Influence of Host Crop on Parasitoids (Hymenoptera) of *Liriomyza* spp. (Diptera: Agromyzidae)

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ABSTRACT Predominant parasitoids reared from the four major *Liriomyza* spp. infesting 12 different host crops in North America and Hawaii are reviewed. No single parasitoid species was found to be the predominant biological control agent in most crops. *Diglyphus begini* (Ashmead), *Halticoptera circulus* (Walker), and *Chrysonotomyia punctiventris* (Crawford) were either the first or second most reared species in 60.9, 26.1, and 21.7% of the studies, respectively. Because of uneven distribution of parasitoids among crops, it is suggested that effective biological control may depend on matching the "most effective" parasitoid species complex with a given *Liriomyza* host and crop. Introduction and augmentation strategies for leafminer parasitoids are suggested.

KEY WORDS *Liriomyza* spp., biological control, parasitoids, host crops, host preference

DURING THE PAST decade, several polyphagous species in the agromyzid genus *Liriomyza* achieved significant economic status (Parrella 1982). In North America, most attention has been directed toward *Liriomyza sativae* Blanchard and *Liriomyza trifolii* (Burgess). Minor species in the complex are *Liriomyza brassicae* (Riley) and *Liriomyza huidobrensis* (Blanchard). Of these species, probably the most serious threat to world agriculture is *L. trifolii* (Poe & Montz 1982). The combination of wide host range (Spencer 1981) and high potential for development of resistance to commonly used pesticides (Parrella et al. 1984) substantially contribute to making *L. trifolii* and *L. sativae* serious pests of many vegetable and ornamental crops. On many vegetable crops, such as tomatoes, additional problems are caused when broad-spectrum pesticides, used for control of primary pests, eliminate natural enemies of the leafminers (Johnson et al. 1980a,b).

Current research efforts have led to the development and evaluation of alternatives to chemical controls for effective *Liriomyza* management. These efforts have been predominantly in the areas of cultural controls (Price & Poe 1976, Broadbent 1984, Oetting & Bodri 1984), host-plant resistance (Kennedy et al. 1975, Schuster 1977, Schuster et al. 1979), and biological control (Lindquist et al. 1979, Nakao & Funasaki 1979, Nakao et al. 1981, Lindquist & Casey 1983, Johnson 1984, Parella et al. 1987).

Many economically important host plants of *Liriomyza* species sustain only indirect damage because the marketable produce is nonfoliar (i.e., tomatoes, watermelon), and no strong correlations have been established between leafminer-induced damage levels and yield loss (Wolfenbarger & Wolfenbarger 1966, Levins et al. 1975, Schuster et al. 1976, Waddill et al. 1981, Johnson 1984). In the absence of insecticide use, biological control agents can be effective in maintaining leafminers at subeconomic levels because the injury level at which yield loss becomes physiologically significant is relatively high (Johnson et al. 1983). Efforts to improve the effectiveness of biological control agents of leafminers have been directed predominantly towards crops falling into this category (Lindquist et al. 1979, Johnson et al. 1980a,b, Johnson 1984, 1987).

The objective of this work was to review available information on the distribution and abundance of natural enemies of the important *Liriomyza* species in North America and Hawaii with respect to their insect hosts and crop habitats. Strategies for introduction and augmentation programs are suggested based on current data.

Biological Control Agents of *Liriomyza* spp.

Although several predators of *Liriomyza* spp. have been identified (Genung et al. 1978, Parella et al. 1982), greater attention has been directed towards the more host-specific parasitoids. Forty hymenopterous parasitoid species in four families have been reared from the major *Liriomyza* species in North America and Hawaii (Table 1). In some locations, as many as 20 parasitoid species have been reared from a single *Liriomyza* species (Oatman & Johnson 1981). Many of these parasitoids are in the family Eulophidae. Most parasitoids have

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Table 1. List of hymenopterous species identified as parasites of the major *Liriomyza* spp. in North America and Hawaii

Family	Species	Host *Liriomyza* spp.				Reference
		sativae	*trifolii*	*huidobrensis*	*brassicae*	
Braconidae	*Desmiostoma parvulum* (Wesmael)	X				Krombein et al. (1979)
	Oenongastra microrhopalae (Ashmead)	X				McClanahan (1977)
	Opius aridis Gahan	X				Harding (1965)
	Opius bruneipes Gahan	X				Harding (1965)
	O. dimidiatus	X	X			Harding (1965), Lindquist & Casey (1983)
	Opius dissitus Muesebeck	X	X			Johnson (1987)
	Opius liriomyzae Fischer	X				Krombein et al. (1979)
	Opius suturalis Gahan	X				Harding (1965)
Cynipidae	*Cothonaspis pacifica* Yoshimoto	X	X			Johnson (1987)
	Ganaspidium hunteri (Crawford)	X	X			Johnson (1987)
	Ganaspidium pusillae Weld	X				Harding (1965)
Eulophidae	*Achrysocharella agromyzae* (Crawford)	X	X			Harding (1965), Stegmaier (1972)
	Achrysocharella diastatae (Howard)	X				Stegmaier (1972)
	Achrysocharella fullowayi (Crawford)	X				Harding (1965)
	Achrysocharella variipes (Crawford)	X	X			Harding (1965), Stegmaier (1972)
	Chrysocharis ainsliei Crawford	X	X	X		Johnson et al. (1980a), Chandler (1982), Lange et al. (1957)
	Chrysocharis caribea Boucek	X				Boucek (1977)
	Chrysocharis giraulti Yoshimoto				X	Oatman & Johnson (1981)
	Chrysocharis mallochi Gahan	X				McClanahan (1977)
	C. parksi	X	X	X		Johnson et al. (1980a), Johnson (1984, 1987)
	Chrysocharis viridis (Provancher)	X				McClanahan (1977)
	Chrysonotomyia formosa (Westwood)	X	X			Lema & Poe (1978), Johnson (1987)
	C. punctiventris	X	X		X	Johnson et al. (1980a), Johnson (1987)
	Chrysonotomyia purpurea (Howard)	X				Boucek (1977)
	Closterocerus cinctipennis Ashmead	X	X			Harding (1965), Stegmaier (1972)
	Closterocerus trifasciatus Westwood	X				Oatman (1959)
	Closterocerus utahensis Crawford	X				Johnson et al. (1980a)
	Diaulinopsis callichroma Crawford	X			X	Oatman (1959), Stegmaier (1972)
	Diglyphus begini (Ashmead)	X	X	X	X	McClanahan (1977), Trumble & Nakakihara (1983), Lange et al. (1957)
	Diglyphus intermedius (Girault)	X	X	X	X	Johnson et al. (1980a), Trumble & Nakakihara (1983), Lange et al. (1957), Oatman & Johnson (1981)
	Diglyphus isaea (Walker)		X			Hara (1986)
	D. pulchripes	X	X			McClanahan (1977), Stegmaier (1972)
	Diglyphus websteri (Crawford)	X				Harding (1965)
	Hemiptarsenus semialbiclavus (Girault)	X	X			Johnson (1987)
	Mirzagrammosoma lineaticeps Girault		X			Stegmaier (1972)
	Pnigalio flavipes (Ashmead)	X				McClanahan (1977)
	Zagrammosoma americanum (Girault)	X	X			McClanahan (1977), Chandler (1982)
	Zagrammosoma multilineatum (Ashmead)	X				Stegmaier (1972)
	Zagrammosoma mirum Girault	X				Oatman (1959)
Pteromalidae	*H. circulus*	X	X	X	X	Johnson (1984), Stegmaier (1972), Oatman & Johnson (1981)

been reported in association with *L. sativae* and *L. trifolii*. The smallest number was recorded from *L. huidobrensis*. This bias in the number of reported parasite species may be a function of the small data base for the less important leafminers as opposed to a significant lack of number and diversity of their parasitoids.

Relationship Between Hosts, Parasitoids, and Crops

Parasitoids of the *Liriomyza* pest species may be grouped with respect to the species of agromyzid host, the crop host of the agromyzid, and the locality of the crop (Table 2). Examination of

Table 2. List of major *Liriomyza* spp. in North America and Hawaii with associated predominant hymenopterous parasites found in various host crops

Liriomyza spp.	Crop	Locality[a]	Predominant parasites[b] 1st Species	Predominant parasites[b] 2nd Species	References
L. sativae	Alfalfa	CA	*Chrysocharis ainsliei*	*Halticoptera circulus*	Jensen & Koehler (1970)
	Beans (bush)	HI	*Diglyphus begini*	*Chrysocharis parksi*	Johnson (1984)
	Beans (pole)	HI	*D. begini*	*H. circulus*	Mothershead (1978)
	Cantaloupe	TX	*Chrysonotomyia* spp.	*Chrysocharis ainsliei*	Chandler (1982)
		CA	*D. begini*	*H. circulus*	Oatman (1959)
	Celery	FL	*Chrysonotomyia formosa*	*Diglyphus intermedius*	Tryon & Poe (1981)
		CA	*Diglyphus intermedius*	*D. begini*	Trumble & Nakakihara (1983)
	Cucumber	HI	*D. begini*	*Chrysonotomyia punctiventris*	Mothershead (1978)
	Tomato	CA	*Chrysonotomyia punctiventris*	*D. begini*	Johnson et al. (1980a)
		CA	*D. begini*	*Chrysonotomyia punctiventris*	Johnson et al. (1980b)
		CA	*Chrysocharis parksi*	*D. begini*	Zehnder & Trumble (1984)
		OH	*Diglyphus pulchripes*	*Opius dimidiatus*	Lindquist et. al. (1979)
		ON[c]	*D. begini*	*O. dimidiatus*	McClanahan (1975)
		FL	*C. formosa*	*D. intermedius*	Schuster et al. (1979)
		HI	*C. punctiventris*	*D. begini*	Mothershead (1978)
	Watermelon	HI	*C. punctiventris*	*H. circulus*	Johnson (1987)
L. trifolii	Celery	CA	*D. intermedius*	*D. begini*	Trumble & Nakakihara (1983)
	Chrysanthemum	CA[c]	*D. intermedius*	*D. begini*	Parrella et al. (1986)
		HI	*D. intermedius*	*Ganaspidium hunteri*	Hara (1986)
	Gypsophila	FL	*Chrysonotomyia* spp.	*D. intermedius*	Price & Stanley (1982)
L. huidobrensis	Onion	HI	*Halticoptera circulus*	*C. parksi*	Johnson (1984)
	Spinach	CA	*D. intermedius*	*D. begini*	Lange et al. (1957)
L. brassicae	Cabbage	CA	*D. begini*	*H. circulus*	Oatman & Platner (1969)

[a] CA, California; FL, Florida; HI, Hawaii; OH, Ohio; ON, Ontario, Canada; TX, Texas.
[b] Reared from foliage samples.
[c] Greenhouse conditions.

the first and second most abundant parasitoids reared from the various *Liriomyza* species revealed much variation among hosts and crops. Nine species were found as either the first or second most abundant species in reported studies (Table 2). Of these, *Diglyphus begini* (Ashmead) was either the first or second most reared species from the four leafminer species in 60.9% of the studies. *Halticoptera circulus* (Walker) and *Chrysonotomyia punctiventris* (Crawford) were the first or second most reared species in 26.1 and 21.7% of the studies, respectively. Within a given crop, the major parasitoids have been found consistently (Table 2). The most frequently reared parasitoid species from *L. sativae* on tomatoes in Ontario, California, and Hawaii were *D. begini* or *C. punctiventris*, or both (McClanahan 1975, Mothershead 1978, Johnson et al. 1980a,b, Zehnder & Trumble 1984), but in Florida, *Chrysonotomyia formosa* (Westwood) and *Diglyphus intermedius* (Girault) were the major parasitoids and in Ohio they were *Diglyphus pulchripes* (Crawford) and *Opius dimidiatus* Muesebeck. There are no records of the presence of *D. begini* or *C. punctiventris* in these two locations. *D. intermedius* is present in the tomato agroecosystem in California and Hawaii but does not play a substantial role in regulating the leafminers (Mothershead 1978, Oatman & Johnson 1981).

Variation also may be found when the major leafminer species differ between adjacent crops. Zehnder & Trumble (1984) found that significantly more *Chrysocharis parksi* Crawford were reared from *L. sativae*-infested tomatoes than from celery, where *L. trifolii* was more dominant. In the celery, significantly more *D. intermedius* were found. *D. begini* was present in large numbers in both crops. Data on the predominance of *D. begini* among crops (Table 2) support their conclusions. *D. begini* was found as an important parasite of *Liriomyza* spp. in 8 of the 12 crops listed. In contrast, *C. parksi* and *D. intermedius* were dominant in only three and five crops, respectively. Studies conducted by Johnson (1984) on beans and onions also support the idea that leafminer parasitoids are not evenly distributed among crops where dominant *Liriomyza* species are different. Attempts at augmentation of leafminer parasitization in onions by planting strips of beans adjacent to onion plots were not successful. Fewer parasitoids (four) were found to attack *L. huidobrensis* infesting the onions compared with the number (eight) parasitizing *L. sativae* in the beans. Parasitization of *L. huidobrensis* by larval parasitoids such as *D. begini* was minimal.

Although *L. sativae* and *L. trifolii* have wide host ranges, this phenomenon is unusual for the Agromyzidae, where true polyphagy is rare and limited to 10 species in the family (Spencer 1964, 1977). Vinson (1975) suggested that phytophagous insects may escape attack by parasitoids by broadening host-plant preferences to include those plant species lacking cues that attract or orient parasitoids. As shown above, even the most predominant parasitoid of the *Liriomyza* spp., *D. begini*, was only dominant in ca. 60% of the host crops (Table 2). Price (1981) suggested that several factors important to the host's survival may change with a shift in host plants. These factors include changes in host-plant odors utilized by natural enemies to locate the habitats of their insect hosts and changes in the physical characteristics of the host plant that could provide increased protection for the herbivore. Price et al. (1980) stated that extensions in host-plant ranges may be reinforced by decreased parasitoid effectiveness on novel host-plant species. They hypothesized that native herbivores may expand their host ranges when exotic agricultural crops are introduced. These species then become pests because their natural enemies have not evolved corresponding host-habitat and host-finding abilities. However, expansions in host-plant range may be limited by natural enemy faunas already associated with new host plants (Price et al. 1980). Askew & Shaw (1978) observed that parasitoids favor a range of insect hosts related by a particular plant or habitat as opposed to phylogenetically related insect hosts. Parasitoids in the genus *Sympiesis*, which predominantly attack leafmining Lepidoptera, also parasitize leafminers in the orders Coleoptera, Diptera, and Hymenoptera (Cushman 1926). This type of parasite behavior could explain the numerous parasite species associated with *L. sativae* and *L. trifolii*.

Increased Effectiveness of Biological Control

Efforts have been made to conserve natural enemies of the agromyzid leafminers by elimination of pesticide treatments (Johnson 1987), reduction of pesticide use (Genung et al. 1978), or substitution of broad-spectrum pesticides with more selective materials (Johnson et al. 1980a,b, Parrella et al. 1983). These conservation methods do not involve the active selection and dispersal of biological control agents. However, classical biological control and augmentation methodologies require that the "most effective" natural enemies be utilized for control of the pest. Recognition of these natural enemies is essential with limited funding and facilities. Indiscriminate releases of parasitoids in introduction and augmentation programs may be unsuccessful unless natural enemies are matched with those crop habitats where they are most efficient.

Given the polyphagous nature of *L. sativae* and *L. trifolii*, effective biological control over a wide area supporting many different host crops may depend on the introduction of many different parasitoid species. This strategy could provide a variety of parasites capable of efficient operation within the various crop host habitats of the *Liriomyza* spp. If control is desired (through augmentation) on a short-term basis within specific crops, then it may be necessary to release those parasite species that are most efficient within the given host crop. This strategy becomes extremely important considering the logistics and expense of commercial mass rearing of three to five species of *Liriomyza* parasites. Before inoculative or inundative releases will be effective, preferences of the parasites for their leafminer hosts and the crop host habitats have to be understood.

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