OPEN ACCESS Pakistan Journal of Biological Sciences

ISSN 1028-8880
DOI: 10.3923/pjbs.2018.

Research Article
Effects of *Aphidius gifuensis* Release on Insect Communities and Diversity in Tobacco Fields of Yunnan Province, China

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Abstract

Background and Objectives: The biocontrol agent *Aphidius gifuensis* has widely been released and applied since 1997 to control *Myzus persicae* in tobacco fields of Yunnan Province, southwestern China, but its ecological effects on the local insect community and diversity have not been described. Biological control agents may effect a diversity of organisms as well as the target for control but such trophic cascades have seldom been studied. This study aimed to explore the effects of *A. gifuensis* on the insect community and diversity in tobacco fields after long-term release and expansion of the biocontrol agent in Yunnan Province. **Materials and Methods:** The effects of *A. gifuensis* on species composition, importance value, species richness, diversity indices and evenness index were studied for insect community samples obtained via field surveys and malaise trap collection in Yunnan Province. **Results:** A total of 39 insect species and 1 spider, principally belonging to 40 families and 13 orders in tobacco fields of Yunnan Province were identified. Among these, there were 20 pests, 14 natural enemies and 6 others, constituting 50, 35 and 15% of total species sampled, respectively. Within insect communities, *M. persicae*, *Empoasca flavescens* and *Drosophila melanogaster* were the dominant species and *Spodoptera litura*, one unidentified species (Ichneumonidae), *Sphex haemorrhoidalis*, *Vespa veutinaauraris*, *Aedes albopictus*, *A. gifuensis* and *Liriomyza huidobrensis* were the subdominant species. From June to August, the relative density of *A. gifuensis* gradually increased and concomitantly the total relative density of other natural enemies exhibited a slight decline in July and marked increase in August. The relative density of *M. persicae* significantly increased in July and then declined precipitously in August. Moreover, the values of Simpson index, Shannon-Wiener index and Pielou index were greater than 0.50, 1.50 and 0.50, respectively, indicating high insect diversity. **Conclusion:** Beneficial insects, in addition to the biocontrol agent are relatively abundant in tobacco fields of Yunnan Province, marking improvement in the local insect community diversity after a long-term release of the biocontrol agent *A. gifuensis*, which, by land area, constitutes one of the largest natural enemy control programs in the world.

Key words: Tobacco, *Aphidius gifuensis* release, natural enemies, insect community, biocontrol agent

Citation: Shicai Shen, Gaofeng Xu, Fushou Chen, David Roy Clements, Xinghui Gu, Sigui Ji, Limeng Zhang, Hailin Yang, Fudou Zhang, Kesuo Yin, Hongmei Zhang, Jiarui Li and Di Wu, 2018. Effects of *Aphidius gifuensis* release on insect communities and diversity in tobacco fields of Yunnan Province, China. Pak. J. Biol. Sci., CC: CC-CC.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tobacco (*Nicotiana tabacum*) (Solanaceae), an annual herb or perennial herb, is native to South America. Because of its high economic value, this plant is the most widely grown as a non-food cash crop worldwide[1]. China is first on the globe with 14.6 million ha planted and an annual production of 2.99 t. Tobacco production is important in the national economy of China[2]. In 2015, China's tobacco industry generated RMB 1.1436 trillion in profit and provided RMB 1.095 trillion in profit, tax and fees to government revenue. Over 4 million Chinese households relied on tobacco for their livelihood, either as tobacco farmers, cigarette industry employees or cigarette retailers[2]. Thus, tobacco has played an important role in poverty alleviation in many rural areas and provided a substantial economic contribution in many Provinces of China.

During tobacco production, the yield and quality of tobacco leaves may be affected by insects and diseases. In order to improve tobacco productivity and reduce labour requirements, chemical pesticides have been widely applied for disease and insect prevention and control in tobacco fields. However, due to long-term and large scale applications, a great number of negative effects of pesticides on environments, agricultural systems and even human and animal health have been recognized, including soil erosion, biodiversity loss, pesticide contamination of offsite or non-target areas and pesticide resistance[3-5]. As an effective environmentally-friendly alternative, biological control with pollution-free, harm-free and long-term management has become more and more important in comprehensive management of tobacco pests, such as the natural enemy *Aphidius gifuensis* (Ashmead) to control tobacco aphids[5-7].

Aphidius gifuensis belonging to Aphidiidae family of Hymentoptera, is widely distributed in Hawaii and eastern Asia, including China, Japan and North Korea[6,7]. *A. gifuensis* is an important parasitic natural enemy of various aphids and has been used as a promising biocontrol agent in various locations throughout the world. In China, mass rearing and release techniques for *A. gifuensis* have been developed and applied on a large scale to manage the major pest *Myzus persicae* (Sulzer) in tobacco fields[8-10]. The mass rearing and release techniques of *A. gifuensis* were initiated in Yunnan Province, southwestern China, in 1997 and 1998[5]. After about 20 years development, these techniques have been widely applied and promoted throughout Yunnan Province and even other regions of China. Currently, *A. gifuensis* release in China has become one of the largest pest biocontrol practices in the world, considering the size of the land area of the release[5]. Various reports have shown that *A. gifuensis* has successfully established stable populations and effectively decreased aphid population in tobacco fields. This parasitoid has demonstrated effective control in tobacco fields by decreasing population of *M. persicae*, lowering costs and reducing pesticide uses[9-12]. Moreover, *A. gifuensis* release has been widely accepted by rural tobacco farmers and technicians[5]. Until now, work has focused on the economic and social evaluation of control effectiveness of the parasitoid release[5,9,10]. There is scant literature available on ecological effectiveness of *A. gifuensis* release on insect community and diversity in tobacco fields. When Yang *et al.*[5] assessed the status of the biocontrol program in 2011, they pointed out that no studies have been conducted on the impact of the release of *A. gifuensis* on its relationship with other organisms such as other natural enemies and that such research would be valuable to understand the overall effectiveness of the program. To our knowledge, this is the first study to look at the impact of the *A. gifuensis* release beginning in 1997 on insect biodiversity in Yunnan.

The present study examined the effects of the biocontrol agent *A. gifuensis* on insect community and diversity in tobacco fields in 19 counties or cities of Yunnan Province, southwestern China. These findings are valuable for increasing our understanding of ecological effectiveness of *A. gifuensis* release including the potential for trophic cascades, establishing multi-evaluation systems for ecological effectiveness and further providing scientific and technological supports for large-scale extension of *A. gifuensis* release.

MATERIALS AND METHODS

Study site: Located in the eastern Hindu-Kush Himalaya region, northern zone of the Southeast Asia sub-continent (21°8'32"-29°15'8"N, 97°31'39"-106°11'47E), the natural conditions of Yunnan Province, southwestern China including longitude, latitude, altitude, soil, temperature, sunshine and rainfall have been known as one of the world's most suitable areas for growing tobacco[13]. As the largest tobacco-producing base within China, tobacco production is a major economic pillar of Yunnan. More than 45% of the Yunnan provincial government's tax receipts come from tobacco and the tobacco industry has made a significant contribution to local economic and social development in Yunnan[14]. As a large biocontrol programme, the mass rearing and release techniques of *A. gifuensis* on *M. persicae* were initiated by Yuxi Tobacco Company in Hongta District, Yuxi City of Yunnan since 1997[5]. Until now, the biocontrol agent has been widely applied and extended throughout Yunnan.

Table 1: Basic information on survey locations to monitor impacts of *Aphidius gifuensis* release in Yunnan Province

Site						
Village	County/District	City/ Prefecture	Longitude (E)	Latitude (N)	Altitude (m)	Release period (y)
Ganhaizi	Hongta	Yuxi	102°33'24"	24°16'13"	1819	15
Laobaidian	Xinping		102°00'52"	23°53'44"	1610	8
Liujie	Tonghai		102°45'53"	24°11'41"	1805	10
Dataiping	Mile	Honghe	103°32'50"	24°25'43"	1452	8
Dizhang	Jianshui		102°59'14"E	23°48'4"	1500	8
Shidong	Mengzi		103°22'30"	23°13'53"	1350	8
Masa	Maguan	Wenshan	104°23'41"	23°5'10"	1370	7
Shuanglongying	Qiubei		104°11'11"	24°10'42"	1450	8
Daxin	Yanshan		103°47'40"	23°44'17"	1487	7
Shaojing	Luquan	Kunming	102°29'21"	25°26'23"	1800	8
Qingshuitang	Shilin		103°21'8"	24°47'29"	1900	8
Daheqiao	Xundian		103°17'6"	25°29'50"	1886	8
Hualuping	Zhaoyang	Zhaotong	103°43'27"	27°14'2"	1933	8
Huashan	Qiajia		103°26'65"	26°85'95"	2138	6
Longdong	Yiliang		104°8'1"	27°24'28"	1886	6
Samayi	Qilin	Qujing	104°3'53"	25°10'52"	1913	7
Reshui	Xuanwei		103°45'50"	26°6'0"	1972	7
Yongan	Shizong		104°5'31"	24°56'21"	1900	8
Daming	Luoping		104°19'6"	24°48'20"	1485	8

The study sites for sampling insect diversity were located in 19 villages belonging to 19 counties or districts of six cities/prefectures in Yunnan Province. The basic information including village, county, city/prefecture and release period of *A. gifuensis* of study sites is shown in Table 1.

Methods: From 2015-2017, field investigations were conducted in 19 tobacco sites of 19 counties and districts in Yunnan Province. First, a contiguous area of tobacco plantation over 15 ha in each site was randomly selected. Then, five transects were set up along the central section of each tobacco field spaced approximately 100 m apart and 4 sample points spacing of 20 m were selected in each transect line. The 100 m transects and 20 m sample points spacing were determined by hand held Global Position System (GPS) devices.

For insect population in tobacco fields, the species and number were recorded among four tobacco plants at each sample point. The field surveys were the responsibility of a local technician from the plant protection station or agricultural technology station at each site. Surveys were conducted once per week from June to August. After the survey was completed, all data and related documents, including questionnaires and photos were collected to establish corresponding archives. Moreover, a malaise trap was established in the vicinity of the center of each tobacco field at each site simultaneously. Each month, the technicians collected the bottles containing insects preserved in 95% ethanol. At the end of August, all insect bottles were taken to the laboratory and the species and number of insects were recorded and identified. Subsequently all specimens collected were deposited in the Laboratory of Insect Research, Agricultural Environment and Resource Research Institute of the Yunnan Academy of Agricultural Science.

Data analyses: On the basis of combined malaise trap and field survey data, insect population and diversity at 19 tobacco sites were analyzed. The relative density was summarized as the number of one species divided by the total number of all individuals of all species in a plot and the species frequency was summarized as the number of quadrats with at least one individual of a given species divided by the total number of the sampled quadrats in all plots. The importance value of a species was the mean value of its relative density and relative frequency using absolute values divided by the sum of the densities and frequencies of all species in a plot, respectively. Additionally, species richness, diversity and evenness were estimated as the following parameters: (1) Simpson diversity index (D)[15] was calculated as:

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

where, Ni is the total number of individuals from i species in a plot, N is the total number of individuals from all species in a plot. D ranges from 0-1, with 1 being the maximal diversity, (2) Shannon-Wiener diversity index (H)[15] was measured as:

$$H = -\sum PilnPi$$

where, Pi is the proportion relative to the total number of species per plot and (3) Pielou evenness index (J)[16] was calculated as:

$$J = \frac{H}{\ln S}$$

where, S is the species richness of each plot.

Data were analyzed by analysis of variance (One-way ANOVA). If significant differences were detected with the ANOVA, Duncan's multiple range tests were used to detect differences among treatments at a 5% level of significance.

RESULTS

Insect species inventory: The present field survey revealed that a total of 39 insect species and 1 spider (including one unidentified species), principally belonging to 40 families and 13 orders at 19 tobacco sites of Yunnan Province (Table 2). Mantodea, Neuroptera, Dermaptera, Araneida, Odonata and Blattaria were represented by one species each; 2 species belonged to the orders Orthoptera and Lepidoptera, 3 species each belonged to the orders Homoptera and Hemiptera, Diptera and Hymenoptera were represented by 6 species each and 12 were representatives of Coleoptera constituting 30% of the total species (Table 2). Functionally speaking, there were 20 pests, 14 natural enemies and 6 others, representing 50, 35 and 15% of the total species sampled, respectively.

Effects of *Aphidius gifuensis* release on relative insect density and importance values: Within insect communities, *M. persicae* had the highest relative density (29.37) followed

Table 2: Species and population of insects observed in field surveys of tobacco fields of Yunnan Province

Order	Family	Latin name	Relative density (%)	Importance value	Group
Homoptera	Aleyrodidae	*Bemisia tabaci* Gennadius	0.07	3.85±2.80	P
	Aphididae	*Myzus persicae* Sulzer	29.37	56.72±5.94	P
	Cicadellidae	*Empoasca flavescens* Fabricuis	20.69	58.27±5.76	P
Lepidoptera	Noctuidae	*Spodoptera litura* Fabricius	7.84	53.92±1.33	P
	Pieridae	*Danaus plexippus* Linnaeus	0.39	39.55±3.13	P
Mantodea	Mantidae	*Hierodula patellifera* Serville	0.01	3.53±1.79	E
Diptera	Syrphidae	*Episyrphus balteatus* De Geer	0.85	40.73±4.74	E
	Calliphoridae	*Calliphora erythrocephala* Meig	0.13	9.71±8.52	N
	Drosophilidae	*Drosophila melanogaster* Brenton R. Graveley	17.31	47.67±21.26	N
	Culicidae	*Aedes albopictus* Skuse	1.97	26.73±21.62	N
	Tephritidae	*Dacus dorsalis* Hendel	0.18	11.51±11.56	P
	Agromyzidae	*Liriomyza huidobrensis* Blanchard	1.45	23.27±17.62	P
Coleoptera	Carabidae	*Calosoma chinese* Kirby	0.34	26.67±6.88	P
	Coccinellidae	*Coccinella septempunctata* Linnaeus	0.39	21.67±6.24	E
	Meloidae	*Mylabris cichorii* Linnaeus	0.05	7.66±3.52	P
	Rutelidae	*Anomala corpulenta* Motschulsky	0.07	8.24±0.99	P
	Lampyridae	*Lamprohiza splendidula* Linnaeus	0.10	13.22±4.62	E
	Curculionidae	*Hypomeces squamosus* Fabricius	0.16	18.34±10.75	P
	Tenebrionidae	*Opatrum subaratum* Faldermann	0.14	9.77±4.04	P
	Chrysomelidae	*Cassida nebulosa* Linnaeus	0.75	23.64±9.30	P
	Cerambycidae	*Batocera lineolata* Chevrolat	0.09	14.13±10.10	P
	Melolonthidae	*Serica orientalis* Motschulsky	0.16	17.40±6.11	P
	Elateridae	*Agriotes subvittaus* Motschulsky	0.25	18.30±4.52	P
	Staphylinidae	*Paederus fuscipes* Curtis	0.74	32.76±4.85	E
Orthoptera	Acrididae	*Xenocatantops brachycerus* Willemse	0.11	18.62±5.99	P
	Gryllidae	*Loxoblemmus doenitzi* Stein	0.05	13.23±4.88	P
Neuroptera	Chrysopidae	*Chrysopa septenpunctata* Wesmael	0.07	20.63±3.06	E
Hymenoptera	Aphidiidae	*Aphidius gifuensis* Ashmead	1.92	40.92±10.42	E
	Ichneumonidae	One unidentified species	7.64	52.65±1.46	E
	Polistidae	*Polistes jadwigae* Dalla Torre	0.15	19.88±13.13	E
	Apidae	*Apis cerana* Fabricius	0.86	44.79±3.78	N
	Sphecidae	*Sphex haemorrhoidalis* Fabricius	2.45	33.60±8.22	E
	Vespidae	*Vespa veutinaauraris* Smith	2.37	45.26±2.49	E
Hemiptera	Reduriidae	*Harpactor fuscipes* Fabricius	0.02	4.15±6.44	E
	Anthocoridae	*Orius similies* Zheng	0.28	26.59±6.13	E
	Coreidae	*Riptortus linearis* Fabricius	0.11	18.38±6.01	P
Dermaptera	Labiduridae	*Euborellia pallipes* Shiraki	0.26	26.02±4.71	P
Araneida	Argiopidae	*Erigonidium graminicola* Sundevall	0.12	26.17±9.53	E
Odonata	Coenagriidae	*Ischnura senegalensis* Rambur	0.03	9.76±3.52	N
Blattaria	Blattidae	*Periplaneta mericana* Linnaeus	0.06	6.70±2.27	N

Data are expressed as Mean±standard deviation, P: Pest, E: Natural enemy, N: Neutral insect

Table 3: Species richness and diversity index of insect communities in tobacco fields of Yunnan Province

Site					
County/District	City/Prefecture	Species richness (S)	Simpson index (D)	Shannon-wiener diversity index (H)	Pielou evenness index (J)
Hongta	Yuxi	24.56±1.90^{a}	0.75±0.12^{ab}	1.97±0.41^{ab}	0.62±0.11^{abc}
Xinping		23.44±1.58^{a}	0.77±0.05^{a}	1.94±0.19^{ab}	0.62±0.05^{abc}
Tonghai		17.67±1.53^{cde}	0.65±0.16^{ab}	1.49±0.43^{abcd}	0.52±0.13^{abcd}
Mile	Honghe	19.33±0.88^{bcd}	0.80±0.06^{a}	1.99±0.23^{a}	0.68±0.09^{ab}
Jianshui		18.22±2.12^{bcde}	0.74±0.03^{ab}	1.75±0.10^{abc}	0.60±0.01^{abc}
Mengzi		21.67±2.33^{ab}	0.67±0.13^{ab}	1.64±0.41^{abc}	0.54±0.14^{abc}
Maguan	Wenshan	15.44±1.39^{e}	0.72±0.08^{ab}	1.68±0.17^{abc}	0.62±0.08^{ab}
Qiubei		17.44±1.07^{cde}	0.77±0.09^{a}	1.97±0.27^{ab}	0.69±0.08^{a}
Yanshan		16.89±2.14^{de}	0.74±0.09^{ab}	1.79±0.25^{abc}	0.64±0.09^{ab}
Luquan	Kunming	21.44±1.71^{ab}	0.80±0.02^{a}	1.98±0.07^{a}	0.65±0.01^{ab}
Shilin		17.11±1.35^{cde}	0.60±0.08^{abc}	1.39±0.24^{bcd}	0.49±0.07^{bcd}
Xundian		17.61±3.70^{cde}	0.54±0.16^{bc}	1.26±0.37^{cd}	0.44±0.10^{cd}
Zhaoyang	Zhaotong	17.56±1.07^{cde}	0.77±0.09^{a}	1.87±0.31^{ab}	0.65±0.11^{ab}
Qiajia		21.11±1.17^{abc}	0.76±0.05^{ab}	1.88±0.14^{ab}	0.62±0.06^{abc}
Yiliang		19.00±1.20^{bcde}	0.64±0.21^{ab}	1.53±0.50^{abcd}	0.52±0.16^{abcd}
Qilin	Qujing	16.89±3.98^{de}	0.43±0.24^{c}	1.00±0.54^{d}	0.35±0.17^{d}
Xuanwei		19.33±1.67^{bcd}	0.64±0.02^{ab}	1.49±0.07^{abcd}	0.51±0.04^{abcd}
Shizong		21.44±0.69^{ab}	0.81±0.03^{a}	2.04±0.13^{a}	0.67±0.04^{ab}
Luoping		17.56±2.04^{cde}	0.54±0.04^{bc}	1.24±0.13^{cd}	0.44±0.06^{cd}

Data are expressed as Mean±standard deviation, Different letters within same column represent significant differences at p<0.05

by *Empoasca flavescens* (20.69), *Drosophila melanogaster* (17.31) and then *Spodoptera litura* (7.84), one unidentified species (Ichneumonidae) (7.64), *Sphex haemorrhoidalis* (2.45), *Vespa veutinaauraris* (2.37), *Aedes albopictus* (1.97), *A. gifuensis* (1.92) and *Liriomyza huidobrensis* (1.45) (Table 2). According to importance values three insects, *M. persicae*, *E. flavescens* and *D. melanogaster* were the dominant species and *S. litura*, one unidentified species (Ichneumonidae), *S. haemorrhoidalis*, *V. veutinaauraris*, *A. albopictus*, *A. gifuensis* and *L. huidobrensis* were the subdominant species. From June to August, the relative density of *A. gifuensis* gradually increased. As the relative density of *A. gifuensis* increased the relative density of other natural enemies declined slightly in July and then increased markedly in August, whereas the relative density of *M. persicae* increased greatly in July before declining precipitously in August (Fig. 1).

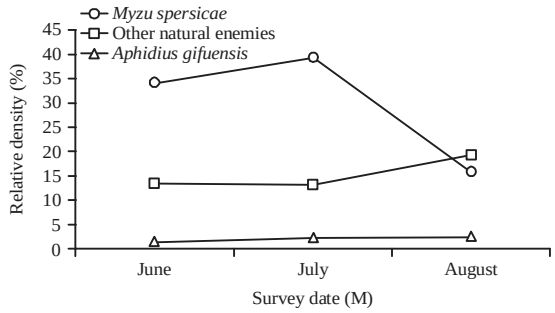

Fig. 1: Relative species density of *Myzus persicae*, *Aphidius gifuensis* and other natural enemies

Effects of *Aphidius gifuensis* release on species diversity: This data showed that Hongta District and Xinping County of Yuxi City, Mile County of Honghe Prefecture, Qiubei County of Wenshan City, Qiajia County of Zhaotong City, Shizong County of Qujing City and Luquan County of Kunming City had the highest species richness, Simpson index, Shannon-Wiener index and Pielou index but there were few significant differences among locations (Table 3). Overall, most Simpson index values were greater than 0.50, most Shannon-wiener index values were greater than 1.50 and most Pielou index values were greater than 0.50, indicating that the release of *A. gifuensis* was associated with maintaining or increasing the diversity of local insect communities in tobacco fields of Yunnan Province.

DISCUSSION

Yunnan Province is the largest producer of cigarettes and tobacco in China and the tobacco industry plays an essential role in the economic development of Yunnan[5,17,18]. In order to implement ecological management of the major pest *M. persicae* in tobacco fields, Yuxi Tobacco Company of Yunnan Province began making efforts to research mass rearing techniques in greenhouses for *A. gifuensis* in 1997 [5].

The augmentative release of *A. gifuensis* was extended more widely in the Yuxi District and other regions of Yunnan Province in 2001 and 2007, respectively[5,19]. Since 2010, augmentative release was also extended to other crops such as rape, vegetable and fruit trees in Yunnan Province[19,20]. The current study found that the release of *A. gifuensis* has achieved positive ecological effects on local insect communities in the tobacco fields of Yunnan Province.

In tobacco production, *M. persicae* is a destructive pest that is parasitized by *A. gifuensis*, a natural aphid parasitoid and both species are widely distributed throughout the world, including much of China[5,21]. Under natural conditions, the parasitism rate of *A. gifuensis* was usually 20-60% and was even recorded as 89.16% in one instance[22]. The population density of *M. persicae* declined from 34.3/plant to 0.1/plant as the parasitism rate increased from 0-95% within 60 days of release but aphid population density increased from 33.2/plant to 51.2/plant with the parasitism rate increasing from 0.1-38.8% in control (blank) fields[22]. Control by *A. gifuensis* released to manage aphids can reach 93-93.5% in tobacco fields late in the season[23]. In years without release of A. *gifuensis*, the mean population densities of *M. persicae* were significantly higher than those in the years with parasitoid release and in years of without *A. gifuensis* release, the *M. persicae* population increased rapidly and the population densities exceeded the action threshold during most of the growing season[5]. The present study found that *M. persicae* was a dominant species and had higher relative density and importance values than most other insects within insect communities. From June to August, the relative density of *A. gifuensis* gradually increased and as relative density increased for *A. gifuensis*, the relative density of *M. persicae* increased greatly in July and then declined precipitously in August. This evidence demonstrated that *A. gifuensis* has become a relatively common species and achieved beneficial control of *M. persicae* in tobacco fields of Yunnan Province after a long-term release.

During virtually any biocontrol programme, the relationship between biocontrol agents and other organisms (e.g., natural enemies) is an important ecological indicator to consider[5]. Biocontrol agents may interact with other organisms in an augmentation programme[24]. Besides *A. gifuensis*, there are many different natural enemies in tobacco fields. Previous studies reported as many as 114 species of natural enemies in tobacco fields of Yunnan Province[25] and 84 species of natural enemies on *M. persicase* in tobacco fields of Fujian Province[26]. The release of *A. gifuensis* has been shown to maintain population densities of *M. persicase* at a low levels both in field experiments and in long-term practical experience but side effects may include impacts on other natural enemies because the parasitoids also attack other aphid species[6,7,22]. It is reported that the control effect of a combined release of both *A. gifuensis* and *Leis axyridis* was better than single release and even better than chemical control late in the season[27]. Some studies found no direct relationships between *A. gifuensis* and other natural enemies, while many natural enemies had mutualistic relations with *M. persicase* in tobacco fields[12,28,29]. In this present study, from June to August, with relative density increases in *A. gifuensis*, the relative density of other natural enemies declined slightly in July and increased markedly in August, indicating that the release of *A. gifuensis* is conducive to promotion of a diversity of other natural enemies in tobacco fields in the late season.

Generally, higher diversity indices mean more stable community structure and diversity of insect fauna in tobacco fields[30]. The diversity of species and community is not only affected by the released species but also influenced by environmental factors and human activities. Although, species richness, Simpson index, Shannon-wiener index and Pielou index varied among insect communities due to varying ecological and environmental conditions at 19 tobacco sites, diversity values were generally quite high. Most Simpson index, Shannon-wiener index and Pielou index values were greater than 0.50, 1.50 and 0.50, respectively, showing that after long-term release of *A. gifuensis*, local insect community structure and diversity in tobacco fields of Yunnan Province has already improved and become more stable. The increased presence of top predators like *A. gifuensis* often create trophic cascades which enable such diversification to occur in various ecological communities.

CONCLUSION

There are now relatively diverse insect communities in tobacco fields of Yunnan Province. Following long-term augmentative release of *A. gifuensis*, this biocontrol agent has achieved highly beneficial ecological effects on local insect diversity in tobacco fields of Yunnan Province, including reducing the relative density of *M. persicae*, increasing the total relative density of other natural enemies in the late season and promoting high Simpson index, Shannon-wiener index and Pielou index values for insect communities.

SIGNIFICANCE STATEMENT

This study discovered that the release of the biocontrol agent *A. gifuensis* has achieved beneficial ecological effects

on local insect community composition and diversity in tobacco fields of Yunnan Province, China. Our contribution helps to elucidate the ecological effectiveness of *A. gifuensis* release, including the potential for trophic cascades, helps to establish multi-evaluation systems for ecological effectiveness and provides scientific and technological support for large-scale extension of *A. gifuensis* which has implications for any region in the world where this biocontrol agent is released.

ACKNOWLEDGMENTS

This study was supported by Yunnan Tobacco Company Science and Technology Program (2015YN14). We wish thank the technicians and local partners from 19 different sites in Yuxi City, Kunming City, Qujing City, Wenshan City and Honghe Prefecture of Yunnan Province for their great field support.

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