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Biological Control of *Liriomyza* Leafminers in the Pacific Basin

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Abstract—The importance of agromyzid leafminers in the genus *Liriomyza* in the Pacific Basin has increased significantly since 1980. This change in pest status has been associated with the introduction of *Liriomyza trifolii* and *L. sativae* to many Pacific islands ranging from Hawaii to Guam above the equator and French Polynesia to New Caledonia below. These species are predominantly pests of vegetable and ornamental crops. On most vegetable crops the leafminers only affect the non-marketable, leafy portions of the plant, reducing photosynthetic capability. Relatively high populations can be tolerated without economic damage, so the potential to control *Liriomyza* through natural enemies is high.

Numerous parasitoid species have been introduced for *Liriomyza* control in Hawaii. These include the effective species *Chrysocharis oscinidis*, *Chrysonotomyia punctiventris*, *Ganaspidum utilis*, and *Halticoptera circulus*. An indigenous species, *Diglyphus begini*, also occurs in Hawaii. Those providing high levels of control in Hawaii have been introduced into Guam, Pohnpei and Tonga. Research in Hawaii indicates that multiple natural enemies are needed to produce *Liriomyza* control in a range of crops. Parasitoid presence and effectiveness can differ significantly between crops, with from 6 to 12 species occurring in particular crops. One of the most significant species introduced to Hawaii is *Ganaspidium utilis*, which quickly made an impact on leafminer densities, successfully competing with previously established parasitoids. Strains of *Diglyphus begini*, highly resistant to pesticides, have been found in Hawaii and laboratory selection has increased resistance in *Ganaspidium utilis*. Research is proceeding on the use of entomopathogenic nematodes against *Liriomyza*.

Introduction

Several members of the genus *Liriomyza* are pests throughout the Pacific Basin (Parrella 1982, Waterhouse & Norris 1987). These include *Liriomyza sativae* Blanchard, *Liriomyza trifolii* (Burgess), *Liriomyza huidobrensis* (Blanchard), and *Liriomyza brassicae* (Riley). Due to its wide host range and ability to develop pesticide resistance rapidly, *L. trifolii* has gained worldwide prominence within the last decade, following its accidental introduction into numerous countries (Parrella 1987). When introduced without their natural enemies and environmental conditions are favourable, the above species of *Liriomyza* may develop devastating populations on a wide range of vegetable and ornamental crops. Recent studies by Carolina et al. (1992) suggest that *L. sativae* has the genetic plasticity to increase its host plant range when introduced into isolated areas (e.g., new island environments) where its common host plants are scarce or absent. Of even greater concern is the possibility that, by exploiting new host plants, a *Liriomyza* species may escape its natural enemies (Herr 1987). Normally effective natural enemies may not be attracted to the new host plants or leafminers developing on the new host may be unsuitable for natural enemy survival or reproduction.

Effectiveness of natural enemies of *Liriomyza* varies with the crop. Johnson & Hara (1987) suggest that biological control introduction and augmentation programs should consider the host crops in which control is desired, so that the most effective leafminer parasitoid is matched with the crop. Due to the polyphagous nature of these *Liriomyza* species, proper identification of the pests and their numerous associated parasitoids is particularly important (Johnson & Hara 1987).

Waterhouse & Norris (1987) list more than 40 parasitoid species that have been reared from *L. sativae*, *L. trifolii* and *L. huidobrensis*. Most of these have not been established in the Pacific, although considerable potential exists to do so.

Importation of Parasitoids

The Hawaii Department of Agriculture has introduced and established by far the largest number of leafminer parasitoids (Funasaki et al. 1988, Waterhouse & Norris 1987). Of these, *Ganaspidium utilis* Beardsley has probably made the greatest impact. This species was initially identified as *Cothonaspis* n. sp. (Nakao et al. 1981), but later determined as *Ganaspidium hunteri* (Crawford) (Beardsley 1986). More recently Beardsley (1988) concluded that the introduced species identified as *G. hunteri* was really an undescribed species which he then named *G. utilis*. It is a larval/pupal parasitoid, with females producing about 50 progeny during their lifetime with a sex ratio of 1:1.4 males:females (Petcharat 1987, Petcharat & Johnston 1988). Johnson (1987) and Hara (1986) reported that *G. utilis* had become a major parasitoid in watermelons on (*L. sativae* & *L. trifolii*) and chrysanthemums (on *L. trifolii*), respectively. Studies on the island of Hawaii suggest that *G. utilis* may be an important parasitoid of *L. trifolii* and *L. huidobrensis* on celery (M.W.J., unpublished data).

Another important parasitoid introduced by the Hawaii Department of Agriculture in 1977 was *Chrysonotomyia punctriventris* (Crawford) (Higa 1980). This larval parasitoid was found to have significant impact on *L. sativae* and *L. trifolii* in watermelons (Johnson 1987); on *L. sativae* in green onion; on *L. sativae* and *L. trifolii* in beans; and on *L. sativae* and *L. trifolii* in tomato (Herr 1987).

Consignment of Parasitoids to Pacific Islands

Natural enemies of *Liriomyza* spp. have been sent from Hawaii to Guam, Tonga and Pohnpei. Although *L. sativae, L. brassicae* and *L. trifolii* are present on Guam, only the latter species causes economic problems (Schreiner et al. 1986). Following the introduction of *L. trifolii* around 1978, it became a problem on beans, causing premature leaf drop and yield losses. Insecticides often failed to control the leafminer. At times, leaves were completely mined due to high leafminer densities. Although leafminers were present on many vegetables they were not a problem until 1985, when increased insecticide use for control of *Thrips palmi* Karny on cucurbits led to increased leafminer populations. Natural enemies recorded on Guam by Schreiner et al. (1986) were the eucoilids *Gronotoma micromorpha* (Perkins) and *Disorygma pacifica* (Yoshimoto), and the eulophids *Hemiptarsenus semialbiclavus* Girault, and *Chrysonotomyia formosa* (Westwood). On beans, the eucoilid fauna was sparse, parasitizing about 2 percent of the leafminers. *H. semialbiclavus* and *C. formosa* were the dominant parasitoids. On cole crops and cucurbits, *G. micromorpha* and *D. pacifica* were the dominant parasitoids, closely followed by *H. semialbiclavus* and *C. formosa.* On tomato, *H. semialbiclavus* was the most abundant parasitoid, but the eucoilids were also important. In attempts to introduce additional agents, *Diglyphus begini* and *Ganaspidium utilis* were released. Three releases of low numbers of *D. begini* were made, but it did not become established. Groups of 200 *G. utilis* were released at several locations over several months and resulted in establishment. *G. utilis* then became the dominant parasitoid on beans, parasitizing up to 78 percent of the leafminers, so that leafminers are no longer a problem in unsprayed plantings. Yudin et al. (1991) reported the capture of *G. utilis* in pan traps placed in watermelon plantings in Guam, suggesting that the parasitoid was common in that crop.

A biological control program for *L. trifolii* was initiated in Tonga in 1988 by the Tongan-German Plant Protection Project after the agromyzid was discovered in 1985 (W.C. Mitchell, personal communication). It became a serious pest on many vegetable crops, the most important hosts being watermelon, pumpkin, tomato, bean and Irish potato. *Chrysocharis oscinidis* (Ashmead) (= *C. parksi*) and *G. utilis* were obtained from Hawaii and colonies established. Releases totalling more than 4,000 individuals of each parasitoid were made in 11 different locations from September to December 1988. Both species became established by 1989 and chemical control of *L. trifolii* was no longer necessary.

Need to Conserve Biological Control Agents for IPM

Disruption of the biological control of agromyzid leafminers may occur in two ways. Firstly, leafminers may be introduced into new locations (e.g., Guam, Hawaii) without effective natural enemy complexes. This problem may be alleviated by introduction programs, such as discussed above. More commonly, pesticide use eliminates or suppresses leafminer parasitoids, promoting increases in *Liriomyza* densities which are classified as either pest resurgences (Johnson 1987) or secondary pest upsets (Oatman & Kennedy 1976, Johnson et al. 1980a). Approaches to conserving natural enemies within agroecosystems may be either direct or indirect. Direct approaches are methods by which adverse agricultural practices are modified to alleviate their detrimental impact on biological control agents as well as the manipulation of natural enemy populations to increase their effectiveness. These approaches may be quite specific for a given pest/natural enemy association or agroecosystem. They include the use of biological control in combination with non-disruptive, non-chemical control methods, the use of supplemental foods and behavioral chemicals to increase natural enemy effectiveness, and the use of selective chemical methods. Indirect approaches are methods by which the necessity and timing of adverse practices may be determined. These apply to most crop production systems and may or may not reduce the impact of adverse practices on natural enemies. They include the use of sampling methods to estimate the abundance of pest species and the potential impact of associated natural enemies. They also include the use of economic thresholds (action thresholds, density treatment levels, etc.) to better determine the need for management intervention.

Development of Economic Thresholds

Various phases of work on this area will be discussed in the context of five crop systems: beans, tomato, watermelon, celery and green onion. The crops vary with respect to the major leafminer species and the relative physiological and economic value of the plant structure attacked.

(i) *Beans*

On most vegetable crops attacked by *Liriomyza* spp., the foliage is the only structure mined, resulting mainly in the reduction of photosynthesis (Johnson et al. 1983). Since the leaves are usually not marketed, the damage caused is not of cosmetic importance. Work by Schreiner et al. (1986) on yardlong beans in Guam showed a significant reduction in yield, from 300 kg to 75 kg beans per 100 m row, as mean *L. trifolii* densities increased from 5 to 70 mines per leaf. Above 40 mines per leaf, virtually all photosynthetic tissue was destroyed as larvae matured, and no increase in yield loss occurred with further increase in leafminer densities. Yield losses were nonlinear with the best fitting equation being:

$$Y = 269.53 - 7.878x + 0.077x^2$$

where Y = bean yield (kg/100 m) and x = mean number of *L. trifolii* mines per leaflet (seasonal average). Although an economic threshold was not established, a small number of mines per leaflet depressed yield sharply. Extrapolating from the above equation, a 5 and 10 percent yield loss can be estimated to occur at a mean seasonal density of about 1.8 and 3.5 mines per leaf, respectively. Given this level of impact, biological control would have to be highly effective to prevent leafminer-induced yield losses.

(ii) *Tomato*

In Hawaii mining damage by *L. sativae* and *L. trifolii* did not reduce tomato yields by 10 percent until peak seasonal densities of *Liriomyza* larvae surpassed about 8 leafmines per tomato leaflet (M.W.J., unpublished data). Below 6 leafmines per tomato leaflet yield losses were negligible. Yield response of tomatoes to peak densities of live *Liriomyza* per tomato leaflet may be expressed as:

$$Y = 421.9 - 0.78x + 0.57x^2$$

where Y = tomato yield in kg/plot and x = peak seasonal number of live *Liriomyza* leafminers per leaflet. Additionally, there was a correlation between yield losses and estimated leafminer-induced reductions in photosynthesis (Johnson et al. 1983).

In contrast to the findings on bean discussed above, *Liriomyza* densities that affect tomato are relatively high, which means that biological control does not have to be extremely effective to limit yield losses in tomatoes. Field surveys conducted by M. Purcell (unpublished data) in Hawaii showed that peak leafminer densities in five tomato plantings on the islands of Maui and Hawaii did not surpass the level of 6 mines per leaflet.

(iii) *Watermelon*

Nominal thresholds (Poston et al. 1983) were established for use in a watermelon IPM program in Hawaii (Johnson et al. 1989) and later introduced to Guam (Yudin et al. 1993). Thresholds were based on type of feeding injury, rate of pest population increase, and growers' estimates of levels of pest-induced plant injury sustainable without significant yield loss (Johnson et al. 1989). For *L. sativae* and *L. trifolii*, treatments were made when 20 leafminer larvae were present per leaf and when vines were less than 50 cm in length. However, when vines were greater than 50 cm in length, 15 larvae on any two consecutive sampling dates (1 week apart) or 35 larvae per leaf on any one sample date led to treatment. In combination with weekly monitoring of watermelon plantings and selective methods of control for melon fly, *Dacus cucurbitae* Coquillett, these guidelines allowed growers to reduce pesticide applications for *Liriomyza* (Johnson 1991). Reduction of the frequency of pesticide applications allowed increased survival of biological control agents (Johnson 1987), thereby further reducing the need to apply insecticides. Surveys conducted in 43 watermelon plantings in Oahu and Molokai showed that *L. sativae* and *L. trifolii* were present in crops on more than 96% of the survey dates, but treatment levels were surpassed on less than 9% (Johnson et al. 1989). On Oahu, pesticide use for *Liriomyza* control was reduced by more than 90%.

Studies in Guam using an IPM program based on that in Hawaii showed that the thresholds applied there also.

(iv) *Celery*

Liriomyza huidobrensis and *L. trifolii* are the major pests of celery in the Kamuela area of the island of Hawaii. Unlike injury to bean, tomato, and watermelon, that to celery may include the stalks as well as the foliage. Mined stalks constitute direct injury to the marketed portion of the plant, in contrast to the leaves which are mostly removed for sale and generally not eaten. Studies on the impact of *L. trifolii* on celery in California (Trumble et al. 1985) indicate that the foliar injury may delay the celery harvest, but not substantially reduce the value of the produce due to impaired cosmetic appearance. In Florida, Foster & Sanchez (1988) reported that celery had to be protected only in the later stages of the crop in order to reduce cosmetic injury to the foliage caused by *L. trifolii.* In contrast to *L. trifolii, L. huidobrensis* frequently mines the stalks as well as the leaves. Mined stalks can result in reduced market price or even rejection at the wholesalers if the damage is extensive. Studies in Hawaii indicate that *L. trifolii* commonly infests celery foliage, but rarely the stalks (M.W.J., unpublished data). Nevertheless, growers frequently direct pesticide applications at *Liriomyza* populations in celery plantings, regardless of the species. This results in destruction of effective natural enemies (e.g., *Halticoptera circulus, Ganaspidium utilis, Chrysocharis oscinidis*). Comparison of an intensely sprayed celergy planting with one receiving no insecticides showed that *L. huidobrensis* injury to the stalks was not significantly different and levels of leafminer injury to the celery foliage, where *L. trifolii* was much more common, was greater in the treated planting than the untreated planting. Future studies in this crop system will be directed at more effective management of *L. huidobrensis* because, without insecticide interference, adequate biological control of *L. trifolii* is possible. Of some influence in this system are the cole crops which are commonly grown adjacent to celery and serve as hosts for *L. huidobrensis* populations, although they are not affected economically.

(v) *Green onion*

Studies by Carolina et al. (1992) indicate that isolated populations of *L. sativae* on the island of Oahu broadened their host range to include green onion. As with celery, leafminer injury to green onion is cosmetically damaging and may reduce market value. Although no economic thresholds have been developed, they would most likely be less than two mines per green onion leaf. *L. sativae* populations often surpass this number in both treated and untreated plantings. Unfortunately, *L. sativae* populations infesting green onions have a less diverse parasitoid fauna than those on other vegetable crops (e.g., beans, tomatoes, cucumber, watermelon) (Herr 1987). Thus, even when attempts are made to conserve natural enemies, biological control may not be effective enough to maintain *L. sativae* densities below the cosmetic thresholds dictated by the market place. Possible approaches are 1) to introduce more effective natural enemy species, 2) to augment natural biological control by mass releases of parasitoids, or 3) to select for increased searching capacity within the onion habitat (or some other vital parameter). All three options require that the natural enemy be matched with the crop system to ensure maximum effectiveness (Johnson & Hara 1987).

Use of Routine Monitoring to Time Management Actions

The importance cannot be stressed enough of routine monitoring of populations of *Liriomyza*, other pests and associated natural enemies in order to establish correct timing of pesticide applications. Given the potential for resurgences and secondary pest outbreaks of *Liriomyza* spp., only monitoring can provide the information necessary for optimal management decisions. Increased efforts should be made to develop simple and effective monitoring programs. Work by Lynch & Johnson (1987) in watermelons showed that significant differences exist in *Liriomyza* densities in foliage taken from the basal to the distal portions of the watermelon vine. Similar results were obtained for the parasitoid *Chrysonotomyia punctiventris*. However, once the full foliage canopy was established, stratification of the plant to increase the precision of sample estimates was not justified since there was only a small increase in precision (<20 percent). However, it was desirable to take foliage samples further than 0.5 m from the basal and distal ends of the vine in order not to over- or under-estimate the mean *Liriomyza* density. Additionally, only medium sized leaves should be sampled instead of either small or large leaves in which leafminer densities would be under- and over-estimated, respectively.

Use of Selective Pesticides to Conserve Natural Enemies

Several studies have shown the detrimental effects of broad spectrum pesticides on *Liriomyza* parasitoids (Johnson et al. 1980a,b, Trumble & Toscano 1983). As new pesticides are introduced to the Pacific, it would be beneficial to determine the susceptibilities of common *Liriomyza* spp. and their natural enemies and this has been done in Hawaii for the pyrethroids permethrin and fenvalerate (Mason et al. 1987). Susceptibilities of several populations of the parasitoids *D. begini* and *G. utilis* have been quantified for permethrin, fenvalerate, methomyl and oxamyl (Rathman et al. 1990; R.J. Rathman, unpublished data). Rathman et al. (1992) showed that the above compounds affected male *D. begini* more than females. Additionally, they showed that, when the synergyst piperonyl butoxide was added to fenvalerate and oxamyl, it increased the mortality of *D. begini*. Synergism of fenvalerate by piperonyl butoxide had a greater effect on females than on males.

Advances in Natural Enemy Augmentation

Augmentation of biological control agents should be employed only after the establishment and conservation of effective natural enemies has failed to provide effective control. Due to the nature of augmentation efforts, they often cost more than introduction and conservation and often have to be repeated.

Inoculative Releases of *Diglyphus begini*

Johnson & Hara (1987) reported that *D. begini* was the first or second most common parasitoid in 60.9 percent of the studies reviewed on biological control of *Liriomyza* spp. in North America and Hawaii. Given its effectiveness in a wide variety of crop systems, *D. begini* is an appropriate natural enemy for which mass rearing and inoculative techniques should be developed. Studies conducted on inoculative releases of *D. begini* for control of *L. trifolii* on chrysanthemums (Jones et al. 1986, Parrella et al. 1987) and marigolds (Heinz & Parrella 1990) indicated that this was a viable option for leafminer control. Parrella et al. (1989) provided a detailed description of a mass rearing technique for the parasitoid using chrysanthemum as the leafminer host plant. Recurring production costs were 97 U.S. dollars per day for 5,000 *D. begini.*

Rathman et al. (1991) developed a mass rearing technique for *G. utilis* which could produce 5,000 parasitoids for about 36 U.S. dollars per day, but no attempts have yet been made to develop an augmentation program.

Pesticide-resistant Parasitoids

Conservation of *Liriomyza* natural enemies would be greatly simplified if parasitoids had significant levels of resistance to commonly used compounds. Procurement of resistant strains may be accomplished either by discovery of geographical strains exhibiting high levels of resistance or by laboratory selection (Croft 1990). Mason & Johnson (1988) reported high levels of tolerance in *D. begini* to permethrin and fenvalerate compared to *Chrysocharis oscinidis*, *Chrysonotomyia punctiventris*, *Halticoptera circulus* (Walker), and *Ganaspidium utilis.* Later, Rathman et al. (1990) discovered geographical strains of *D. begini* which exhibited significantly different levels of resistance to oxamyl, methomyl, permethrin, and fenvalerate. Pyrethroid-resistant *D. begini* strains were not killed at recommended application rates of fenvalerate and permethrin. Work is in progress to determine the mode of resistance and its stability in *D. begini.*

Laboratory selection for increased fenvalerate resistance in *G. utilis* is also in progress (M.W. Johnson & B.E. Tabashnik, unpublished data). A selected strain currently exhibits LC_{50} levels greater than twice the field rate. The aim is to increase LC_{50} levels to 10 times the recommended application rate.

Development of a Nematode Strain to Attack *Liriomyza* spp.

Harris et al. (1990) reported that *Liriomyza* spp. could be controlled in greenhouse chrysanthemums using the nematode *Steinernema carpocapsae* (Rhabditida: Steinernematidae). Research in Hawaii showed that the infective stage of *S. carpocapsae* could kill first instar *L. trifolii* larvae within minutes of entering the individual (L. M. LeBeck, unpublished data). Greater time was required for mortality as larvae increased in size. The nematode was unable to enter day-old puparia or adults. Selection for enhanced ability of *S. carpocapsae* to find and enter leafminer mines via the oviposition hole was attempted with encouraging laboratory results (L.M. LeBeck, unpublished data). Field results are pending.

The Future

Natural enemy introductions should continue where effective biological control has not been achieved on all crops. Studies should continue on the crop habitat preferences of the major leafminer parasitoids so as to maximize the effectiveness of introduction and augmentation programs. Studies should continue on the impact of *Liriomyza* damage on crop yields and monitoring to provide guidelines for determining density levels for treatments in IPM programs and to quantify the levels of biological control necessary. Sampling programs suitable for grower and consultant use should be developed to permit the implementation of treatment thresholds. Information should be collected on the impact of commonly applied pesticides on predominant parasitoids in crops where leafminers occur with other pest species and where natural enemies are reduced in abundance by pesticide use. Efforts should be made to identify both selective pesticides and natural enemy populations exhibiting resistance to commonly used pesticides. Major parasitoids (e.g., *G. utilis*) should undergo laboratory selection for enhanced pesticide resistance.

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