HAYATI
Journal of Biosciences

Vol. 30 No. 3, May 2023 432-444
DOI:10.4308/hjb.30.3.432-444
ISSN: 1978-3019
EISSN: 2086-4094

Evaluation of the Community Structure Leafminer Fly, *Liriomyza* spp. (Diptera: Agromyzidae) and Their Parasitoids on Various Host Plant Families in Bali Province

I Wayan Supartha[1*], I Wayan Susila[1], Aunu Rauf[2], B. Merle Shepard[3], I Wayan Eka Karya Utama[4], I Wayan Sandikayasa[5], I Kadek Wisma Yudha[4], Putu Angga Wiradana[6]

[1]*Laboratory of Integrated Pest Management (IPMLab), Faculty of Agriculture, Udayana University, Denpasar City, Bali 80231, Indonesia*
[2]*Department of Plant Protection, Faculty of Agriculture, Institut Pertanian Bogor, IPB University Campus Dramaga, Bogor 16680, Indonesia*
[3]*Coastal Research and Education Center, Clemson University, 2700 Savannah Highway, Charleston 29414, USA*
[4]*Doctoral Student of Agricultural Sciences, Faculty of Agriculture, Udayana University, Denpasar City, Bali 80231, Indonesia*
[5]*Graduate Program of Biotechnology, Faculty of Agriculture, Udayana University, Denpasar City, Bali 80231, Indonesia*
[6]*Study Program of Biology, Faculty of Health, Science, and Technology, Universitas Dhyana Pura, Badung, Bali 80361, Indonesia*

ARTICLE INFO

Article history:
Received April 14, 2022
Received in revised form August 15, 2022
Accepted November 11, 2022

KEYWORDS:
Liriomyza spp.,
Chickpea,
Biocontrol,
Parasitoids,
Crop protection

ABSTRACT

Leaf miners, *Liriomyza* spp., have developed as a severe pest in recent years, reducing the production of several ornamental and crops in Indonesia. As a result, monitoring and control mechanisms have been proposed. This research aimed to investigate community structure and identify *Liriomyza* spp., which impacts crops and natural parasitoids in Bali Province. Leaf samples of vegetables, ornamental plants, and related species were collected in all regencies/cities of Bali Province in 2019 and 2020 and preserved in the laboratory for observation and counting of leaf miners and related parasitoids. The findings revealed that four *Liriomyza* spp. were detected in host plants, namely *Liriomyza sativae* Blanchard (Diptera: Agromyzidae), *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae), *Liriomyza chinensis* Kato (Diptera: Agromyzidae), and *Liriomyza trifolii* Burgess (Diptera: Agromyzidae). Asteraceae species were the most common host plants attacked by leaf miners in the field. The same occurrence was discovered at both heights (high and lowlands). The dry season is the most crucial component in the abundance of *Liriomyza* spp. In addition, parasitoids of the type *Opius cromatomiyae* Belokobylskij and Wharton (Hymenoptera: Braconidae) and *Hemiptarsenun varicornis* Girault (Hymenoptera: Eulophidae) were identified in abundance in Asteraceae plants. Similarly, the parasitization rate of the two parasitoids was found to be high in plants of the Asteraceae and Brassicae families. This approach highlights the decision-making process for controlling *Liriomyza* spp. on diverse host plant families by developing ecologically beneficial and sustainable parasitoids.

1. Introduction

The *Liriomyza* spp. leafminer is a polyphagous pest of vegetables and other horticulture crops that has the potential to reduce agricultural output globally (Gao and Reitz 2017). *Liriomyza trifolii* Burgess (Diptera: Agromyzidae) was discovered in America and spread over the country (Scheffer *et al.* 2006). Aside from that, the three most abundant leafminer pests in China are *L. trifolii*, *L. huidobrensis*, and *L. sativae*. They each have a unique ability to compete with their host plants. (Chang *et al.* 2020; Gao and Reitz 2017).

Nine leafminer species have been documented in Indonesia, with several being found in Bali Province, including *L. huidobrensis*, *L. sativae*, and *L. brassica* (Pratama *et al.* 2013; Supartha 1998; Supartha and Sasromarsono 2000). Meanwhile, the most recent investigation showed the existence of *L. chinensis* in shallot plantations by finding DNA barcodes (Hamid *et al.* 2018). *L. trifolii* has also been observed to invade

* Corresponding Author
E-mail Address: yansupartha@yahoo.com

Chrysanthemum sp. in Bali Province. Aside from Bali, leafminer fly infestations on shallot types have been observed in the Palu Valley, Central Sulawesi, with attack intensity reaching 65.9% (Shahabuddin *et al.* 2012). An *L. sativae* infestation on cucumber and potato farms in West Java reduced output by up to 60% (Rauf *et al.* 2000; Supartha 2002).

Efforts to manage *Liriomyza* spp. in most regions of Indonesia increasingly depend on synthetic chemicals such as insecticides, which have major environmental and human health problems (Supartha *et al.* 2020; Wahyuni *et al.* 2017a; Yuliadhi *et al.* 2021a). On the other side, the usage of pesticides allows for the development of pest resistance to synthetic chemicals that are still widely utilized in agriculture (Anderson *et al.* 2019; Deguine *et al.* 2021; Living with Resistance project 2018). The widespread use of insecticides ecologically reduces non-target targets organisms like natural enemies, parasitoids and predators, and other biological agents, disrupting the agroecosystem's stability (Bottrell and Schoenly 2018; Hill *et al.* 2017; Messelink *et al.* 2014). Based on this, it is required to conduct comparatively safer pest management efforts, such as using biological agents, which are more ecologically friendly and have fewer health-related negative impacts (Nicolopoulou-Stamati *et al.* 2016).

Biological control is a supportive activity involving parasites, diseases, and predators to manage pests and their impact (UC IPM 2014). Many studies have highlighted the use of parasitoids in the control of leafminer fly attacks in various regions, including 23 species in the Nearctic region, 28 species in Japan, 72 species in South America, 14 species in Florida, 8 species in Malaysia, 18 species in Vietnam, and several reports from Europe and Turkey (Liu 2009). Until recently, 17 different parasitoids were identified as effective control agents for *Liriomyza* spp. in Indonesia.

Susila *et al.* (2005) discovered up to eight different species of parasitoids of *Liriomyza* spp. have been discovered in various legumes, including *Neochrysocharis okazakii, Asecodes deluchii, Hemiptarsenus varicornis, Pnigalio katonis, Quadrasticus Liriomyzae, Ophius chromatomiyae, Sphegigaster* sp., and *Closterocerus* sp. Six species are members of the Eulophidae and Braconidae families (Susila *et al.* 2005). The many forms of parasitoids and pests described in the literature demonstrate how they are impacted by biotic and abiotic stimuli (Durocher-Granger *et al.* 2021; Harush *et al.* 2021; Kruitwagen *et al.* 2018; Marchioro and Foerster 2016). Temperature, rainfall, season, and geography have the greatest influence on biotic variables. Therefore natural enemies play an essential role in pest infestations and the prevalence of natural enemies in an ecological community (Chidawanyika *et al.* 2012; Clavijo McCormick 2016; Skendži *et al.* 2021; Thomson *et al.* 2010).

However, till now, no comprehensive research on the community structure of the leafminer fly and its parasitoids on numerous host plant families in Bali Province has been documented. The research aimed to determine (i) the community structure of *Liriomyza* spp. on various host plant families and (ii) the community structure of *Liriomyza* spp. it is based on the altitude of the host plant, (iii) the effect of season on the population abundance of *Liriomyza* spp., (iv) the community structure of the parasitoid *Liriomyza* spp. The findings of this research are likely to be beneficial and significant to those in charge of pest management in the Bali province, particularly when utilizing biological agents against *Liriomyza* spp.

2. Materials and Methods

2.1. Study Area

This research was carried out on a field and laboratory scale. Field research was conducted in all horticultural planting areas (covering vegetables, ornamental plants, and wild plants) in all districts and cities of Bali Province. Laboratory-scale research was conducted at the Integrated Pest Management Laboratory (IPMLab), Faculty of Agriculture, Udayana University-Bali.

2.2. Research Procedure

2.2.1. Determination of Sampling Location and Sample Handling

Locations of sampling were taken in all regencies/cities in the province of Bali, which have varying altitudes (Table 1 and Figure 1). A purposive sample strategy was used to collect leaves from plants that exhibited indications of leafminer fly attack, as many as 50–100 leaves per site. Leaf samples are collected at each site, placed in 1 kg sterile plastic bags tagged and sent to the laboratory. Leaf samples were then separated based on the development of larvae infestation and grown in a transparent plastic container with specifications based on the study of Yuliadhi *et al.* (2022), namely a height of 10 cm and

Table 1. Sampling site leafminer and parasitoids

Regency	Coordinate point	Altitude (m.asl)
Badung	8°75'87"S 115°12'97"E	827
	8°75'27"S 115°13'45"E	214
	8°75'37"S 115°9'45"E	745
	8°75'77"S 115°12'79"E	824
	8°75'21"S 115°18'53"E	113
	8°76'78"S 115°21'79"E	25
	8°67'86"S 115°13'11"E	37
	8°71'27"S 115°25'34"E	39
	8°80'23"S 115°24'21"E	97
	8°80'22"S 115°24'09"E	95
	8°75'87"S 115°12'59"E	357
	8°67'87"S 115°12'79"E	824
	8°75'87"S 115°2'79"E	890
	8°75'87"S 115°36'79"E	320
	8°71'22"S 115°25'34"E	39
	8°75'67"S 115°12'79"E	890
	8°75'67"S 115°12'79"E	890
	8°76'32"S 115°18'42"E	100
	8°75'67"S 115°13'45"E	109
Bangli	8°31'87"S 115°21'25"E	1023
	8°31'90"S 115°24'29"E	1200
	8°31'87"S 115°21'25"E	987
	8°31'87"S 115°27'29"E	1349
	8°31'87"S 115°27'29"E	987
	8°31'87"S 115°24'25"E	670
	8°31'87"S 115°25'26"E	765
	8°31'87"S 115°21'28"E	567
	8°31'87"S 115°21'27"E	578
	8°31'87"S 115°21'25"E	459
	8°31'87"S 115°24'37"E	349
	8°31'87"S 115°24'38"E	650
	8°31'87"S 115°22'29"E	289
	8°31'87"S 115°23'30"E	278
	8°31'87"S 115°19'23"E	570
	8°31'87"S 115°23'34"E	356
	8°31'87"S 115°17'34"E	457
	8°31'87"S 115°17'34"E	357
	8°31'87"S 115°19'31"E	115
	8°31'87"S 115°24'25"E	670
	8°31'87"S 115°24'37"E	349
	8°31'87"S 115°23'30"E	278
	8°31'87"S 115°24'25"E	670
	8°31'87"S 115°25'26"E	765
	8°31'87"S 115°22'29"E	289
	8°31'87"S 115°23'30"E	278
	8°31'83"S 115°25'32"E	567
Buleleng	8°23'78"S 115°5'78"E	125
	8°25'76"S 115°10'89"E	541
	8°23'98"S 115°12'87"E	1098
	8°25'81"S 115°10'80"E	87
	8°28'89"S 115°'12'98"E	924
	8°45'98"S 115°32'94"E	68
	8°46'65"S 115°59'102"E	976
	8°53'102"S 115°89'105"E	1325
	8°34'86"S 115°18'107"E	995
	8°35'68"S 115°13'78"E	32
	8°45'87"S 115°18'97"E	1245
	8°45'87"S 115°18'97"E	1245

Table 1. Continued

Regency	Coordinate point	Altitude (m.asl)
Buleleng	8°34'86"S 115°18'107"E	1245
	8°23'78"S 115°10'78"E	125
	8°25'81"S 115°10'80"E	87
	8°45'98"S 115°32'94"E	68
Denpasar	8°14'17"S 115°05'02"E	80
	8°14'17"S 115°05'02"E	14
	8°32'38"S 115°11'05"E	80
	8°32'38"S 115°12'05"E	70
	8°32'38"S 115°12'06"E	70
	8°37'49"S 115°13'07"E	80
	8°37'47"S 115°12'07"E	90
	8°36'38"S 115°14'05"E	9
	8°36'35"S 115°13'05"E	11
	8°32'38"S 115°12'05"E	70
Gianyar	8°18'52"S 115°22'23"E	78
	8°23'54"S 115°22'23"E	96
	8°23'55"S 115°22'23"E	90
	8°23'55"S 115°22'23"E	87
	8°25'58"S 115°22'23"E	25
	8°22'45"S 115°22'23"E	98
	8°23'21"S 115°22'23"E	98
	8°23'19"S 115°22'23"E	97
	8°21'32"S 115°22'23"E	101
	8°32'35"S 115°22'23"E	107
	8°32'36"S 115°22'23"E	112
	8°33'37"S 115°22'23"E	113
	8°34'39"S 115°22'23"E	119
	8°32'42"S 115°22'23"E	342
	8°32'44"S 115°22'23"E	345
	8°32'48"S 115°22'23"E	360
	8°32'49"S 115°22'23"E	370
	8°20'43"S 115°22'23"E	245
	8°20'47"S 115°22'23"E	256
	8°20'48"S 115°22'23"E	321
	8°20'49"S 115°22'23"E	421
	8°20'50"S 115°22'23"E	552
	8°20'53"S 115°22'23"E	342
	8°20'54"S 115°22'23"E	556
	8°23'55"S 115°22'23"E	87
	8°23'19"S 115°22'23"E	97
	8°32'36"S 115°22'23"E	112
	8°32'49"S 115°22'23"E	370
	8°20'49"S 115°22'23"E	421
	8°23'55"S 115°22'23"E	87
Jembrana	8°18"S 114°40"E	98
	8°18"S 114°39"E	67
	8°16"S 114°32"E	76
	8°15"S 114°32"E	89
	8°12"S 114°30"E	56
	8°10"S 114°40"E	47
	8°10"S 114°23"E	69
	8°15"S 114°33"E	67
	8°15"S 114°31"E	79
	8°18"S 114°27"E	90
	8°18"S 114°39"E	67
	8°17"S 114°40"E	79
	8°16"S 114°40"E	23
	8°9"S 114°40"E	4

Table 1. Continued

Regency	Coordinate point	Altitude (m.asl)
Klungkung	8°14'17"S 115°05'02"E	9
	8°17'19"S 115°05'02"E	24
	8°18'20"S 115°09'03"E	45
	8°18'21"S 115°09'03"E	54
	8°18'21"S 115°09'03"E	102
	8°17'19"S 115°08'02"E	10
	8°18'21"S 115°09'05"E	26
	8°14'18"S 115°07'02"E	27
	8°14'18"S 115°08'02"E	38
	8°29'47"S 115°15'07"E	98
	8°14'14"S 115°08'02"E	125
	8°23'32"S 115°11'07"E	205
	8°45'22"S 115°09'04"E	157
	8°45'22"S 115°13'07"E	98
	8°45'43"S 115°34'05"E	101
	8°14'57"S 115°15'09"E	7
	8°38'53"S 115°12'07"E	45
	8°18'21"S 115°09'34"E	102
	8°322"S 115°453"E	107
	8°320"S 115°457"E	6
	8°326"S 115°451"E	157
	8°312"S 115°471"E	1015
	8°312"S 115°451"E	450
	8°234"S 115°461"E	670
Karangasem	8°220"S 115°461"E	345
	8°229"S 115°472"E	380

Table 1. Continued

Regency	Coordinate point	Altitude (m.asl)
Karangasem	8°17"S 114°40"E	1015
	8°34"S 115°46"E	25
	8°229"S 115°461"E	20
	8°17"S 114°40"E	1015
	8°326"S 115°471"E	1098
	8°311"S 115°461"E	1570
	8°229"S 115°461"E	598
	8°227"S 115°451"E	350
	8°227"S 115°452"E	346
	8°229"S 115°442"E	290
	8°231"S 115°452"E	1625
	8°235"S 115°442"E	378
	8°225"S 115°439"E	34
	8°225"S 115°449"E	29
	8°53'102"S 144°89'105"E	1325
	8°14'18"S 115°04'02"E	29
	8°18'20"S 115°09'03"E	45
	8°18'21"S 115°09'03"E	102
Tabanan	8°75'987"S 115°13'32"E	1227
	8°45'89"S 115°9'90"E	90
	8°75'97"S 115°13'132"E	241
	8°75'98"S 115°13'1°3"E	1068
	8°75'87"S 115°13'1°2"E	1123
	8°75'37"S 115°13'141"E	90

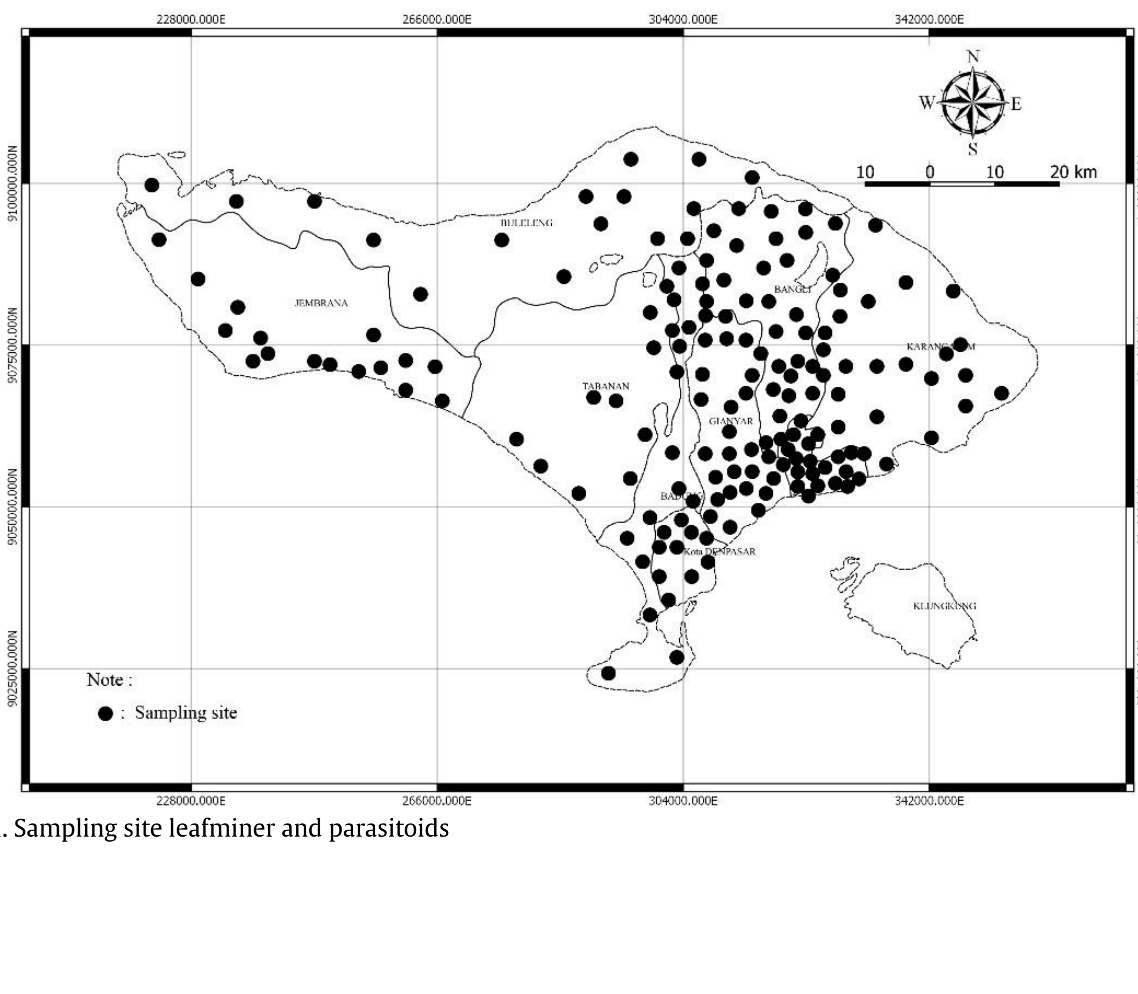

Figure 1. Sampling site leafminer and parasitoids

a width of 8 cm, with the container covered with gauze. The imago *Liriomyza* spp. or the parasitoid imago was maintained till finally formed.

2.2.2. Inventory and Morphological Identification of *Liriomyza* spp. and the Parasitoids

Leafminer flies and their parasitoids that emerged during the rearing period were counted and documented by type before being collected separately in bottles filled with 80 percent ethanol for identification. After that, each collecting bottle was tagged with the location, host plant, and sample date (Yuliadhi *et al.* 2021a). The identification of the leafminer fly was based on its morphological traits, which were based on Shiao (2004). Meanwhile, identifying parasitoids refers to the key determination from Fisher *et al.* (2005) and Wahyuni *et al.* (2017b).

2.2.3. Community Structure *Liriomyza* spp. and its Parasitoids in Bali

The community structure was determined to obtain comprehensive results. In several stages, namely I determining the community structure of *Liriomyza* spp. on various host plant families, (ii) the community structure of *Liriomyza* spp. on various host plants based on altitude differences, (iii) the community structure of *Liriomyza* spp. on various host plants by season, and (iv) their parasitoid community structure. Several factors, including the following, are used to evaluate community structure.

2.3. Data Analysis

2.3.1. Diversity Index (H')

The diversity index is calculated using the equation developed by (McCarthy and Magurran 2004), namely:

$$H' = -\sum_{t=1}^{S} p_i \, Ln \, p_i$$

Where H' is the Shannon-Wiener diversity index, Pi is the proportion of the i species in the community, Ln is the logarithm of nature, ni is the abundance of individuals of the i species, and N is the total number of individuals of all species.

Value: $H' < 1.0$ = Low
$1 < H' < 3$ = Moderate
$H' > 3.0$ = High

2.3.2. Species Abundance Index (R1)

The species abundance index (R1) was measured using the Margalef index (McCarthy and Magurran 2004) through the following equation:

$$R1 = \frac{S - 1}{lnN}$$

Where $R1$ is the species abundance index, S is the number of species found, Ln is the logarithm of nature, N is the total number of individuals.

Value: $R1 < 3.5$ = Low
$3.5 < R1 < 5.0$ = Moderate
$R1 < 5.0$ = High

2.3.3. Species Dominance Index (D)

The species dominance index determined using the Menhinick index (McCarthy and Magurran 2004) is as follows:

$$D = \sum \frac{ni\,(ni - 1)}{N\,(N - 1)}$$

Where D is the dominance index, N is the total number of individuals, Ni is the number of individuals of type-i.

Value: $0.00 < D < 0.30$ = Low
$0.30 < D < 0.60$ = Moderate
$0.60 < D < 1.00$ = High

2.3.4. Parasitization Rate

The level of parasitization of the parasitoids was calculated using the equations from the studies of Yuliadhi *et al.* (2021b) and Supartha *et al.* (2020) as follows:

$$Parasitization\ rate = \frac{\sum number\ of\ parasitoids}{\underset{fly}{\sum adult\ fruit} + \underset{parasitoid}{\sum adult}} \times 100\%$$

(a + b + c)

3. Results

3.1. The Community Structure of *Liriomyza* spp. on Various Host Plant Families

According to our research findings, up to four different species of leafminer pests target several vegetables, ornamentals, and wild plants in the field. *Liriomyza sativae, L. huidobrensis, L. trifolii,* and *L. chinensis*. The families Asteraceae (3,578 individuals), Brassicaceae (1,701 individuals), Fabaceae (1,054 individuals), Cucurbitaceae (810 individuals), Solanaceae (299 individuals), and Liliaceae (286 individuals) had the greatest numbers of leafminer flies. This study's leafminer fly community structure has a low abundance index value *H'* = 0.28–0.64. The diversity index value is included in the low-medium range *H'* = 0.39-1.07. The dominance index falls within the medium-high range *D* = 0.40–1.39 (Table 2).

3.2. The Community Structure of *Liriomyza* spp. on Various Host Plant Families Based on the Altitudes of the Planting Location

Our study shows that the community structure of the leafminer fly differed depending on altitude (highlands vs lowlands). Surprisingly, the quantity of *Liriomyza* spp. we have discovered that the lowlands and highlands were higher in plants from the Asteraceae family, with 1,522 and 2,056 individuals, respectively (Table 3). On the other hand, the general community structure was greater in the highlands than in the lowlands. Although the *Liriomyza* spp. community structure in the lowlands is small; it should be highlighted that it is still possible to alter as the dynamics of this pest population adjust to the presence of host plants in the lowlands. The results found at both altitudes in the province of Bali confirm that this invasive pest is adaptable by utilizing host plants grown by farmers in both locations -especially host plants from the Asteraceae, Brassicaceae, Cucurbitaceae, Fabaceae, and Solanaceae families.

3.3. The Abundance of *Liriomyza* spp. on Various Host Plants Based on the Different Seasons

Our results demonstrated that the community structure of the leafminer fly differed in seasons (wet vs dry season)-notably, the quantity of *Liriomyza* spp. In the wet and dry seasons, there were higher populations of *L. sativae* from the *Vigna unguiculata* and *Tegetes erecta* host plant species, with 5,521 and 3,984 individuals, respectively (Table 4). The results found at both seasons in the province of Bali confirm that this invasive pest is adaptable by utilizing host plants grown by farmers in both locations-especially host plants from the *Vigna unguiculata,*

Table 2. Community structure *Liriomyza* spp. on various host plant families in Bali

Family	Spesies		Index		
	N. Liriomyza spp.	*S. Liriomyza* spp.	*R*1	*H'*	*D*
Asteraceae	3,578	4	0.37	0.89	0.46
Amaranthaceae	35	2	0.28	0.62	1.39
Brasicaseae	1,701	4	0.54	1.05	0.42
Cucurbitaceae	810	4	0.60	1.07	0.41
Chnopodiaceae	8	2	0.48	0.66	0.46
Euporbhiaceae	5	2	0.62	0.67	0.40
Fabaceae	1,054	4	0.43	0.39	0.83
Liliaceae	286	3	0.35	0.99	0.40
Mackinlayaceae	23	2	0.32	0.69	0.48
Solanaceae	299	4	0.53	1.67	0.36

N = population abundance, *S* = number of species, *R*1 = species abundance index, *H'* = species diversity index, *D* = Dominance Index

Table 3. Community structure *Liriomyza* spp. on the host plant family based on the altitude of the location in Bali

Family	Lowland					Lowland				
	N	*S*	*R*1	*H'*	*D*	*N*	*S*	*R*1	*H'*	*D*
Asteraceae	1,522	4	0.41	1.00	0.19	2,056	3	0.26	0.91	0.47
Amaranthaceae	15	2	0.37	0.64	0.30	20	2	0.33	0,42	0.73
Brassicasea	509	2	0.16	0.69	0.50	1,192	4	0.42	1.25	0.31
Cucurbitaceae	298	4	0.53	0.70	0.63	512	3	0.16	0.97	0.41
Chenopodiaceae	0	0	0.00	0.00	0.00	8	1	0.00	0.00	0.12
Euphorbiaceae	5	2	0.20	0.67	0.15	0	0	0.00	0.00	0.00
Fabaceae	654	4	0.46	1.07	0.41	400	4	0.33	0.87	0.40
Liliaceae	0	0	0.00	0.00	0.00	286	3	0.35	0.79	0.51
Lamiaceae	6	1	0.00	0.00	0.17	0	0	0.00	0.00	0.00
Mackinlayaceae	23	2	0.32	0.81	0.49	0	0	0.00	0.00	0.00
Solanaceae	123	4	0.62	0.68	0.65	176	3	0.39	1.07	0.35

N = population abundance, *S* = number of species, *R*1 = species abundance index, *H'* = species diversity index, *D* = Dominance Index

Table 4. The abundance of *Liriomyza* spp. on various species of host plants by season in Bali

Host plant species	Species sbundance *Liriomyza* spp. in the rainy and dry season							
	L. sativa		*L. huidobrensis*		*L. chinensis*		*L. trifolii*	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Solanum Lycopersicum	6	324	14	78	4	0	124	37
Vigna unguiculata ssp.	265	5,521	7	12	0	0	194	1,759
Tegetes erecta	1,542	3,984	57	89	0	3	582	3,714
Brassica rapa subsp. Chinensis	98	121	7	14	0	0	56	87
Vigna unguiculata subsp. Unguiculata	77	34	0	0	0	0	60	56
Cucumis sativus	78	412	0	11	0	0	124	176
Brassica chinensis var. parachinensis	80	265	8	12	1	3	97	204
Luffa acutangular	22	1,183	0	0	0	0	6	235
Chrysanthemum morifolium	3	58	0	0	0	0	197	84
Cucurbita moschata	4	12	0	0	0	0	3	2
Allium fistulosum	23	35	10	14	84	106	12	13
Apium graveolens	0	0	0	0	0	0	6	0
Helianthus annuus L.	23	45	0	3	0	0	45	56
Zininia elegans. Jacg	0	0	0	0	0	0	24	32
Gerbera jamesonii	0	13	0	0	0	0	16	10
Brassica napus	0	2	0	0	0	0	2	4
Brassica rapa	0	4	0	0	0	0	0	0
Cucurbita pepo L	5	11	0	0	0	0	0	3
Citrullus lanatus	36	87	0	0	0	0	43	126
Cucumis melo L	21	36	0	0	0	0	33	125
Phaseolus vulgaris	321	421	10	7	0	0	54	89
Phaseolus vulgaris subs. Cylindrica	13	23	0	0	0	0	5	12
Glycine max L	2	10	0	0	0	0	0	3
Allium ascalonicum L.	43	54	18	21	88	108	11	21
Solanum tuberosum	8	12	23	45	0	0	3	12
Solanum melongena L.	8	40	0	0	0	0	0	0
Physalis angulata L.	0	4	0	0	0	0	0	0
Beta vulgaris L.	0	0	3	0	0	0	0	5
Amaranthus hybridus L.	0	12	0	0	0	0	0	24
Ocimum sanctum	0	3	0	0	0	0	0	2
Centela asiatica	0	11	0	0	0	0	0	12

Tegetes erecta, Luffa acutangular, Cucumis sativus and *Phaseolus vulgaris* species.

3.4. Parasitoid Community Structure in Various Host Plant Families in Bali

There were nine different parasitoids reported with *Liriomyza* species, including *Opius chromatomyie* and *Opius disstus* and *Closterserus* spp., *Hemiptarsenus varicornis, Neochrysocaris formosa*, and *Pnigalio* sp. The Asteraceae family has the most parasitoid populations (1,392 individuals), whereas the Amaranthaceae family has the fewest (15 individuals).

Interestingly, the parasitoid population associated with *Liriomyza* spp. differed in each host plant family in the field. The parasitoid community in the Fabaceae family is composed of 10 parasitoid species with "low" levels of diversity, abundance, and dominance. Compared to the Asteraceae and Cucurbitaceae families, which are host to nine parasitoid species with a diversity index' value in the medium category, abundance, and a low dominance index. Table 5 shows the community structure of the parasitoid *Liriomyza* spp. it is linked with various host plant families.

3.5. Parasitization Rate of the Parasitoid *Liriomyza* spp. on Various Host Plant Families

The finding showed that the degree of parasitization reflected by the kinds of parasitoids detected in different host plant families in the field varied greatly. Overall, *O. chromatomiyae* was the parasitoid with the greatest parasitization rate on diverse host plants in the field (Figure 2). Certainly, the parasitization rate of this parasitoid species completely controls all host plant families identified in the field, except for the Asteraceae family, which is still dominated by *H. varicornis*. Our findings could

Table 5. The community structure of the parasitoid *Liriomyza* spp. on various host plant families in Bali

Species	Family						
	Asteraceae	Brasicaseae	Cucurbitaceae	Fabaceae	Solanaceae	Eupharbhiaceae	Amaranthaceae
Opius cromatomiyae	353	189	56	114	22	7	6
Hemiptarsenus varicornis	324	111	33	62	11	1	5
Opius dissitus	188	87	25	29	0	3	0
Closterocerus sp.	143	100	27	21	10	0	0
Neochrysocaris formosa	136	24	1	36	2	2	0
Neochrysocaris okazakii	134	25	23	24	0	3	2
Pnigalio sp.	111	26	22	20	1	0	2
Gronotoma micromopha	3	0	3	3	0	0	0
Eukeryotoma sp.	0	0	0	1	0	0	0
N. Parasitoid	1,392	562	190	310	46	16	15
N. Liriomyza spp.	3,580	1,683	810	1,054	299	5	35
S. Parasitoid	8	7	8	9	5	5	4
S. Liriomyza spp.	4	2	4	4	3	2	2
R1	0.97	1.11	1.33	1.22	1.83	2.52	2.58
H'	1.85	1.52	1.77	1.78	1.25	1.42	1.27
D	0.99	0.98	0.96	0.97	0.91	0.73	0.78

N = population abundance, *S* = number of species, *R1* = species abundance index, *H'* = species diversity index, *D* = Dominance Index

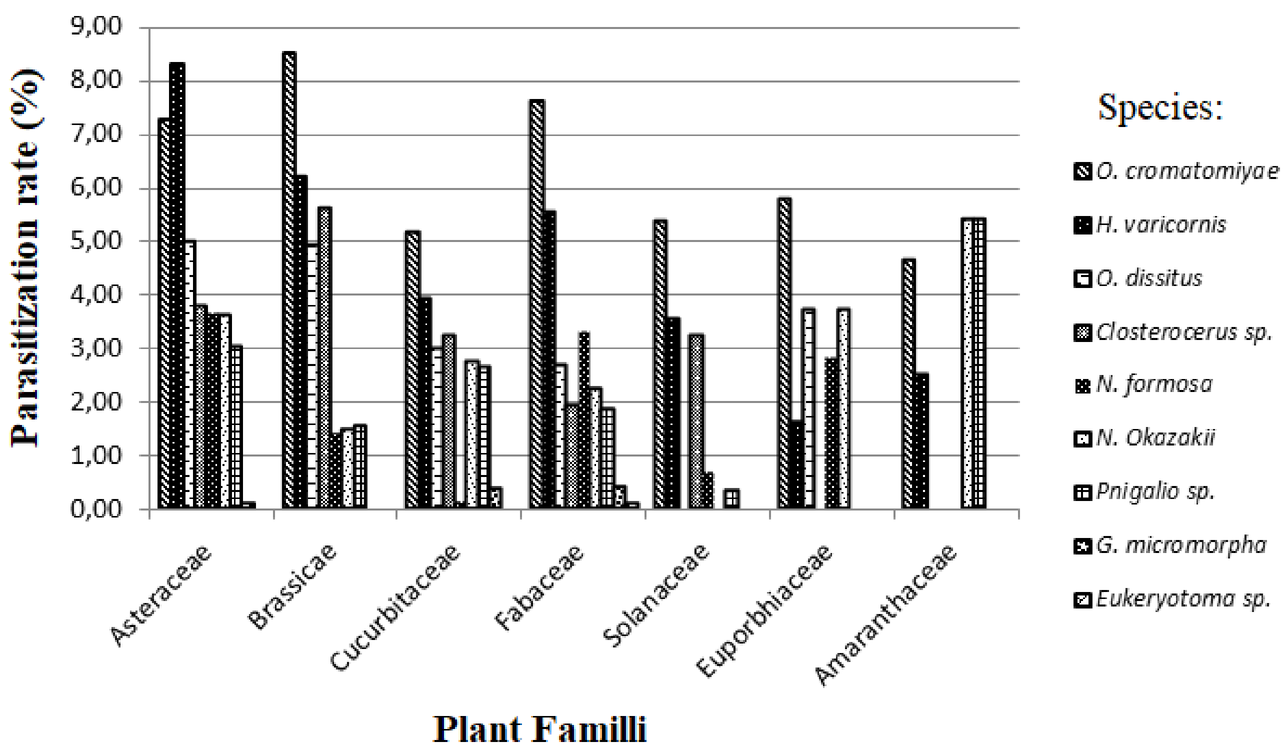

Figure 2. Parasitization rate of parasitoids associated with various host plant families in Bali Province

be very useful for future research into the parasitoid *O. chromatomiyae* ability, particularly in controlling leaf borer attacks.

4. Discussion

Leafminer flies, *Liriomyza* spp., are significant invasive insects with great tolerance to various environmental situations (Ridland *et al.* 2020; Wahyuni *et al.* 2017b). The availability of suitable host plants is one element that defines the spreading of *Liriomyza* spp. in a specific geographic region (Rodríguez-Castañeda *et al.* 2017). As a result, the population of *Liriomyza* spp. will increase gradually in a geographical environment with more different host plants (Tran *et al.* 2007b; Xu *et al.* 2021). This study showed that the population abundance of *Liriomyza* spp. was greatest on host plants from the Asteraceae family. Interestingly, aside from attractive plants, valuable vegetable commodities from the Brassicaceae, Fabaceae, Cucurbitaceae, and Solanaceae families may also function as significant host plants for *Liriomyza* spp. to survive and expand. Previous research found that the population density of *L. brassicae* found in cabbages grown in the Kintamani and Kembangmerta areas of Bali Province increased in 2018 (Putra *et al.* 2018). The use of a multicultural plant cultivation system and the presence of non-cultivated agricultural crops in the agroecosystem region are assumed to provide macrohabitats that alter the variety of *Liriomyza* spp. and further induce pest population dynamics (Tantowijoyo and Hoffmann 2010). According to this perspective, monitoring population structure is critical for giving more precise information in developing a comprehensive pest management approach (Waongo *et al.* 2015) particularly in providing early warning of host plant growth (Supartha *et al.* 2022a).

Temperature is one of the most significant environmental elements influencing insect distribution and is related to altitude (Ahmed *et al.* 2016). In this research, the community structure of *Liriomyza* spp. indicates a similar value all over the two elevations (lowland–highland) in the Bali province. *Liriomyza* spp. is abundant at both altitude locations, particularly in the plant groups Asteraceae, Brassicaceae, Cucurbitaceae, Fabaceae, Liliaceae, and Solanaceae. Temperature fluctuations influence insect pests' community structure through changes in physiological responses and insect behaviour (Estay *et al.* 2009). The previous study has shown that *L. trifolii* can support heavy environmental temperatures. These results further demonstrate that *L. trifolii* tolerance abilities not only influence the host plant but are also capable of being resistant to pesticide sprays used by farmers in the lowlands (Wang *et al.* 2021). Similarly, *L. huidobrensis*, which attacks potato crops in Korea, has a high development value at low ambient temperatures or up to a temperature threshold of 9.46°C before declining with rising environmental temperature to 30°C (Maharjan and Jung 2016). This information is important because it may be one of the most recent predictive models for understanding the future evolution of plant pest community structures by using the information on changes in regional temperature (Azrag *et al.* 2018; Wang *et al.* 2020).

Fluctuations in insect pest density are more strongly connected with seasonal variations that occur in a region (Walter *et al.* 2018). According to our results, the seasonal element significantly influences the number and species of *Liriomyza* spp. on diverse types of host plants in Bali Province. Our findings also show that the population abundance of *L. sativae* and *L. trifolii* increased significantly over the wet-dry season, particularly in the host plants *Vigna unguiculata, T. erecta*, and *Luffa acutangular* during the dry season. Increasing temperatures during the dry season may impact the physiological reactions of insects, causing them to increase their metabolic processes and consume additional host plants, resulting in higher crop damage and poorer yields (Tonnang *et al.* 2022). The seasonal incident activity of *L. huidobrensis* on several vegetable crops in Indonesia has previously been recorded, revealing that the leafminer population had the greatest assault rate on potatoes, leeks, and broccoli, particularly towards the end of the rainy season (March) (Shepard and Braun 1998). Similarly, *L. sativae* was seen attacking vegetable crops throughout the season in three vegetable fields in Ho Chi Minh City, Vietnam, dominated by cucumbers and okra (Tran *et al.* 2007a).

Several different kinds of general and particular natural enemies may support the biological control of *Liriomyza* spp. in the field (Liu 2009). This study's results show the prevalence of parasitoids present in the Asteraceae family, particularly the *O. cromatomiyae* and *H. varicornis* species.

Surprisingly, the number of parasitoids detected in Asteraceae hosts was related to the number of *Liriomyza* spp. observed on the same plant. We assume that the Asteraceae in this research served as a suitable host plant for *Liriomyza* spp. and a prey source for parasitoids. More extensive research is required to verify this, however, since in our data, the quantity of *Liriomyza* spp. still outnumbers the number of parasitoids identified in certain host plants. As a result, the ecological balance is one of the most important qualities of a successful pest management program (Dara 2019). An increase in parasitoids found in some host plants compared to their prey can lead to competition between parasitoid species for prey on their hosts (Aguirre *et al.* 2021). Whereas an increase in pests compared to their natural enemies may indicate a decrease in the quality of agroecological health, such as exposure to non-targeted insecticides or other nuisance factors (Gagic *et al.* 2021).

Insect parasitoids are species whose larvae may grow by feeding on or on the body of an arthropod host, ultimately killing them (Supartha *et al.* 2020). Insect parasitoids have a wide range of biological and ecological activities (Clarke *et al.* 2019). They can play an important role in the natural control of pest insect populations (Bompard *et al.* 2013). The parasitoids observed in this research showed various percentages of parasitoid ability based on the kind of host plant and the amount of prey. Overall, *O. chromatomyiae* and *H. varicornis* had the highest parasitization rates in the field across all host plant families. When the population size of these natural parasitoids is too small to offer effective control, they may be mass maintained and released back into the wild on a regular basis (augmentation biological management) (Sow *et al.* 2019).

Opius chromatomyiae was previously used as a biological agent to suppress two species, *L. huidobrensis* and *L. chinensis,* with parasitization rates ranging from 24.36 to 28.45% in leek cultivation (Rustam *et al.* 2009). Hemiptarsinus varicornis has also been shown to parasitize *L. huidobrensis* in potato crop production in Indonesia (Maryana *et al.* 2005). Our earlier experiments with *Gronotoma micromorpha* revealed that it has a high potential for regulating *L. huidobrensis* variety of biological features and functional response modes (Supartha *et al.* 2022b).

Differences in community structure and parasitization levels were associated with host density in the field. In general, there will be a correlation between insect pest abundance and their parasitoids (Yuliadhi *et al.* 2021a, 2021b, 2022). Host predation by parasitoids may be completed by habitat finding, host existence, host acceptance, and host compatibility (Konopka *et al.* 2018). Maintaining parasitoids' abundance in the field can also be enhanced by effective manipulation of their habitat (e.g., conservation of biological control), which includes manipulation of plant microclimates, conservation of seasonal shelters, provision of alternative hosts, and adult parasitoids' access to important food sources such as flowers (Driesche *et al.* 2008; Van Driesche and Hoddle 2000).

According to this report, the community structure of *Liriomyza* spp. in Bali Province is still a major risk to diverse host plant families cultivated by farmers. This pest is also highly adaptable to changing environmental conditions due to altitude and season. The parasitoids discovered in relationship with *Liriomyza* spp. already have the potential to be developed as biological control agents, as shown by the parasitization rate and abundance of diverse host plants in the field. More study is necessary, particularly to evaluate the development of existing parasitoids on a field scale to contribute to the control of *Liriomyza* spp. significantly. Parasitoid conservation strategies are also required to improve their abundance in the environment.

Conflict of Interest

The authors declare that they have no competing interest.

Acknowledgements

The authors would like to thank the Chair of the Integrated Pest Management Laboratory (IPMLaB), Faculty of Agriculture, Udayana University (UNUD), Bali, Indonesia, has provided facilities and funding support through the 2020 Study Grant Research Group (Hibah Penelitian Grup Riset) with Contract Number: B/1588 24/UN14.4.A/PT.01.03/2020.

References

Aguirre, M.B., Bruzzone, O.A., Triapitsyn, S.V., Diaz-Soltero, H., Hight, S.D., Logarzo, G.A., 2021. Influence of competition and intraguild predation between two candidate biocontrol parasitoids on their potential impact against *Harrisia cactus* mealybug, *Hypogeococcus* sp. (Hemiptera: Pseudococcidae). *Sci. Rep.* 11, 13377 https://doi.org/10.1038/s41598-021-92565-6

Ahmed, A.G., Murungi, L.K., Babin, R., 2016. Developmental biology and demographic parameters of antestia bug *Antestiopsis thunbergii* (Hemiptera: Pentatomidae), on *Coffea arabica* (Rubiaceae) at different constant temperatures. *Int. J. Trop. Insect Sci.* 36, 119–127 https://doi.org/10.1017/S1742758416000072

Anderson, J.A., Ellsworth, P.C., Faria, J.C., Head, G.P., Owen, M.D.K., Pilcher, C.D., Shelton, A.M., Meissle, M., 2019. Genetically engineered crops: importance of diversified integrated pest management for agricultural sustainability. *Front. Bioeng. Biotechnol.* 7, 1-14. https://doi.org/10.3389/fbioe.2019.00024

Azrag, A.G.A., Pirk, C.W.W., Yusuf, A.A., Pinard, F., Niassy, S., Mosomtai, G., Babin, R., 2018. Prediction of insect pest distribution as influenced by elevation: combining field observations and temperature-dependent development models for the coffee stink bug, *Antestiopsis thunbergii* (Gmelin). *PLoS One.* 13, e0199569. https://doi.org/10.1371/journal.pone.0199569

Bompard, A., Amat, I., Fauvergue, X., Spataro, T., 2013. Host-parasitoid dynamics and the success of biological control when parasitoids are prone to allee effects. *PLoS One.* 8, e76768 https://doi.org/10.1371/journal.pone.0076768

Bottrell, D.G., Schoenly, K.G., 2018. Integrated pest management for resource-limited farmers: challenges for achieving ecological, social and economic sustainability. *J. Agric. Sci.* 156, 408–426. https://doi.org/10.1017/S0021859618000473

Chang, Y.W., Wang, Y.C., Zhang, X.X., Iqbal, J., Lu, M.X., Gong, H.X., Du, Y.Z., 2020. Comparative transcriptome analysis of three invasive leafminer flies provides insights into interspecific competition. *Int. J. Biol. Macromol.* 165, 1664–1674 https://doi.org/10.1016/j.ijbiomac.2020.09.260

Chidawanyika, F., Mudavanhu, P., Nyamukondiwa, C., 2012. Biologically based methods for pest management in agriculture under changing climates: challenges and future directions. *Insects.* 3, 1171–1189 https://doi.org/10.3390/insects3041171

Clarke, C.W., Calatayud, P.A., Sforza, R.F.H., Ndemah, R.N., Nyamukondiwa, C., 2019. Editorial: parasitoids' ecology and evolution. *Front. Ecol. Evol.* 7, 1-3. https://doi.org/10.3389/fevo.2019.00485

Clavijo McCormick, A., 2016. Can plant–natural enemy communication withstand disruption by biotic and abiotic factors?. *Ecol. Evol.* 6, 8569–8582 https://doi.org/10.1002/ece3.2567

Dara, S.K., 2019. The new integrated pest management paradigm for the modern age. *J. Integr. Pest Manag.* 10, 1-9. https://doi.org/10.1093/jipm/pmz010

Deguine, J.P., Aubertot, J.N., Flor, R.J., Lescourret, F., Wyckhuys, K.A.G., Ratnadass, A., 2021. Integrated pest management: good intentions, hard realities. a review. *Agron. Sustain. Dev.* 41, 38. https://doi.org/10.1007/s13593-021-00689-w

Driesche, R. Van, Hoddle, M., Center, T., 2008. *Control of Pests and Weeds by Natural Enemies: An Introduction to Biological Control*, first ed. Wiley-Blackwell, USA.

Van Driesche, R.G., Hoddle, M.S., 2000. Classical Arthropod Biological Control: Measuring Success, Step By Step, in: Gurr, G., Wratten, S. (Eds.). *Biological Control: Measures of Success*. Springer Netherlands, Dordrecht, pp. 39–75.

Durocher-Granger, L., Mfune, T., Musesha, M., Lowry, A., Reynolds, K., Buddie, A., Cafà, G., Offord, L., Chipabika, G., Dicke, M., Kenis, M., 2021. Factors influencing the occurrence of fall armyworm parasitoids in Zambia. *J. Pest Sci.* 94, 1133–1146 https://doi.org/10.1007/s10340-020-01320-9

Estay, S.A., Lima, M., Labra, F.A., 2009. Predicting insect pest status under climate change scenarios: combining experimental data and population dynamics modelling. *J. Appl. Entomol.* 133, 491–499. https://doi.org/10.1111/j.1439-0418.2008.01380.x

Fisher, N., Ubaidillah, Reina, La Salle, J., 2005. *Liriomyza Parasitoids of South East Asia*. ACIAR, Australia.

Gagic, V., Holding, M., Venables, W.N., Hulthen, A.D., Schellhorn, N.A., 2021. Better outcomes for pest pressure, insecticide use, and yield in less intensive agricultural landscapes. *Proc. Natl. Acad. Sci.* 118, 1-6. https://doi.org/10.1073/pnas.2018100118

Gao, Y., Reitz, S.R., 2017. Emerging themes in our understanding of species displacements. *Annu. Rev. Entomol.* 62, 165–183. https://doi.org/10.1146/annurev-ento-031616-035425

Hamid, Supartha, I.W., Susila, I.W., Sudiarta, I.P., 2018. Morphological and molecular characteristics of *Liriomyza* sp. (Diptera: Agromyzidae) on onion plants (*Allium cepa* L.) in Bali. *Asian J Agri Biol.* 6, 524–529.

Harush, A., Quinn, E., Trostanetsky, A., Rapaport, A., Kostyukovsky, M., Gottlieb, D., 2021. Integrated pest management for stored grain: potential natural biological control by a parasitoid wasp community. *Insects.* 12, 1038 https://doi.org/10.3390/insects12111038

Hill, M.P., Macfadyen, S., Nash, M.A., 2017. Broad spectrum pesticide application alters natural enemy communities and may facilitate secondary pest outbreaks. *PeerJ.* 5, e4179 https://doi.org/10.7717/peerj.4179

Konopka, J.K., Poinapen, D., Gariepy, T., McNeil, J.N., 2018. Understanding the mismatch between behaviour and development in a novel host-parasitoid association. *Sci. Rep.* 8, 15677. https://doi.org/10.1038/s41598-018-33756-6

Kruitwagen, A., Beukeboom, L.W., Wertheim, B., 2018. Optimization of native biocontrol agents, with parasitoids of the invasive pest Drosophila suzukii as an example. *Evol. Appl.* 11, 1473–1497. https://doi.org/10.1111/eva.12648

Liu, T.X., 2009. Biological control of Liriomyza leafminers: progress and perspective. *CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* 4, 1-16. https://doi.org/10.1079/PAVSNNR20094004

Living with Resistance project, 2018. Antibiotic and pesticide susceptibility and the Anthropocene operating space. *Nat. Sustain.* 1, 632–641. https://doi.org/10.1038/s41893-018-0164-3

Maharjan, R., Jung, C., 2016. Thermal requirements and development of the Korean population of the potato leafminer, *Liriomyza huidobrensis* (Diptera: Agromyzidae). *J. Asia. Pac. Entomol.* 19, 595–601. https://doi.org/10.1016/j.aspen.2016.06.001

Marchioro, C.A., Foerster, L.A., 2016. Biotic factors are more important than abiotic factors in regulating the abundance of *Plutella xylostella* L., in Southern Brazil. *Rev. Bras. Entomol.* 60, 328–333 https://doi.org/10.1016/j.rbe.2016.06.004

Maryana, N., Pudjianto, Rauf, A., 2005. *Ectoparasitoid Hemiptarsenus Varicornis (Girault) (Hymenoptera: Eulophidae) as Natural Enemies of Leafminer Flies: Demographic Parameters, Parasitization, and Functional Response*. Competitive Grant (Hibah Bersaing), Bogor.

McCarthy, B.C., Magurran, A.E., 2004. Measuring biological diversity. *J. Torrey Bot. Soc.* 131, 277. https://doi.org/10.2307/4126959

Messelink, G.J., Bennison, J., Alomar, O., Ingegno, B.L., Tavella, L., Shipp, L., Palevsky, E., Wäckers, F.L., 2014. Approaches to conserving natural enemy populations in greenhouse crops: current methods and future prospects. *BioControl.* 59, 377–393. https://doi.org/10.1007/s10526-014-9579-6

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P., Hens, L., 2016. Chemical pesticides and human health: the urgent need for a new concept in agriculture. *Front. Public Heal.* 4, 1-8. https://doi.org/10.3389/fpubh.2016.00148

Pratama, I., Susila, I., Supartha, I., 2013. Keragaman dan kelimpahan populasi *Liriomyza* spp. (Diptera : Agromyzidae) serta parasitoidnya pada pertanaman sayuran dataran sedang dan tinggi di Bali. *Journal Trop. Agroecotechnology.* 2, 204–213.

Putra, W.S., Supartha, I.W., Widaningsih, D., 2018. Populations development of *Liriomyza brassicae* Riley (Diptera: Agromyzidae) and community structure of parasitoid associated with Cabbage (*Brassicaceae*) in Bali. *Agroekoteknologi Trop.* 7, 532–541.

Rauf, A., Shepard, B.M., Johnson, M.W., 2000. Leafminers in vegetables, ornamental plants and weeds in Indonesia: surveys of host crops, species composition and parasitoids. *Int. J. Pest Manag.* 46, 257–266. https://doi.org/10.1080/09670870050206028

Ridland, P.M., Umina, P.A., Pirtle, E.I., Hoffmann, A.A., 2020. Potential for biological control of the vegetable leafminer, *Liriomyza sativae* (Diptera: Agromyzidae), in Australia with parasitoid wasps. *Austral Entomol.* 59, 16–36. https://doi.org/10.1111/aen.12444

Rodríguez-Castañeda, G., MacVean, C., Cardona, C., Hof, A.R., 2017. What limits the distribution of *Liriomyza huidobrensis* and Its congener *Liriomyza sativae* in their native niche: when temperature and competition affect species' distribution range in Guatemala. *J. Insect Sci.* 17, 1-13. https://doi.org/10.1093/jisesa/iex059

Rustam, R., Rauf, A., Maryana, N., Pudjianto, Dadang., 2009. Study of the leaf miner flies *Lirlomyza* spp. on onion plants, and parasitoids opius chromatomyiae Belokobylskij and Wharton (Hymenoptera: Braconidae). *J. HPT Tropika.* 9, 22-31.

Scheffer, S., Lewis, M., Joshi, R., 2006. DNA barcoding applied to invasive leafminers (Diptera: Agromyzidae) in the Philippines. *Ann. Entomol. Soc. Am.* 99, 204–210.

Shahabuddin, S., Anshary, A., Gellang, A., 2012. Tingkat serangan dan jenis lalat pengorok daun pada tiga varietas lokal bawang merah di Lembah Palu Sulawesi Tengah. *Hama dan Penyakit Tumbuh. Trop.* 12, 153–161.

Shepard, B.M., Braun, S.A.R., 1998. Seasonal incidence of *Liriomyza huidobrensis* (Diptera: Agromyzidae) and its parasitoids on vegetables in Indonesia. *Int. J. Pest Manag.* 44, 43–47. https://doi.org/10.1080/096708798228518

Shiao, S.F., 2004. Morphological diagnosis of six *Liriomyza* species (Diptera: Agromyzidae) of quarantine importance in Taiwan. *Appl. Entomol. Zool.* 39, 27–39. https://doi.org/10.1303/aez.2004.27

Skendžić, S., Zovko, M., Živković, I.P., Lešić, V., Lemić, D., 2021. The impact of climate change on agricultural insect pests. *Insects.* 12, 440. https://doi.org/10.3390/insects12050440

Sow, A., Brévault, T., Benoit, L., Chapuis, M.P., Galan, M., Coeur d'acier, A., Delvare, G., Sembène, M., Haran, J., 2019. Deciphering host-parasitoid interactions and parasitism rates of crop pests using DNA metabarcoding. *Sci. Rep.* 9, 3646. https://doi.org/10.1038/s41598-019-40243-z

Supartha, I.W., 1998. Bionomi *Liriomyza huidobrensis* (Blanchard) (Diptera : Agromyzidae) pada Tanama Kentang [Dissertation]. Bogor, Indonesia: Institut Pertanian Bogor.

Supartha, I.W., 2002. Development of biological control of Liriomyza spp. on various vegetable crops in Bali. Materi disampaikan dalam Kongres VI Perhimpunan Entomologi Indonesia dan Simposium Entomologi 2002 di Cipayung Bogor.

Supartha, I.W., Sasromarsono., 2000. Identifikasi dan gejala serangan *Liriomyza* spp. (Diptera: Agromyzidae) pada tanaman kentang. *Agritrop. J. Agric. Sci.* 19, 5–8.

Supartha, I.W., Susila, I.W., Sumiartha, I.K., Rauf, A., Cruz, L.B.D.C., Yudha, I.K.W., Utama, I.W.E.K., Wiradana, P.A., 2022a. Preference, population development, and molecular characteristics of *Spodoptera exigua* (Lepidoptera: Noctuidae) on shallot cultivars: a field trial scale. *Biodiversitas J.* 23, 783-792. https://doi.org/10.13057/biodiv/d230224

Supartha, I.W., Susila, I.W., Yohanes, Yudha, I.K.W., Wiradana, P.A., 2022b. Potential of parasitoid *Gronotoma micromorpha* perkin (Hymenoptera: Eucoilidae) as a biocontrol agent for pea leafminer fly, *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae). *Acta Ecol. Sin.* 42, 90–94. https://doi.org/10.1016/j.chnaes.2021.06.008

Supartha, I.W., Yudha, I.K.W., Wiradana, P.A., Susila, I.W., 2020. Response of parasitoids to invasive pest *Phenacoccus manihoti* matile-ferrero (Hemiptera: Pseudococcidae) on cassava crop in Bali, Indonesia. *Biodiversitas J.* 21, 4543-4549. https://doi.org/10.13057/biodiv/d211011

Susila, I., Supartha, I., Sumiartha, K., 2005. Complexity and parazsitization rate of parasitoid associated with leafminer flies. *Liriomyza* spp. on Broadbean In Bali. *In: The International Society for Southeast Asian Agricultural Sciences (ISSAAS)*. Thailand: Kasetsart University.

Tantowijoyo, W., Hoffmann, A.A., 2010. Identifying factors determining the altitudinal distribution of the invasive pest leafminers Liriomyza huidobrensis and *Liriomyza sativae. Entomol. Exp. Appl.* 135, 141–153. https://doi.org/10.1111/j.1570-7458.2010.00984.x

Thomson, L.J., Macfadyen, S., Hoffmann, A.A., 2010. Predicting the effects of climate change on natural enemies of agricultural pests. *Biol. Control.* 52, 296–306. https://doi.org/10.1016/j.biocontrol.2009.01.022

Tonnang, H.E., Sokame, B.M., Abdel-Rahman, E.M., Dubois, T., 2022. Measuring and modelling crop yield losses due to invasive insect pests under climate change. *Curr. Opin. Insect Sci.* 50, 100873. https://doi.org/10.1016/j.cois.2022.100873

Tran, D.H., Tran, T.T.A., Mai, lan P., Ueno, T., Takagi, M., 2007a. Seasonal abundance of *Liriomyza sativae* (Diptera: Agromyzidae) and its parasitoids on vegetables in Southern Vietnam. *J. Fac. Agric. Kyushu Univ*. 52, 49–55. https://doi.org/10.5109/9280

Tran, D.H., Ueno, T., Takagi, M., 2007b. Comparison of the suitability of *Liriomyza chinensis* and *L. trifolii* (Diptera: Agromyzidae) as hosts for *Neochrysocharis okazakii* (Hymenoptera: Eulophidae). *Biol. Control.* 41, 354–360. https://doi.org/10.1016/j.biocontrol.2007.02.007

UC IPM. 2014. Biological Control and Natural Enemies of Invertebrates. Available at: https://ipm.ucanr.edu/PMG/PESTNOTES/pn7410.html. [Date accessed: 10 March 2022]

Wahyuni, S., Supartha, I.W., Ubaidillah, R., Wijaya, I.N., 2017a. Parasitoid community structure of leaf miner *Liriomyza* spp. (Diptera: Agromyzidae) and the rate of parasitization on vegetable crops in Lesser Sunda Islands, Indonesia. *Biodiversitas.* 18, 593–600. https://doi.org/10.13057/biodiv/d180221

Wahyuni, S., Supartha, I.W., Ubaidillah, R., Wijaya, I.N., 2017b. Parasitoid community structure of leaf miner *Liriomyza* spp. (Diptera: Agromyzidae) and the rate of parasitization on vegetable crops in Lesser Sunda Islands, Indonesia. *Biodiversitas J.* 18, 593–600. https://doi.org/10.13057/biodiv/d180221

Walter, J.A., Ives, A.R., Tooker, J.F., Johnson, D.M., 2018. Life history and habitat explain variation among insect pest populations subject to global change. *Ecosphere.* 9, 1-9. https://doi.org/10.1002/ecs2.2274

Wang, Y.C., Chang, Y.W., Bai, J., Zhang, X.X., Iqbal, J., Lu, M.X., Hu, J., Du, Y.Z., 2021. High temperature stress induces expression of CYP450 genes and contributes to insecticide tolerance in *Liriomyza trifolii. Pestic. Biochem. Physiol.* 174, 104826. https://doi.org/10.1016/j.pestbp.2021.104826

Wang, R., Yang, H., Wang, M., Zhang, Z., Huang, T., Wen, G., Li, Q., 2020. Predictions of potential geographical distribution of *Diaphorina citri* (Kuwayama) in China under climate change scenarios. *Sci. Rep.* 10, 9202. https://doi.org/10.1038/s41598-020-66274-5

Waongo, A., Ba, N.M., Dabiré-Binso, L.C., Sanon, A., 2015. Diversity and community structure of insect pests developing in stored sorghum in the Northern-Sudan ecological zone of Burkina Faso. *J. Stored Prod. Res.* 63, 6–14. https://doi.org/10.1016/j.jspr.2015.05.002

Xu, X., Ridland, P.M., Umina, P.A., Gill, A., Ross, P.A., Pirtle, E., Hoffmann, A.A., 2021. High incidence of related *Wolbachia across* unrelated leaf-mining diptera. *Insects.* 12, 788. https://doi.org/10.3390/insects12090788

Yuliadhi, K.A., Supartha, I.W., Darmiati, N.N., Bangun, A., Yudha, I.K.W., Utama, I.W.E.K., Wiradana, P.A., 2021a. *Silba adipata* (Diptera: Lonchaeidae) parasitoids on cayenne pepper (Capsicum frutescens) in Bali, Indonesia. *Biodiversitas J.* 22, 3929-3935. https://doi.org/10.13057/biodiv/d220939

Yuliadhi, K.A., Supartha, I.W., Wijaya, I.N., Pudjianto, P., Nurmansyah, A., Susila, I.W., Yudha, I.K.W., Utama, I.W.E.K., Wiradana, P.A., 2021b. The preference and functional response of *Sycanus aurantiacus* (Hemiptera: Heteroptera: Reduviidae) on three prey types in laboratory conditions. *Biodiversitas J.* 22, 5662-5667. https://doi.org/10.13057/biodiv/d221252

Yuliadhi, K.A., Susila, I.W., Supartha, I.W., Sultan, A., Yudha, I.K.W., Utama, I.W.E.K., Wiradana, P.A., 2022. Interaction of parasitoids associated with fruit flies attacking star fruit (*Averrhoa carambolae*) in Denpasar City, Bali Province, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 980, 012051. https://doi.org/10.1088/1755-1315/980/1/012051