https://doi.org/10.17221/29/2024-PPS

Critique on the dipteran pests of commercial flower crops: An obligate threat to the floral industry

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Citation: Anand B.B.S., Suganya K.S., Muthiah C., Rajangam J., Rajesh S., Nalini R., Suganthi A. (2024): Critique on the dipteran pests of commercial flower crops: An obligate threat to the floral industry. Plant Protect. Sci., 60: 328–353.

Abstract: The floral industry grapples with challenges like changing climatic scenarios, differences in market trends, rising costs, and severe losses posed by insect pests. The management of dipteran pests encompassing diverse species, such as leaf miners, midges, flies, and mosquitoes, has emerged as an obligate adversary, inflicting substantial economic losses in the cut and loose flower industry. Through a comprehensive analysis of existing literature, this paper delves into the diverse array of dipteran species of leaf miners and midges, their life cycles, distribution, host range, damaging symptoms, insecticide resistance, and the management strategies practised to date. Furthermore, this critique underscores the urgent need for innovative approaches and integrated pest management techniques to mitigate the escalating menace of dipteran pests. By elucidating the multifaceted challenges and proposing strategic interventions, this critique aims to foster dialogue and inspire concerted action among researchers, stakeholders, and scholars to safeguard the sustainability and profitability of the floral industry.

Keywords: dipteran; flowers; leaf miner; midge; management

Floriculture is the most significant part of ornamental plant growing and meeting people's aesthetic needs. Global floral industries are focused on the propagation, cultivation, production, distribution, and sale of cut flowers, which contribute a large part to agribusiness and increase the country's economic profile (Kuzichev & Kuzicheva 2016). Over 90 world countries are known to be active in the floral industry market (IFTS 2004). In 2022, a net worth of 50 040 mil. USD is estimated to have a market value of around 58 030 mil. USD by 2028 with a compound annual growth rate of 2.5% during the review period (Floriculture Market 2022).

https://doi.org/10.17221/29/2024-PPS

Commercial floriculture has gained momentum globally with the boom in floriculture trade for quality flowers at international standards. The major challenge in quality flower production is diseases and pests. Although insect pests play a role in pollination as flower visitors, they cause potential damage as defoliators and sucking pests. The flower crops are vulnerable to many insect pests, such as bud borers, leaf miners, budworms, midges, and nematodes, which were recorded. The Diptera, true or two-winged flies, have approximately 150 000 described species. Ubiquitous groups of dipterans with considerable economic importance, including pestiferous groups, can have significant impacts on agriculture (Agromyzidae, Tephritidae), forestry (Cecidomyiidae), animal health (Oestridae), and human health (Culicidae, Simuliidae, Psychodidae). Other groups can be a general nuisance if present in high numbers (Muscidae, Ceratopogonidae) or because of allergic reactions to detached body hairs (Chironomidae) (Merritt et al. 2009). The extreme diversity of dipteran pests increases crop damage, especially in the families Agromyzidae and Cecidomyiidae, with considerable economic losses in the floral industry. From the elegant roses of Ecuador to the iconic orchids of Thailand, no country of the globe is immune to the threat of dipteran infestations that impact the global economy and are the reason for several crop losses.

The control of dipteran pests should be done with a proper understanding of their biology and behaviour and a wide range of feeding patterns, life cycles, and ecological niches. With the changing climatic conditions, the adaption strategies of dipterans play an immense role in flower crop damage potential that demands a multimodal approach to pest management.

This article covers two economically important dipteran families affecting the commercial cut flowers (Alstroemeria, carnation, chrysanthemum, daylily, dendrobium, gerbera, marigold, rose) and also loose flowers (jasmine, marigold, rose, tuberose) with a brief description on its pest's species, distribution, damage, bio ecology, insecticide resistance and their management strategies. We aim to create a complete resource for flower producers, researchers, scholars and other stakeholders by combining the best research findings and best practices.

ECONOMICALLY IMPORTANT DIPTERAN PESTS ON COMMERCIAL FLOWER CROPS

The most important dipterans affecting the commercial cut and loose flowers mainly comprise two families: Agromyzidae and Cecidomyiidae (Table 1). Agromyzidae, leaf-minor flies because of their highly

Table 1. Economically important dipteran pests on commercial flower crops

Crop	Common name	Scientific name	Reference
Alstroemeria	Lily midge	*Contarinia jongi* (Kolesik)	Kolesik et al. (2018)
Carnation	Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Stegmaier (1966)
		L. trifolii	
Chrysanthemum	Leaf miner	*L. huidobrensis* (Blanchard)	Ledieu & Bartlett (1983)
	Leaf miner	*L. sativae* (Blanchard)	
	Chrysanthemum gall midge	*Diarthronomyia hypogaea* (Low)	Essig (1916)
		Rhopalomyia longicauda (Sato)	Yukawa and Masuda (1996); Gagne and Jaschhof (2004)
Daylily	Daylily midge	*C. quinquenotata* (Low)	Halstead and Harris (1990); McLean and Ian (2011)
		Ophiomyia kwansonis (Sasakawa)	Steck and Williams (2012)
Dendrobium	Blossom midge	*C. maculipennis* (Felt)	Gagne (1995)
Gerbera	Leaf miner	*L. trifolii*	Stegmaier (1966)
Jasmine	Blossom midge	*C. maculipennis*	Jensen (1946); Gagne (1995); Uechi et al. (2011); Harini et al. (2019); Kamala 2020
Marigold	Leaf miner	*L. trifolii*	Stegmaier (1966)
Rose	Rose gall midge	*Dasineura rhodophaga* (Coquillet)	Bilal (2016)
Tuberose	Blossom midge	*C. maculipennis*	Firake et al. (2024)

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herbivorous nature with 3 000 species (Merritt et al. 2009), well known for the plant mining habits of their larvae (Spencer 1973, 2012; Lonsdale 2011) having the majority of the populations choose both monocot and dicot flora as host plants as in *Agromyza, Cerodontha, Liriomyza, Phytomyza* whereas a host of *Melanagromyza dianthereae* (Malloch) is a flowering plant (Merritt et al. 2009). Among the lower Diptera, the gall midges (Cecidomyiidae) are abundant minute flies, species-rich with a total of 6 000 species and cosmopolitan. Most species produce galls within which the maggots (Merritt et al. 2009). As with many fruit flies and other plant pests, their effects include direct damage and economic losses related to quarantine issues (Gagne et al. 2000).

Leaf miner population and midges augmented as a result of the usage of a wide range of pesticides to combat pest damage, which had a significant effect on their biocontrol agents (Abraham et al. 2012), and this facilitated the changeover to economically important pests (Parrella & Keil 1984). Leaf miners encompass genera *Agromyza, Liriomyza and Phytomyza* and are known to be destructive worldwide in several agricultural crops (Spencer 1973) and horticultural crops specific on ornamental flowers and edible leaf crops (Spencer 1973; Minkenberg & van Lenteren 1986; Maier 2001). The leaf miners of the family Agromyzidae comprise 1 800 species that mine the leaves (Bader et al. 2006) and affect the economic value of ornamental and edible leaves (Spencer 1973; Minkenberg & van Lenteren 1986; Maier 2001). The genera *Liriomyza* contains 330 species (Liu et al. 2009), of which 23 are economically important species that affect a wide range of cultivated crops (Banchio et al. 2003; Barros et al. 2017). With the most economically important species noted on crop plants were *L. sativae*, *L. trifolii*, *L. bryoniae* (Kaltenbach), *L. strigsata* (Meigen), and *L. longei* (Frick) occur across the globe (Boot et al. 1992; Bouček 1977; Caixia 1997; Abd-Rabou, 2006). Earlier, it was recorded as a minor pest due to the high natural parasitisation by hymenopterans (Parrella & Keil 1984), but in the late 1980s, the pest population increased drastically due to the indiscriminate use of insecticides. Eventually, species like *L. trifolii* and *L. sativae* developed resistance against insecticides that created a threat to flower cultivation, influencing chrysanthemum and celery industries in North America (Boot et al. 1992; Darvas & Polgar 1998). *Contarinia* is a genus of midges and small flies consisting of 311 species across the globe (Gagne & Jaschof 2021). Cecidomyid larvae feed within plant tissue, producing galls and creating abnormal plant growth (Edde 2021), affecting the flower market. The cecidomyid species *C. maculipennis, C. quinquenotata, C. jongi. C. maculipennis* was described by Felt (1933) through the collection of adult insects from flowers of Hibiscus crops grown in Hawaii and the USA. Other economically important midge species are *R. longicauda*, *D. hypogaea* and *D. rhodophaga.*

SPECIES AND DISTRIBUTION

The leaf miner, *L. trifolii*, was described as a serpentine leaf miner and American serpentine leaf miner (Malipatil & Ridland 2008) distributed worldwide (Table 2 and Figure 1A). The literature on polyphagous behaviour and host range recognised *L. trifolii* as the dominant species among the leaf miners (Schuster & Beck 1981) (Table 3). *L. trifolii* was recorded for the first time by Pagliarini and Komnenovic (1981) as a pest of gerbera in a glasshouse in Yugoslavia and spread throughout the state as it was imported with gerbera seedlings from the Netherlands. Another polyphagous leaf miner is *L. bryoniae*, a Palearctic species originating in Southern Europe. It is commonly used outdoors, but in central and northern Europe, it was seen only inside greenhouse crops

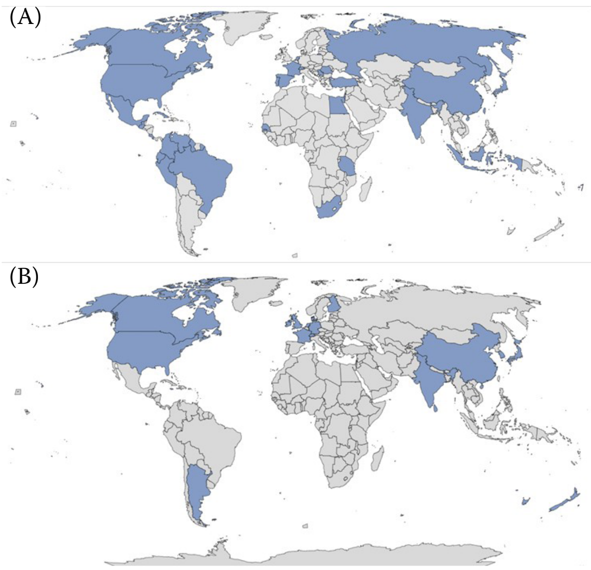

Figure 1. Geographical distribution of dipteran pest of commercial flower crops
(A) Geographical distribution of leaf miners in flower crops;
(B) Geographical distribution of midges in flower crops

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Table 2. Geographical distribution of dipteran pests in commercial flower crops

Species	Distribution	Reference
Leaf miners		
Liriomyza trifolii	Washington D.C., Iowa	Charlton and Allen (1981)
	Kenya, France, Netherlands	Spencer (1981, 1985); Pagliarini and Komnenovic (1981)
	California, Colombia, Turkey	Price (1982); Uygun et al. (1995)
	Israel, Senegal, Tanzania, Turkey	Deeming (1992)
	Korea	Han et al. (1996)
	Japan	Abe and Kawahara (2001); Seebens et al. (2017)
	India	Suganthy (2007); Shakti Khajuria et al. (2013); EPPO (2022)
	Indonesia	Baliadi and Tengkano (2010)
	China	Seebens et al. (2017); Zhang et al. (2017)
	South Africa	Zengeya and Wilson (2020)
	Africa, Malta, Moldova, Netherlands, Portugal, Romania, Russia, Serbia, Spain, Switzerland, North America, Canada, Costa Rica, Cuba, Dominican Republic, Guadeloupe, Guatemala, Martinique, Mexico, Saint Kitts and Nevis, Trinidad and Tobago, U. S. Virgin Islands, US, Oceania, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Venezuela, Federated states of Micronesia, Fiji, Guam, Northern Mariana Islands, Samoa, Tonga	EPPO (2022)
L. bryoniae	Egypt	Abul-Nasr and Assem (1961)
	Japan	Kamijo (1978)
	Israel	Berlinger et al. (1983)
	Southern Europe (outdoors) Central and Northern Europe (Inside greenhouses)	Minkenberg and Van Lenteren (1986)
L. huidobrensis	Colombia, California	Price (1982)
	Netherlands	Lanzoni et al. (2002)
L. sativae	California	Spencer (1965)
L. hemerocallis	Japan	Iwasaki (1993)
Ophiomyia kwansonis	Japan	Sasakawa (1961); Steck and Williams (2012)
	Taiwan	Shiao and Wu (1999)
Midges		
Contarinia maculipennis	India	Thirumala Rao et al. (1954); David (1958); Jayasheelan et al. (2018)
	Florida, Jamaica, New York, Los Angeles, California, Hawaii	Gagne (1995)
	Florida	Gagne (1995); Tokuda et al. (2002)
	Japan	Tokuda et al. (2002); Uechi et al. (2007, 2011)
	Netherlands, Dutch	Gaag et al. (2007)
	Korea republic	Kang et.al. (2010)
	Sri Lanka	Dias et al. (2017)
	Argentina	Cáceres et al. (2018)

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Table 2. to be continued...

Species	Distribution	Reference
C. quinquenotata	United Kingdom,	Halstead and Harris (1990); Halstead (2011); Gagne and Jaschhof (2014)
	Asia	Hulme (2009); Rosetta (2017)
	USA	Halstead (2011); Gagne and Jaschhof (2014)
	Europe, Australia	McLean and Ian (2011); Seebens et al. (2017)
	Norway	Skuhravá and Skuhravý (2012)
C. jongi	New Zealand, Japan	Iwaizumi et al. (2007)
	South Australia, Queensland, Netherlands	Kolesik et al. (2018)
Rhopalomyia longicauda	Japan	Yukawa and Masuda (1996)
	China and Korea	Paik et al. (2004)
Dasineura hypogaea	Europe, Britain, Denmark, Finland, France, Germany, Ireland, Northern Sweden, Switzerland, Australia, New Zealand, North America, Canada, U.S.A.	DMPP (1975)
D. rhodophaga	Pacific Northwest, California, Northeastern states, Colorado, Illinois, Ohio, Wisconsin, Canadian provinces of British Columbia and Ontario Portland, Oregon	Rosetta (2019)

(Minkenberg & van Lenteren 1986). It was also reported in North Africa (Morocco and Egypt) and several Asian countries (CABI Knowledge Bank 2019). *L. huidobrensis,* an economically important pest on flowers (Scheffer 2000), causes severe crop losses (Spencer 1973; Shepard et al. 1998) by broad mines both on the upper and lower sides of the leaves. It poses major issues in the world flower market (Abraham et al. 2012). It has been classified as a quarantine pest by the European and Mediterranean Plant Protection Organization (Menken & Ulenberg 1986). Along with this, *L. sativae* was also reported as a major pest on chrysanthemum in California (Spencer 1965) and *L. hemerocallis* (Iwasaki) in Japan on *Hemerocallis*, where its larvae were categorized as pod and seed feeders (Iwasaki 1993). The leaf miner *O. kwansonis* was found to damage daylily flowers in Japan (Sasakawa 1961) and Taiwan (Shiao & Wu 1999). In nurseries, leaf mines were abundant in larvae and pupae, leading to damage to crops (Steck & Williams 2012).

The spread of *Contarinia* spp. is assumed to occur from larvae within buds of imported plants or the soil in plant containers (McLean 2011) and dispersed worldwide in many countries (Table 2 and Figure 1B). Among the ornamentals, the most important is the gall midge pest of *Hemerocallis*, *C. quinquenotata,* which affects the developing buds and arrests the blooming which was found to exist in Britain during the 1980s, ruining many garden plants of economic importance (Cross et al. 2012). *C. jongi* is native to South America and has been overlooked and introduced to other countries through international flower trade. *C. jongi* was the first gall midge known to feed on a host plant from the family Alstroemeriaceae (Kolesik et al. 2018).

Rhopalomyia (Rubsaamen), 1892, comprises at least 253 described species across the globe. Most species induce galls on the Asteraceae group of crops, of which 167 occur on Artemisia, 13 on Solidago, 9 on Aster, and remaining on other scattered unknown genera (Gagne & Jaschhof 2004). From *Chrysanthemum* (*Dendranthema*), only three described and two unidentified species of *Rhopalomyia* have been recorded and they were *R. hypogaea* on *Chrysanthemum atratum* (Linnaeus) in Europe (Redfern et al. 2002; Skuhravá 2005), *R. chrysanthemum* (Monzen), on *C. morifolium* (Ramatuelle) in Japan (Monzen), and *R. chrysanthemi* (Ahlberg) which is found in all parts of the world on cultivated *C. morifolium* (Barnes & Barnes 1948; Gagne & Jaschhof 2004). Whereas *Diarthronomyia* differs morphologically from *Rhopalomyia* by the presence of only one caudal setae on the abdominal terga

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Table 3. Host range of dipteran pests affecting commercial flower crops

Species	Host	Reference
Leaf miners		
Liriomyza trifolii	Chrysanthemum, verbena, calendula	Parrella et al. (1984a)
	Gerbera, chrysanthemum, celery, cherry tomato, watermelon and pumpkin in Korea	Han et al. (1996)
	Being a polyphagous of 47 plant genera in ten families includes melon, cucumber, squash, bean, pea, onion, pepper, tomato, egg plant, potato, celery, lettuce and carrot and among the ornamentals are chrysanthemum, gerbera, gypsophila and marigold.	Stegmaier (1966)
L. bryoniae	Asteraceae, Brassicaceae, Cucurbitaceae or Solanaceae grown under glass	Smith et al. (1997)
	Lettuces, tomatoes, watermelons, cabbages, courgettes and melons	EFSA (PLH) et al. (2020)
L. huidobrensis	Chrysanthemum	Ledieu and Bartlett (1983)
	365 host plant species in 49 plant families such as Alstroemeriaceae, Asteraceae, Liliaceae, Rosaceae, Brassicaceae etc.	Weintraub et al. (2017)
L.sativae	Chrysanthemum	Ledieu and Bartlett (1983)
	Families of Cucurbitaceae, Fabaceae and Solanaceae with vegetable crops including beans, eggplant, potato, pepper, tomato, squash and watermelon. Celery and wild plants such as *Solanum americanum* and *Bidens alba*.	Capinera (2001)
Ophiomyia kwansonis	Daylily *Hemerocallis fulva* (Kwanso)	Steck and Williams (2012)
Midges		
Contarinia maculipennis	Malvaceae as the first described host [*Hibiscus rosa sinensis* (Linnaeus)]	Felt (1933); Jensen (1946); Uechi et al. (2003)
	Jasminum sambac (Linnaeus) Aiton	Jensen (1946); Gagne (1995); Uechi et al. (2011); Harini et al. (2019); Kamala (2020)
	J. auriculatum (Vahl)	David (1958); Kamala (2020)
	Plumeria rubra (Linnaeus)	Nakahara (1981); Uechi et al. (2011)
	Dendrobium sp. (Olof Peter Swartz)	Gagne (1995); Tokuda et al. (2002); Jayasheelan et al. (2018)
	D. phalaenopsis (Fitzg)	Gagne (1995); Tokuda et al. (2002)
	J. grandiflorum (Linnaeus), *J. nitidum* (Skan)	Kamala (2020)
	Capsicum annuum (Linnaeus) *C. frutescens* (Linnaeus) *Lycopersicon chilense* (Dunal) Reiche *L. pimpinellifolium* (Linnaeus) *L. peruvianum* (Linnaeus) *L. esculentum* (Mill.) *Solanum melongena* (Linnaeus) *S. rantonnetti* (Carriere) Bitter *S. tuberosum* (Linnaeus) *Brassica chinensis* (Linnaeus)	Jensen (1946); Jensen (1950); Uechi et al. (2003)
	Momordica charantia (Linnaeus)	Gagne (1995); Uechi et al. (2003, 2007)

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Table 3. to be continued ...

Species	Host	Reference
Contarinia maculipennis	*Pseuderanthemum laxiflorum* (A. Gray) F. T. Hubb. ex L. H. Bailey	Mohan and Manjunath (2005)
	Oxalis corniculate (Linnaeus)	Uechi et al. (2011)
	Citrus	Cáceres et al. (2018)
	Agave amica (Medikus) Thiede and Govaerts	Firake et al. (2024)
C. quinquenotata	Daylily, tawny daylily	McLean and Ian (2011)
C. jongi	*Alstroemeria* (Inca lily)	Kolesik et al. (2018)
Rhopalomyia longicauda	*Chrysanthemum indicum* (Linnaeus) *C. morifolium* (Ramatuelle)	Yukawa and Masuda (1996); Gagne and Jaschhof (2004)
Dasineura hypogaea	*C. leucanthemum* (Lam)	Essig (1916)
	Chrysanthemum, Achillea, Senecio	DMPP (1975)
D. rhodophaga	Rose and hybrid tea types	Bilal (2016)

of the adults, in which *Rhopalomyia* have additional tergal setae basal of the caudal row (Gagne 1975)

The rose midge, *D. rhodophaga* (Coquillett), is one of the serious pests of roses. This midge was first reported in 1886 in New Jersey with severe damages. The adult midge lays its eggs, and the tiny maggot feeds, causing blackened tissue, tip abortion, and distorted flower buds, which tend to increase through the season (Rosetta 2019).

BIOLOGY

Leaf miner

Liriomyza spp. deposits eggs on the adaxial or abaxial leaf surface, which is whitish translucent of varying sizes from species to species. The egg size of *L. congesta* (Becker) is 0.25 × 0.10 mm (Dimetry 1971) and *L. huidobrensis* 0.28 × 0.15 mm (Aguilera 1972). The size of the eggs enlarges after oviposition due to the fluid's imbibition from the plant tissues and increases in size after oviposition (Dimetry 1971; Tilden 1950). About 2–8 days is required for egg development, and it is influenced by temperature (Parrella 1987). Larva, with its anterior extremity, which contains the mouth hook, orients towards the terminus of the egg and furthest from the original oviposition puncture made by the female and hatches (Speyer & Parr 1950). In some species, eggshells will be eaten by the larva before moving into mesophyll cells of leaves (Beri 1974). A cylindrical or maggot-like (Parrella 1987) larva starts feeding immediately after eclosion (Webster & Parks 1913), and different species of *Liriomyza* feed in different sections of the leaf mesophyll, e.g., palisade mesophyll by *L. trifolii* and *L. huidobrensis* feeds on spongy mesophyll (Parrella et al. 1985). Larva's anterior end tapers, whereas the posterior end is truncated with four moults between puparium formation and pupation (Tauber & Tauber 1968). Larval duration of many *Liriomyza* spp. ranges between 4–6 days in field/greenhouse temperatures (Fagoonee & Toory 1983; Liebee 1985). For pupation, the larva cuts a semicircular slit at or near the end of the mine on the upper or lower surface of leaves, depending on the location of the larva and emerges with characteristic peristaltic locomotion such that it falls out (Oatman & Michelbacher 1959). Pupation occurs on leaves with large curled leaves (squash, gerbera, etc.) or at the base of leaves, stems, or occasionally on stalks (Oatman & Michelbacher 1959). The development period for the prepupal period is about 2–4 h (Oatman & Michelbacher 1959; Liebee 1985) and inversely proportionate to temperature in different hosts (Parrella 1987). Nevertheless, 50% of the development period is gone in this stage, with a mean development time of pupa 8–11 days (Oatman & Michelbacher 1959; Liebee 1985). Adults emerge from the dorsal end of puparium with the help of ptilinum and being a positive phototactic insect that climbs up stalk of a plant, where they remain quiescent for approximately 20 min while expanding their wings and body. The body is fully sclerotized and coloured within 20 min–2 h (Oatman & Michelbacher 1959; Dimetry 1971). Adult females are usually larger than males (Oatman & Michelbacher 1959; Parrella 1983), and puparium size positively correlates with adult vigour (Parrella 1983). Generally, both adults emerge during the early morning hours (Oatman & Michelbacher 1959).

Temperature adversely affects fertility; increasing the temperature increases egg laying (Parrella 1983).

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Table 4. Effect of temperature on development stages (days) of *Liriomyza* spp. with slight modifications of Barranco (2003)

Species	Life stages									
	Egg		Larva		Pupa		Adults			
	15–25 °C	25–27 °C	20–25 °C	15–25 °C	15–25 °C	20–27 °C	19 °C	15–38 °C	15–25 °C	Fecundity (nos/female)
Liriomyza trifolii	4.0–7.7	–	–	4.3–9.1	10.0–26.6	–	3.1–16.7	–	–	389
L. huidobrensis	–	2.1–3.0	5.8–6.7	–	–	9.0–12.6	–	11.4	–	131
L. bryoniae	3.0–6.1	–	–	5.0–12.3	9.2–22.2	–	–	–	6.6–13.6	163

Table 5. Temperature of different stages of *Liriomyza trifolii*

Species	Host	Life stage	Estimated threshold temperature for development (°C)	Reference
L. trifolii	*Chrysanthemum moriolium*	egg	13.4	Charlton and Allen (1981)
		larval	6.1	Bodri and Oetting (1985)
		pupa	9.0	Parrella et al. (1981)
		egg – adult	6.3	Charlton and Allen (1981)
	Dendranthema spp.	pupa	10.4	Miller and Isger (1985)
		egg – pupa	10.1	Miller and Isger (1985)

With respect to relative humidity, the egg laying is stimulated if it is between 80–90% (Malais & Ravensberg 2006). Other abiotic factors (Tables 4 and 5, Figure 2) that influence fertility are brightness, the female becomes inactive, egg laying gets limited under poor brightness (Alba 2014), and biotic factors like leaf surfaces with hooked trichomes act as a barrier (e.g., pink beans) influencing the survival and cause premature death (Charlton & Allen 1981)

Midges

The eggs of *C. maculipennis* are laid inside the flower buds and hatch within five to seven days (Jensen 1950). The larvae mature within five to seven days, then enter the soil (moist not wet), where they pupate. Adults normally emerge in 14 days, but its longevity is only for 4 days in their bio ecology study done by Allwin et al. (2023), and they presented that the total duration of the life cycle from egg to adult is approximately 21–28 days. Usually, *C. maculipennis* prefers the flowering stage in all crops for its growth/development cycle. It is considered a multivoltile species (CABI International 2022), whereas *C. quinquenotata* is a univoltine species, which are tiny whitish maggots that feed on the buds (sometimes outside) (Rosetta 2017) and pupates the same as that of *C. maculipennis* and emerges in the succeeding spring. *C. jongi* differs from *C. maculipennis* in its shape and with female vestiture. In *C. jongi*, the male cercus is widened and ovoid, while in *C. maculipennis,* it's narrow and triangular. More distintly, male circumfila loops of *C. jongi* are shorter, with the longest loops approaching the bases, while, in *C. maculipennis* it approaches beyond the following nodes. Yellow-coloured larvae infest the buds and move towards soil for pupation, crawling, and jumping (Kolesik et al. 2018); the same case in most of the *Contarinia* spp., (Kolesik 1995; Kolesik & Cunningham 2000).

Rhopalomyia genus is distinct in the supertribe oligotrophid with five generations in a year as fe-

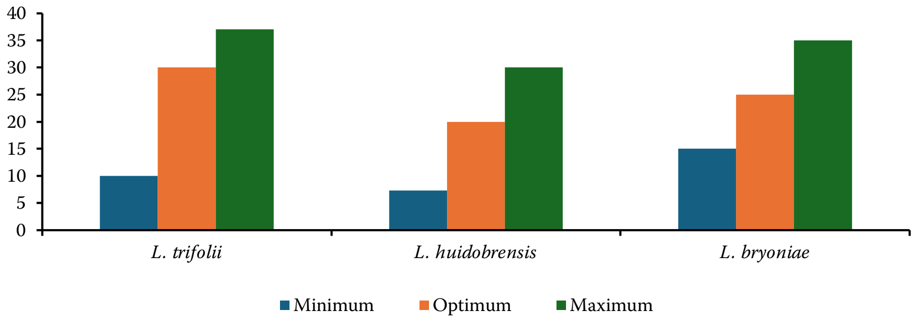

Figure 2. Threshold temperatures (°C) of different *Liriomyza* spp. with slight modifications of Barranco (2003)

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males lay eggs singly or in clusters, and the developing larvae feed and then pupate in the galls; thereby, adults start to emerge from the galls (Liu 1987; Liu et al. 2007).

Tiny adult brown-red flies of *D. rhodophaga* usually overwinters in the pupal stage in the soil. Eggs are laid inside the sepals of flower buds or on plant terminals (Dunwell et al. 2014) and in the shoots (Stroom et al. 1997). Creamy white to pale pink maggots that hatch and move into flower buds for feeding result in withering, blackening, and death of flower buds with 2 to 4 generations per year (Dunwell et al. 2014).

The population of *C. maculipennis* is positively correlated with maximum temperature, morning hours, evening relative humidity, evaporation and rainfall but non-significant and negatively correlated with minimum temperature. In contrast, a non-significant and negative correlation in the incidence is obtained with wind velocity and sunshine hours in *J. sambac* (Pirithiraj et al. 2020). Also, tropical monsoon, tropical wet and dry savanna, and humid subtropical are preferable climates (CABI International 2022) with a 10–35 °N latitude range.

The incidence of blossom midge is significant and positively correlated with sunlight intensity under different shade net conditions of 35%, 50% and 75%, where the rainfall is significant and negatively correlated with incidence in orchid cultivation. (Jayasheelan & Allwin 2018) also, the peak emergence of *C. maculipennis* was observed during the full moon day and a day after, while the least emergence was noticed during the new moon and a day before (Macdonald 1956; Conlee 1995; Jayasheelan & Allwin 2018).

SYMPTOMS OF DAMAGE

Leaf miners and midges

The damage caused by *Liriomyza* spp. can be divided into two categories: direct and indirect.

1. Direct damage. Mining activity of larvae reduces the plant's photosynthetic rate, and severe infestation leads to desiccation and premature fall of leaves (Michelbacher et al. 1951). Adult females also cause damage by feeding punctures.

2. Indirect damage. Invasion of feeding punctures followed by fungi and bacteria (Price & Harbaugh 1981) causes an increase in disease development, such as bacterial leafspot disease, probably *Pseudomonas cichorii* (Swing) Stapp, in chrysanthemum infested by *L. trifolii*. *Liriomyza* flies transmit viruses like watermelon mosaic virus, etc. (Zitter & Tsai 1977).

Damages caused by leaf miners (Figure 3) and midges (Table 6 and Figure 4) are shown.

MANAGEMENT OF LEAF MINERS AND MIDGES IN COMMERCIAL FLOWERS

Pest management ensures a proper selection (Rossi et al. 2019) of action measures to mitigate ecological and social consequences and ensure sustainable economic conditions best suited for the agricultural, public welfare and amenity pest management situation (Sandler 2010). Integrated pest management (IPM) is a dynamic process involving an ecological approach to various pest control approaches with economic, environmental and social considerations. IPM endorses the cultiva-

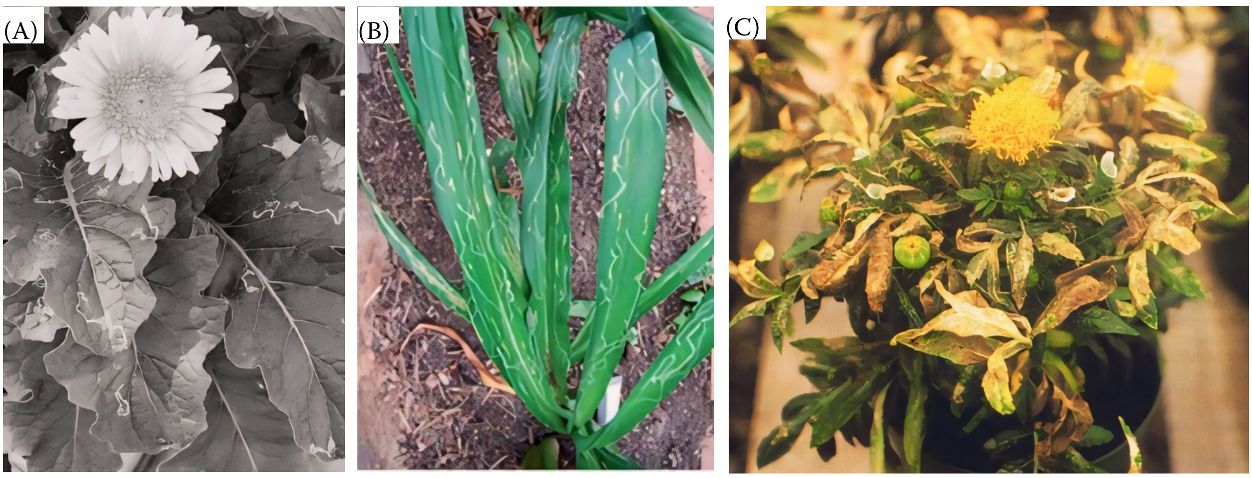

Figure 3. Damaging symptoms in different flower crops by leaf miners
(A) *Liriomyza trifolii* in gerbera; (B) *Ophiomyia kwansonis* in daylily; (C) *L. trifolii* in marigold

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Table 6. Symptoms of damage by midges

Contarinia maculipennis [Tokuda et al. 2002 (1); CABI International 2022 (2)]	*C. quinquenotata* (Rosetta 2017)	*C. jongi* (Kolesik et al. 2018)
1. Adult females cause the damage, as the newly hatched larva feeds on the flower, resulting in deformation of the floral structure or even severe economic loss of the crop 2. Symptoms and signs can be seen in both plant part and inflorescence characterized by distortion/fall or shedding/ internal feeding	Maggots primarily feed on developing lily buds, causing distorted growth and later, the bud swells and becomes discolored. Severe may lead to shrivelling of buds and often produces crinkled petal edges	Infested buds became abnormally thickened, small show necrosis and darker at the later stage
Rhopalomyia longicauda (Sato et al. 2009)	*Dasineura hypogeae* (Essig 1916)	*D. rhodophaga* (Stroom et al. 1997)
It produces large sub-globular swelling with less hairy growth on the surface. Green in colour but somewhat with a purple tinge and a pointed tip. Galls are induced on the terminal and lateral buds, stems, and the upper surface of leaves and fusion of galls may also occur	Characteristic galls are found on the leaves, leaf-petioles stems and buds of the food plants. The galls are decidedly cone-shaped. Very often, they may be almost wholly enclosed within the tissues so that only the tips are exposed. Infested shoots arc often distorted beyond recognition and are eventually killed. The colour is somewhat lighter than the surrounding tissues at first, but it turns bright red or brown in time. The size of the fully-developed galls is quite uniform, averaging about 3 mm in length and 1 mm in diameter at the base.	Damage by the larvae causes bent, misshapen, or blasted buds and withering of stem tips, and at a later stage, flower buds and growing shoots turn brown and finally become black.

tion of healthy crops with the least disturbance to agro-ecosystems by natural pest control mechanisms. It combines biological, chemical, physical and cultural management strategies to minimize pesticide usage for sustainable pest management.

Cultural, Physical and Botanicals

Management starts with monitoring, inspection and identification, followed by establishing EIL (Economic Injury Levels) and with all cultural, mechanical, physical, and botanicals (Tables 7 and 8).

Physical methods

Experiments of releasing sterile *L.trifolii* males by Kaspi & Parrella (2006) in three different ratios (3:1, 5:1, 10:1) of sterile to fertile males successfully shown to reduce the number of offspring of the pest population (Chrysanthemum). Further techniques of irradiating eggs, larvae and pupae at 100 Gy in *L. trifolii* highly inhibit adult emergence (Kumagai & Dohino 1995). Similarly, the evaluation of the same radiation doses of 150, 250, 350 and 450 Gy at room temperature as the I experimental set (27 °C ± 1 °C) and others at the refrigerated condition as the II experimental set (4 °C) noting the percentage of flower damage concluded with the results that, there was no flower damage up to 7 days at room temperature. Surprisingly, even in refrigerated conditions, there was no flower damage for up to 20 days in all irradiated orchid-cut flowers, which will help to control *C. maculipennis* (Madhubala et al. 2021). Installing sticky yellow traps helps control the leaf miner population (Chavez & Raman 1987; Song et al. 2000; Weintraub 2001; Rose et al. 2019). In case of midges, field studies on efficacy of controlling orchid midge, *C. maculipennis* with very low and high-volume cold fogger sprayer treatments were applied with the cold fogger sprayer at 6, 8, 10

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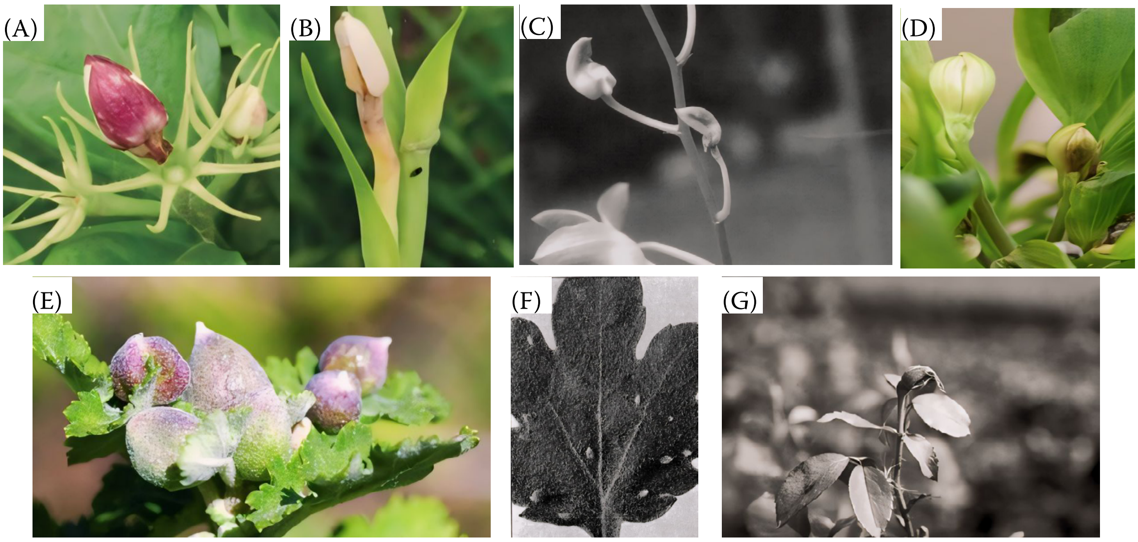

Figure 4. Damaging symptoms in different flower crops by midges
(A) *Contarinia maculipennis* in jasmine; (B) *C. maculipennis* in tuberose; (C) *C. maculipennis* in orchids; (D) *C. jongi* in alstroemeria; (E) *Rhopalomyia longicauda* in chrysanthemum; (F) *Dasineura hypogaea* in chrysanthemum; (G) *D. rhodophaga* in rose

and 12 L/rai with the application of thiamethoxam/ lambda-cyhalothrin (24.7%) at 120 and 160 mL/rai (1 rai = 1 600 m^2) controls orchid midge of all treatments were equally effective (Punyawattoe et al. 2019). Felt (1915) suggested that fumigation with hydrocyanic acid gas is passed for the management.

Host plant resistance

Leaf miners. The line Nantais Oblong, a melon of Charentais type, conferred with antibiosis type of resistance against *L. trifolii* (Burgess) and monogenic resistance of *L. trifolii* in melons has also been studied (Dogimont et al. 1999). In the field with Fuego, the lowest number was caught. Results showed that the degree of injury could be arranged in the order of Ambition ≥ Jamilla > Cinderella ≥ Merigold > Fuego. A non-preference host study on gerberas with *L. trifolii* by Abraham et al. (2013) revealed resistance in cultivars like 'Jaguar Pink', 'Jaguar Rose Deep', 'Jaguar Salmon Pastel', and 'Revolution Spring Pastel' which were the least damage of less than 20% of the highest damage.

Midges. Flower buds of plants with tightly fitted buds are less susceptible to infestation. (Hara & Niino-DuPonte 2002). Kamala (2020) found that *J. nitidum* and *J. grandiflorum* showed high resistance to *C. maculipennis* and floral traits of different genotypes of *J. sambac* flowers with less bud length (accession No: 13 = 1.66 cm) are more suspectible for the infestation when compared with more bud length (Aswini et al. 2023). Kamala et al. (2017) identified saturated hydrocarbons from the *C. maculipennis* infested buds (jasmine) through GC–MS analysis which includes linalool, allyl isothiocycnate, naphthalene, azulene, methyl salicylate etc. which acts as semiochemicals and responsible for the attraction of the natural enemies.

Biological control

Method of controlling pests such as insects and mites, weeds, or pathogens affecting animals or crops plants by using other suitable living organisms (Table 9) focussing on different principles like predation, parasitism (Tables 10 and 11), herbivory, or other natural mechanisms as an integral component of integrated pest management (IPM) programs (Flint & Dreistadt 1998).

Deterrents and repellants

Foliar sprays of permethrin and microencapsulated methyl parathion (separately and in combination) significantly reduce feeding and oviposition on *L. trifolii* in choice trials. On the other hand, systemic like aldicarb, acephate, disulfoton, methamidophos, and oxamyl produced antifeeding effects in no-choice trials. In contrast, aldicarb, oxamyl, and disulfoton produced oviposition-deterring effects in both choice and no-choice trials (Robb & Parrella 1985). Later, Parrella et al. (1988) found that adult female leaf miners were repelled from feeding and ovipositing

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Table 7. Cultural methods for the management of leaf miners and midges in commercial flowers

Cultural control	Reference
Leaf miners	
Removal of weed host from the cropping ecosystem	Price and Harbaugh (1981)
Soil drenching of Methoprene	Parrella et al. (1982)
Application of gravel as a substrate	Oetting (1985)
Addition of silicon (potassium silicate) at 200 ppm	Parrella et al. (2006)
C + reflective plastic mulch (RPM) and vermicompost (V)	Suryawan and Reyes (2016)
Use of trap crops such as shallots and cucumbers	Saleh et al. (2018)
Soil drenching with Cyantraniliprole at 8 rate fl.oz./100 gal	Klittich et al. (2016)
Midges	
Burning of infested plants either by cutting off and destroying infested portions of others that exterminate the pest population.	Felt (1915)
Growing of chrysanthemum under reduces the gall fly populations Allow the old plants to grow during the winter and following with trimming at spring possibly kills the hibernating larvae	Essig (1916)
Proper sanitization and drainage in the greenhouses	Gagne (1995); Suganthy and Kamala (2016)
Pruning of infested buds reduces the rose midge population	Stroom et al. (1997)
Collection and destruction of fallen and discoloured buds	Hara and Niino-DuPonte (2002) Uechi et al. (2011) Suganthy and Kamala (2016)
Removal and avoid planting of alternate host crops like tomato, eggplant, bitter gourd	Hara and Niino-DuPonte (2002); Suganthy and Kamala (2016)
Soil treatment with *Metarhizium* spp.	Glare et al. (2010); Lacey et al. (2015)
a) raking the soil kills the pupae b) pruning of bushes also during winter Soil application of carbofuran 3G at 30 kg/ha Drenching soil around plant base with chlorpyriphos 20EC at 5 mL/L	Suganthy and Kamala (2016)
Avoid planting of early blooming cultivars (yellow-coloured)	Rosetta (2017)
Remove and destroy the infected daylily buds Removing the mulch and replacing it with another fresh mulch at the very end of the growing season that removes rose midges that overwinters	Rosetta (2019)
Selection and growing of late-flowering varieties of daylily with non-yellow flowers	Cattiaux et al. (2021)

on chrysanthemum plants treated with formulated abamectin 0.012 g/L up to 7 days after foliar application in choice and no-choice assays. Some fruit extracts of *Melia azedarach* (Linnaeus) showed deterrent properties that affect the feeding behaviour of adult females and were also found to reduce the oviposition rates thus by exhibiting deterrent properties against *L. huidobrensis* (Banchio et al. 2003). David et al. (1990) studied and presented the repellency effect of NO 2% against *C. maculipennis.*

Sex pheromones

Analysis of the volatile revealed the presence of natural pheromone contained (2S,8Z)-2-butyroxy-8-heptadecene and field tests with rubber septa containing racemic (Z)-2-butyroxy-8-heptadecene were attractive to control *R. longicauda* males (Liu et al. 2009).

Legal method

Mortimer and Powell (1984) suggested the adoption of statutory quarantine treatment of 2 days in cold storage at 1–2 °C followed by methyl bromide fumigation at 15 °C with a concentration-time product (CTP) of 54 g h/m^3 against *L. trifolii* is found to be the best prophylactic treatment. *C. maculipennis* is recognized as a quarantined pest in Australia (Department of Agriculture, Water and the Environ-

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Table 8. Botanicals for the management of leaf miners and midges in commercial flowers

Botanicals	Reference
Leaf miners	
Smearing of some oils such as basil oil, spruce oil, juniper oil and clove oil in yellow sticky traps	Górski (2005)
NeemAzal-T/S (1% azadiractin)	Hossain and Poehling (2006)
Fish amino acid 0.5% and NSKE 5%.	Mohan and Anitha (2017)
NSKE at 5% and azadirachtin at 1 500 ppm	Hirekurubar and Tatagar (2018)
Chinese mahogany leaf extract 0.25%, *Chrysanthemum pyrethru*m petal at 0.15 and 0.30%, and chinaberry leaf at 0.3%, 0.35%	Rahardjo et al. (2020)
Midges	
The purple discolouration was reduced in bushes (Jasmine) treated with neem oil 2% against *C. maculipennis*	David et al. (1992)
Increased efficacy on control on *C. maculipennis* by pungam oil 2% followed by the NSKE 5% (1), which is also confirmed in field studies (2) 5% of NSKE managed to reduce the infestation (*C. maculipennis*)	(1) Harini et al. (2019); Kamala (2017) (2) Hemalatha (2009)

ment 2021), and it is also a quarantined pest in Korea because of its potential to damage the horticultural and ornamental plants (Kang et al. 2010). Blossom midge has been recorded in the Netherlands by Gaag et al. (2007) by the interception records in *Dendrobium* flowers imported from Thailand in 2001 and 2007, and since it has been eradicated in a Dutch orchid greenhouse after its introduction.

One method to reduce the risk of introducing this pest is to buy bare-root roses or discard the soil and rinse the roots of plants brought in from infested sites (Rosetta 2019) against rose midge.

Insect growth regulators

Evaluation with six insect growth regulators against the leaf miner larvae in chrysanthemum

Table 9. Biocontrol agents for the management of leaf miners and midges in commercial flowers

Biological control	Reference
Leaf miners	
Diglyphus isaea (Walker)	Calabretta and Nucifora (1985)
Steinernema carpocapsae (Weiser) at a rate of 10 000 infective juveniles/mL	Broadbent and Olthof (1995)
Diglyphus begini (Ashmead)	Heinz and Parrella (1990) Parrella et al. (1992)
Nematodes	Harris et al. (1990); Broadbent and Olthof (1995); Liu et al. (2009)
Neochrysocharis formosa (Westwood) and *Opius pallipes* (Wesmael)	Shimomoto (2005)
Dacnusa sibirica (Nedstam) along with *D. isaea*	Abd-Rabou (2006)
Ganaspidium utilis (Baerdsley), *Neochrysocharis punctiventris* (Crawford) and *Chrysocharis oscinidis* (Ashmead) *Metarhizium anisopliae* (Mechnikov) and *Paecilomyces lilacinus* (Thom & Samson)	Liu et al. (2009)
Midges	
Large number of parasites were reared from infested plants and identified *Amblymerus* sp. a hymenopterous parasite	Essig (1916)
Five species of parasitoid wasps in China under chrysanthemum cultivation	Liu (1987)
Beauveria bassiana (Bals.-Criv) and *M.anisopilae*	
P. lilacinus	Kamala and Kennedy (2018)
M. anisopliae and *Lecanicillium lecanni* (R. Zare & W. Gams)	
Trichogramma chilonis (Ishnii)	Suganthi et al. (2019)

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Table 10. Hymenopteran parasitoids on leaf miners

Species	*L. t*	*L. s*	*L. h*	*L. b*	Reference
Achrysocharella agromyzae (Crawford)	–	–	+	–	Harding (1965); Stegmaier (1972)
A. diastatae (Howard)	+	–	+	–	Stegmaier (1972)
Aehrysocharella fulloway (Crawford)	+	–	+	–	Harding (1965)
A. variipes (Crawford)	–	–	+	–	Harding (1965); Stegmaier (1972)
Chrysoeharis ainsliei (Crawford)	–	–	–	–	Johnson et al. (1980); Chandler (1982)
C. brethesi (Schauff & Salvo)	–	–	+	–	Hansson (1997)
C. caribea (Bouček)	–	+	+	–	Bouček (1977)
C. liriomyzae (Delucch)	+	–	–	–	Murphy & LaSalle (1999)
C. orbicularis (Nees)	+	–	–	–	
C. oscinidis	+	+	+	–	Kaneshiro & Johnson (1996)
C. parksi (Walker)	–	–	–	+	Nedstam (1983)
C. pentheus (Walker)	+	–	–	–	Tran (2009)
C. pubicornis (Zetterste dt)	+	–	–	–	Johnson et al. (1980); Johnson & Hara (1987); Bouček (1977)
Chorebus daimenes (Nixon)	–	–	–	+	Spencer (1973)
Cirrospilus ambiguus (Hansson & LaSalle)	+	–	–	–	Hansson & Lasalle (1996)
Closterocerus purpureus (Howard)	–	+	–	–	Murphy & LaSalle (1999)
C. trifasciatus (Westwood)	–	+	–	–	Oatman & Kennedy (1976)
C. utahensis (Crawford)	+	+	–	–	Johnson et al. (1980)
Cyrtogaster vulgaris Walker	–	–	–	+	Nedstam (1983)
Dacnusa spp	+	–	–	-	Poe & Montz (1981)
D. areolaris (Nees)	–	–	–	+	Nedstam (1983)
D. hospita (Förster)	–	–	–	+	
D. maculipes (Thomson)	–	–	–	+	Spencer (1973)
D. sibirica	–	–	–	+	
D. begini	+	+	+	–	Schuster et al. (1991)
Diglyphus intermedius (Girault)	+	+	+	–	Johnson et al. (1980); Trumble & Nakakihara (1983)
D. isaea	+	+	+	+	Hara (1986); Nedstam (1983)
Hemiptarsenus ornatus (Nees)	+	+	–	–	Johnson (1987)
Meruana liriomyzae (Bouèek)	+	+	–	–	Murphy & LaSalle (1999)
Neochrysocharis diastatae (Howard)	+	+	–	–	Hansson (1997)
N. formosa	+	+	–	–	
N. okazakii (Kamijo)	+	–	–	–	Caixia (1997)
Oenonogastra microhopalae (Ashmead)	–	+	–	–	Mc Clanahan (1980)
O. pallipes	–	–	–	+	
Pediobius acantha (Walker)	–	–	–	+	Spencer (1973)
Pnigalio soemius (Walker)	–	–	–	+	
Quadrastichus liriomyzae (Hansson & LaSalle)	+	–	–	–	Hansson & LaSalle (1996)
Halticoptera aenea (Walker)	+	+	+	–	
H. arduine (Walker)	–	–	+	–	Johnson (1987); Stegmaier (1972)
H. circulus (Walker)	+	+	+	–	
H. patellana (Dalman)	–	–	+	–	
Hemiptarsenus zilahisebessi (Erdös)	–	–	–	+	Spencer (1973)
Lamprotatus tubero (Walker)	–	–	+	–	Murphy & LaSalle (1999)
Epiclerus nomocerus (Masi)	+	–	–	–	Franco & Panis (1991)

L. t – *Liriomyza trifolii*; *L. s* – *L. sativae; L. h* – *L. huidobrensis; L. b* – *L. bryoniae*; + – present; (–) – absent

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shows that maximum mortality of larvae is obtained in the CGA 77622 treatment (100%) followed by RO 13-5223E and Methoprene (90%) in controlling the adult emergences (Parrella et al. 1982).

Chemical control

Substances of a chemical nature used for destroying harmful organisms like insects (pests), which are more dangerous for humans/animals and plants, are insecticides, some of which are used against leaf miners and midges (Table 12). Every year, a billion kilograms of insecticide are procured to fight against crop infestations (Alavanja 2009). Eventually, this extensive use of insecticides creates pest resistance, creating micro-evolution. Several biological, genetic, and operational factors bring resistance to insecticides, while genetic factors are considered the most advantageous (Perveen 2012). However, the continuous spreading of insecticide resistance (Table 13) makes it more challenging to control future populations (Stratonovitch et al. 2014).

Integrated Pest Management

Experiments conducted by Nucifora and Calabretta (1985) proved that using yellow sticky traps along with spraying of three pyrazophos treatments at 0.03% against *L. trifolii* on gerbera under glasshouses promoted the activity of biological control agents like (*D. isaea*) upto 90% during spring. Similarly, in gerbera under cold greenhouses, the same combination of sticky traps but with a aqeuous spray of pyrazophos showed 100% larval mortality but not paves the way for the natural enemies (Calabretta & Nucifora 1985).

Mortality of *L. trifolii* increases by spraying *S. carpocapsae* with glycerin as an adjuvant (Broadbent & Olthof 1995), together with the release of the parasitoid *D. begini* for effective management (Sher et al. 2000). Kaspi & Parrella (2006) proved that augmentative release of *D. isaea* with sterile male leaf miner in both ratios (1:10 and 1:3) is found to be efficient due to its synergistic effects than their usage as alone in controlling *L. trifolii.* A combination with plant extracts by Hammad and McAuslane (2010) states in enumerating the effects of *M. azedarach* fruits was more compatible to use with the parasitoid *D. isaea* and, in the meantime reducing leaf miner population to the low level.

The biointensive treatment by releasing *Trichogramma* and applying *M. anisopilae* @ 5 g/L showed a reduction in the blossom midge infestation, and also similar effectiveness was seen with

Table 11. Predators on leaf miners and midges in commercial flowers

Insect species	Type	References
Leaf miners		
Drapetis subaenescens (Collin) *Tachydromia annuluta* (Fallen) *Coenosia attenuata* (Zetterstedt)	Predator	Friedberg and Gijswijt (1983)
Ants (Ponerinae)	Larval predator	Prieto and Chaco de Ulloa (1980)
Spiders (Oxyopidae) Flies (Dolichopodidae)	Adult predator	
Cyrtopeltis modestus (Distant)	Predator	Parrella and Bethke (1982)
Midges		
Web spinning spiders and ants	Pupal predator	Hara and Niino-DuPonte (2002)
Brumoides suturalis (Fabricius) *Cheilomenes sexmaculata* (Fabricius) *Chrysoperla zastrowi* (Esben-Petersen) *Coccinella septempunctata* (Linnaeus) *Coccinella transversalis* (Fabricius) *Illeis cincta* (Fabricius) *Mallada desjardins* (Navas) *Scymnus spp* (Kugelann) *Systasis dasyneurae* (Mani)	Predator	Kamala (2018); CABI International (2022)

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Table 12. Insecticides for the management of leaf miners and midges in commercial flowers

Crop	Chemical	Dosage	Reference
Leaf miners			
Chrysanthemum	Fenvalerate	0.24 g/ha	Alverson and Gorsuch (1982)
	Permethrin 3.2 EC	24.0 g/m^2	Hara (1986)
	Microencapsulated methyl parathion 2.0 F	60.0 g/m^2	
Potato	Cyromazine	75 g/ha	Weintraub (2001)
	Abamectin + Ultrafine oil	10.8 g/ha + 1%	
Gerbera	Cyantraniliprole	1,2,4,8,12,26 fl oz/ 100 gal	Klittich et al. (2016)
Snap beans	Abamectin	9.7 g/ha	Devkota et al. (2016)
	Spinosad	176 g/ha	
Gerbera	Chlorantraniliprole 18.5% SC	0.03%	Smitha et al. (2016)
Potato	Vertimec 18 EC	1 000 mL cp/ha	Barros et al. (2017)
	Chlorantraniliprole 18.5 SC	0.03%	Mohan and Anitha (2017)
Tomato	Tetraniliprole 200 SC	60 and 50 g/ha	Kousika and Kuttalam (2020)
	Chlorantraniliprole 4.3% + Abamectin 1.7% SC	24, 30, 36 and 60 g/ha	Selvaraj et al. (2017)
	Propargite 50 + Bifenthrin 5 SE	621 + 62.1 g/ha	Jat et al. (2018)
	Profenofos + cypermethrin 44 EC	0.044% each	Kotak et al. (2020)
Midges			
Jasmine	Endosulfan 35 EC	0.1%	David et al. (1990)
	Chlorpyriphos 25 EC	0.05%,	
	Monocrotophos 36 SL (or) Quinalphos 25 EC	2 mL/L	
	Monocrotophos	0.1%	David et al. 1992
	Chlorpyriphos	0.05%.	
	Thiacloprid 240 SC	0.6 mL/L	Kamala (2017)
	Carbofuran	20 g/plant	Suganthi et al. (2019)
	Flubendiamide 39.35 SC	0.75 mL/L	Harini et al. (2019)
	Chlorantranliprole 18.5 SC	0.10 mL/L	
	Thiamethoxam 25 WG	0.40 g/L	
Chrysanthemum	Nicotine sulphate or "Black Leaf 40"	–	Essig (1916)
	DDT and parathion aerosol	–	Smith et al. (1948)
Rose	Acephate (Orthene) and dimethoate (Cygon-2E)	–	Stroom et al. (1997)
	Imidacloprid granular insecticide (Merit)	12 sprays applied at 1.8 lbs/ 1 000 ft^2 (80 lbs/acre)	Rosetta et al. (2006)
	Cyfluthrin (Tempo)	45 mL/100 gal	
Daylily	Acetamiprid	10 mL/L of water	Halstead (2012)
	Thiacloprid	20 mL/L of water	

the application of *B. bassiana* @ 5 g/L with a reduction in infestation (Suganthi et al. 2019).

TNAU (2015) used an integrated cost-effective package after experimenting through many field trials which includes weekly collection and destruction of infested buds, proper pruning and maintenance of hygiene, use of light traps (number not specified), spraying of NSKE 5%, monocrotophos 36 SL at 2 mL/L, profenophos 50 EC at 1 mL/L or thiacloprid 240 SC at 1 mL/L can

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Table 13. Insecticide resistance on leaf miners

Insecticide resistance on leaf miners	Reference
Successive applications of methomyl cause outbreaks of *Liriomyza sativae* on tomatoes due to the negative effect of methomyl on parasites	Oatman and Kennedy (1976)
Reports with findings say that *L. trifolii* was more tolerant compared to *L. sativae* to pyrethroids like permethrin and fenvalerate	Mason et al. (1987)
Insecticides like permethrin and bifenthrin become more susceptible to some leaf miner populations in chrysanthemum crop	Parkman and Pienkowski (1989)
Leaf miners *L. trifolii* from Florida and California showed resistance against DDT, cypermethrin, permethrin, methyl parathion and methamidophos	Keil and Parrella (1990)
Populations of *L. trifolii* have shown resistance to abamectin, spinosad and cyromazine	Ferguson (2004)
Maggots of *L. trifoli*i showed low resistance towards Imidacloprid, endosulfan and acephate	Sushila et al. (2010)
Esterases and monooxygenases in *L. sativae* are responsible for resistance development against fenpropathrin	Askari et al. (2014)

minimize the pest management cost and has been recommended to the farmers.

CONCLUSION

In conclusion, dipteran pests in commercial flower crops pose significant challenges to cultivation, thereby impacting both yield and quality among the world countries, being with a great species diversity, well established with a strong reproducing ability and developing against control measures and behavioural adaptation to the changing climatic scenario highlighting the necessity for integrated management and improved biotechnological applications to control the pest status. By combining cultural, physical, biological, host plant resistance and chemical control methods, growers can effectively mitigate the impact of dipteran pests while minimizing environmental harm. However, ongoing research and vigilance are essential to stay ahead of emerging pest threats and ensure the long-term sustainability of flower crop production.

Funding acknowledgement statement: Gratitude to the Dean School of Post Graduates, Tamil Nadu Agricultural University, Coimbatore, for assisting me in financial support for the publication of this review work.

Acknowledgement: My sincere thanks to Horticultural College and Research Institute (TNAU) Coimbatore for providing browsing facilities during the literature collection and a sincere thanks to Agricultural College and Research Institute for providing guidance on scientific writing throughout the review period.

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Received: February 28, 2024
Accepted: May 17, 2024
Published online: July 26, 2024