leafminer populations as well as increased the parasitoid population and parasitism.	Saleh *et al.*, 2018
6.	Among five treatments [standard cultural practice (C), C plus reflective plastic mulch (RPM) (CM), farmer's practice (F), vermicompost (V), and V plus RPM (VM)] evaluated in Bali against pea leaf miner, (*L. huidonbrensis*), the population of adults, larvae of *L. huidobrensis*, and mines were less in C, CM, V, and VM treatments when compared to other treatments.	Suryawan and Reyes, 2016

Physical Control

1.	Yellow sticky traps were used to monitor adult population levels, and leaf samples were used to monitor larval population levels	Weintraub, 2001
2.	Yellow sticky traps trapped higher leaf miner fly and significantly reduced the leaf miner populations in Uganda	Rose *et al.*, 2019
3.	Among four types of trap viz., yellow water, yellow sticky board, bottle with 20% protein hydrolysate, and funnel with 10% casein hydrolysate, against *Liriomyza huidobrensi*s (Blanchard) in the coastal region of Peru, the yellow sticky boards were the most effective in trap capture with a mean of 1193.92 *L. huidobrensis* per week.	Chavez and Raman, 1987

Biological Control

Liriomyza leafminers are known to be attacked by a variety of natural enemies which includes predators, entomopathogenic nematodes, entomopathogens and parasitoids (Liu *et al.*, 2009). Liu *et al*. (2009) submitted a list of the parasitoid species reported around the world including 23 species in the Nearctic region, 28 from Japan, 72 from South America, 14 in China, 11 in Indonesia, 14 from Florida, eight species in Malaysia, 18 species in Vietnam and several from Europe and Turkey. These species belong to the Hymenoptera of families Braconidae, Figitidae, Cynipidae, Pteromalidae, and Eulophidae.

1	In Mexico, a decrease in the density of leafminer is also found to be associated with the conventional insecticide program	Trumble and Alvarado-Rodriguez, 1993
2	In California, natural enemies have kept leafminer population below the permitted threshold in tomato and celery fields	Trumble and Alvarado-Rodriguez (1993); Trumble *et al.* (1997)
3	In Hawaii, *Ganaspidium utilis* Baerdsley, *Neochrysocharis punctiventris* and *Chrysocharis oscinidis* were released for *L trifolli* and *L. sativae* control in watermelons, legumes, tomatoes, pumpkin, beans, and Irish potatoes with great success	Liu *et al.*, 2009
4	*Dacnusa sibirica* along with *Diglyphus isaea* is as inundative biological control. *L. trifolii* was effectively being controlled by releasing these two parasitoids in tomatoes and cucumbers greenhouse; the combination of these parasitoids is available commercially.	Abd-Rabou, 2006
5	*D. isaea* is available commercially to control Liriomyza, and has been reported to be effective against *L. trifolii* and *L. bryoniae* in crops including tomato and nursery plant.	Ulubilir and Sekeroglu (1997); Sampson and Walker (1998)
6	*N. formosa* is also effective in controlling *L. trifolii* on eggplant and *Opius pallipes* improved the control of *L. bryoniae*	Shimomoto (2005); Hondo *et al.* (2006)
7	In Europe, *L. bryoniae* was managed by the inoculative release of *D. isaea*	Boot *et al.*, 1992
8	*D.isaea* and *D. Sibirica* were established in Senegal for the control of *L. trifolii*	Neuenschwander *et al.*, 1987

Hymenopteran parasitoids of Liriomyza leaf miners

SPECIES	***Lt***	***Ls***	***Lh***	**Reference**
*Achrysocharella agromyza*e (Crawford)	-	-	+	Harding (1965); Stegmaier (1972)
Achrysocharella diastatae (Howard)	+	-	+	Stegmaier, 1972
Aehrysocharella fulloway (Crawford)	+	-	+	Harding, 1965
Aehrysocharella variipes (Crawford)	-	-	+	Harding (1965); Stegmaier (1972)
Chrysoeharis ainsliei (Crawford)	-	-	-	Johnson *et al.* (1980); Chandler (1982)
*Chrysocharis brethes*i (Schauff & Salvo)	-	-	+	Hansson, 1997
Chrysocharis caribea (Bouèek)	-	+	+	Bouček, 1977
Chrysocharis liriomyzae (Delucch)	+	-	-	Murphy and LaSalle, 1999
Chrysocharis orbicularis (Nees)	+	-	-	Murphy and LaSalle, 1999
Chrysocharis oscinidis (Ashmead)	+	+	+	Kaneshiro and Johnson, 1996
Chrysocharis pentheus (Walker)	+	-	-	Tran, 2009
Chrysocharis pubicornis (Zetterste dt)	+	-	-	Johnson *et al.* (1980); Johnson and Hara (1987); Bouček (1977)
Cirrospilus ambiguus (Hansson & LaSalle)	+	-	-	Hansson and LaSalle, 1996
Closterocerus purpureus (Howard)	-	+	-	Murphy and LaSalle, 1999
Closterocerus trifasciatus (Westwood)	-	+	-	Oatman and Kennedy, 1976
Closterocerus utahensis (Crawford)	+	+	-	Johnson *et al.*, 1980
Diglyphus begini (Ashmead)	+	+	+	Schuster *et al.*, 1991
Diglyphus intermedius (Girault)	+	+	+	Johnson *et al.* (1980); Trumble and Nakakihara (1983)
Diglyphus isaea (Walker)	+	+	+	Hara, 1986
Hemiptarsenus ornatus (Nees)	+	+	-	Johnson, 1987
Meruana liriomyzae (Bouèek)	+	+	-	Murphy and LaSalle, 1999
Neochrysocharis diastatae (Howard)	+	+	-	Hansson, 1997
Neochrysocharis formosa (Westwood)	+	+	-	
Neochrysocharis okazakii (Kamijo)	+	-	-	Caixia, 1997
Quadrastichus liriomyzae (H& LS)	+	-	-	Hansson and LaSalle, 1996
Halticoptera aenea (Walker)	+	+	+	Johnson (1987); Stegmaier (1972)
Halticoptera arduine (Walker)			+	
Halticoptera circulus (Walker)	+	+	+	
Halticoptera patellana (Dalman)	-	-	+	
Lamprotatus tubero Walker	-	-	+	Murphy and LaSalle, 1999
Epiclerus nomocerus (Masi)	+	-	-	Franco and Panis, 1991

Lt - L. trifolii Ls - L.sativa Lh - L. huidobrensis

Botanicals

1	Margosan-O $^{\text{TM}}$ a commercial formulation of neem seed extract was tested for their efficiency against leaf miner, *L.trifoli*. From the result, it is evident that Margosan-O at different foliar concentrations viz., 0.41%, 0.84%, and 1.25% were found to significantly reduced the leaf miner populations	Knodel *et al.*, 1986
2	Steam distillates of neem leaves were reported to reduce the leafminer population in onion plantation.	Fagoonee and Toory, 1983
3	Neem Azal-S and Margosan-O (2%) were found to be an efficient feeding and ovipositional deterrent against *L. trifolii.*	Dimetry *et al.*, 1995
4	Neem-based insecticides like azadirachtin are also expanding the spectrum of compounds available to control Liriomyza	Weintraub and Horowitz, 1997
5	Some fruit extracts such as *Melia azedarach* (Meliaceae) have also been investigated for their effects on the control of leafminers	Banchio *et al.*, 2003
6	The use of basil oil, spruce oil, juniper oil and clove oil in yellow sticky traps predominantly increased the number of insects trapped	Górski, 2005
7	NeemAzal-T/S has greatest potential to control *L. sativae* in netted greenhouses.	Hossain and Poehling, 2006
8	CURACRON®, Belt ® and botanical extracts of Almond Extract, @3.00%, Walnut Extract @3.00 were also tested for their efficiency against the pea leaf miner.	Rizvi *et al.*, 2015
9	Fish amino acid 0.5% and NSKE 5% at 10 days interval was found to be the efficient method for controlling leaf miner population.	Mohan and Anitha, 2017
10	The effects of M. azedarach fruits on survival of *L. sativae* Blanchard and its parasitoid *D. isaea* (Walker) were tested under laboratory conditions. It has been found that the *M. azedarach* was more compatible to use with biological control by the parasitoid *D. isaea* and at the same time, it lowers the leaf miner population to considerable level	Hammad and McAuslane, 2010

Chemical Control

1	Nicotine was one among the first used insecticides to control leaf miner, kills the larvae by osmosis through the leaf epidermis and adult by contact	Sanders, 1912
2	The use of nicotine for leaf miner control was popular from 1900 to 1940	Spencer, 1973
3	Several granular systemic insecticides were tested on cucumbers and southern peas against *L. sativae* in Texas, finding successful control with Di-syston, and phorate.	Harding and Wolfenbarger, 1963
4	Oxamyl, oxamyl plus methomyl (tank-mix), and permethrin plus microencapsulated methyl parathion (tank-mix) effects were studied in leafminer and its parasitoids, *D. imermedius* (Girault) and *Ganaspidium hunieri.* Among that permethrin and microencapsulated methyl parathion in a tank-mix were found to be producing effective results.	Hara, 1986
5	Two translaminar insecticides, cyromazine and abamectin were reported to reduce the leafminer population to significant level but, at the same time it had negative effects on the population of the parasitoid, *D. iseae*	Weintraub and Horowitz, 1998
6	Cyromazine and Abamectin significantly reduced leaf miner population in Isreal; however, cyromazine was significantly more effective than abamectin	Weintraub, 2001
7	More recently, populations of *L. trifolii* have shown resistance to abamectin, spinosad and cyromazine	Ferguson, 2004
8	About eight insecticides were tested for their efficacy against *L. trifolii* on variety Avinash of tomato. From the result, it is concluded that Profenophos 40% + Cypermethrin 4% was found to be the most effective in control over other insecticides	Rai *et al.*, 2013
9	NSKE offers economically viable solution as comparable to new molecules available in market	Pawar and Patil, 2013
10	The mixture of abamectin and plant oil showed synergistic effect against leaf miner control which paved way to reduce the usage recommended concentration of insecticide abamectin, thus reduces the treatment cost	Mujica *et al.*, 1999
11	Chlorantraniliprole 4.3% + Abamectin 1.7% SC was significantly effective while spraying twice fortnightly and also incidence of *L. trifoli* were reduced and fruit yield was increased.	Selvaraj *et al.*, 2017
12	Vertimec 18 EC in the dose of 1000 ml cp / ha showed 80% efficiency against *L. huidobrensis* in potato cultivation.	Barros *et al.*, 2017
13	Chlorantraniliprole 18.5 SC 0.03% at 10 days interval reduces the leaf minor damage, number of mines and larvae per plant.	Mohan and Anitha, 2017
14	The insecticides like profenophos, buprofezin, spinosad, chlorantraniliprole, thiamethoxam, acephate, malathion along with NSKE @ 5% and azadirachtin 1500 ppm were shown to reduce the leaf miner population to considerable level.	Hirekurubar and Tatagar, 2018
15	The use of Dudu-acelamectin reduces the leaf miner infestation and similarly yellow sticky traps trapped higher leafminer population. However, there was no significant difference between the mulched and control plot	Rose *et al.*, 2019
16	The insecticide combination Propargite 50 + Bifenthrin 5 SE was reported to have efficient control over the leaf miner, *L.trifolii.*	Jat *et al.*, 2018
17	The insecticide cyantraniliprole 10.26 OD, abamectin 1.9 EC and deltamethrin 2.8 EC registered lower leaf miner infestation.	Ramesh *et al.*, 2020
18	The effectiveness of five insecticides was tested under field conditions in southern Florida for controlling *L. trifolii*. Abamectin and spinosad were generally the most effective whereas Cyromazine and azadirachtin were less effective than abamectin or spinosad but better than *I. fumosorosea* or the untreated control.	Devkota *et al.*, 2016
19	Insecticide combination like profenofos + cypermethrin 44 EC (0.044%) was found to be significantly effective against leaf miner *(Liriomyza trifolii*) and also increased the yield of the tomato in Junagadh.	Kotak *et al.*,2020
20	Tetraniliprole 200 SC as foliar application was found to be more effective in controlling tomato leaf miner, *L.trifolii*	Kousika and Kuttalam, 2020

Insecticide resistance to leafminer species

1	Repeated applications of methomyl induce *L. sativae* outbreaks on tomato and it was primarily because of negative effect of methomyl on parasites.	Oatman and Kennedy, 1976
2	It has been reported that *L. trifolii* was found to be more tolerant than *L. sativa* to pyrethroids like permethrin and fenvalerate.	Mason *et al.*, 1987
3	Insecticides like permethrin and bifenthrin become susceptible to some leafminer populations in chrysanthemum crop at California, Florida and Maryland	Parkman and Pienkowski, 1989
4	Colonies of *L. trifolii* from Florida and California were shown to be resistant to DDT, cypermethrin, permethrin, methyl parathion and methamidophos	Keil and Parrella, 1990

Effect of Insecticides on Natural Enemies of Leafminer species

1	Insecticides that affect the parasitoid food chain by killing leaf miners would always have a negative effect on their natural enemies.	Darvas and Polgar, 1998
2	It has been reported that insecticides, permethrin and methomyl shows high toxicity to leafminer parasitoids, *D. interrmedius* and *N. punctiventris* whereas methamidophos was toxic only to the adult and showed fewer toxic effects to larva and pupae of both parasitoids. On the other side, endosulfan was highly toxic to *N. punctiventris* but less toxic to *D.intermedius*. The less toxic insecticides were thiodicarb, fenvalerate and abamectin and least toxic were *Bacillus thurungiensis* and cyromazine.	Schuster, 1994
3	A field trial showed that methomyl encouraged pest growth through the disturbance of the parasitoid guilds, and methamidophos was safer than methomyl to the natural enemies	Trumble and Toscano, 1983
4	Abamectin in contrast with methomyl and methamidophos, showed higher population densities of the leaf miner parasitoid *D. isaea* on treated potatoes compared to cyromazine	Weintraub, 2001
5	Prijono *et al.* (2004) reported that abamectin showed negative impact against *H. varicornis* Gerault, *Opius sp., G. micromorpha* Perkins, and *D. isaea.*	Prijono *et al.*, 2004
6	The compatibility of abamectin insecticide with the commercially available parasitoid *D. isaea was* studied. Topical applications greatly affected parasitoid survival. Abamectin residue on plants also negatively affected *D. isaea* survival up to 5 days after application. Parasitism of treated leafminer larvae was lethal for the natural enemy. However, application of insecticide after the leafminer was parasitized and parasitoid larvae started feeding, did not affect *D. isaea* emergence and longevity.	Kaspi and Parrella, 2005
7	The susceptibility of the insecticides imidacloprid, pymetrozine and lufenuron to the leafminer parasitoid *N. formosa* (Westwood) were investigated using glass vials coated with different insecticide solutions	Tran *et al.*, 2005
8	The effects of profenofos, carbosulfan, and abamectin against the parasitoids of leafminers were studied. They observed that profenofos, and carbosulfan reduced parasitism by *H. varicornis*, *O. chromatomyiae* and *C. humilis*, and abamectin did not reduce parasitism.	Hidrayani *et al.*, 2005
9	Abamectin caused mortality to the larvae and pupae of the two parasitoid species *H. varicornis* (Girault) and *D. isaea* (Walker); cyromazine and mancozeb did not. In addition, cyromazine and mancozeb did not cause a reduction in longevity and progeny production compared to the control, and abamectin. They concluded that cyromazine and mancozeb were compatible in an IPM program in Australia, and that abamectin should be used with caution.	Bjorksten and Robinson, 2005
10	The effects of neem (azadirachtin), abamectin and spinosad to *N. formosa* and *O. chromatomyiae* were summarized. Neem-Azal-U is used for soil applications, and it caused low mortality on *O. chromatomyiae* when the parasitized *L.sativae* pupae came in contact with the insecticide; the longevity of the emerged parasitoids was unaffected. The foliar formulations of azadirachtin, spinosad and abamectin were all highly toxic to *O. chromatomyiae*. The application of spinosad and abamectin to parasitized leafminer larvae by N. formosa had strong negative effects on its emergence. However, Neem Azal-T/S (azadirachtin) had no detrimental effects on the parasitoid observed.	Hossain and Poehling, 2006
11	The effect of four insecticides viz., novaluron, abamectin, λ-cyhalothrin and spinetoram on two important parasitoids of leaf miner, *N. Formosa* and *G. nigrimanus* were studied using three different bioassay techniques viz., direct insecticide application, insecticide intake and insecticide residue. Spinetoram was found to be more harmful for both parasitoids in all the three bioassays. Abamectin was effective in both direct application and insecticide intake bioassay against both the parasitoid. λ-cyhalothrin was harmful in direct application to *G. nigrimanus* and has no effect on N. Formosa. At last, Novaluron showed the least effect against the parasitoids than other insecticides.	Hernández *et al.*, 2011

Conclusion

Leaf miners being a polyphagous pest cause significant problems all over the world. This review provides a glimpse of information about leafminers, their host range, distribution, parasitoid complex and various management techniques. The management options so far practiced provides satisfactory control against leafminer populations. Yet newer insecticide molecules should be evaluated for their effectiveness against leafminer and a more ecofriendly strategy such as IPM needs to be optimized and implemented.

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