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Current Status and Future Trends of Augmentative Release of *Aphidius gifuensis* for Control of *Myzus persicae* in China's Yunnan Province

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ABSTRACT

Augmentative releases of *Aphidius gifuensis* have been made in Yunnan Province of China for more than 10 years, and much work has been conducted in this biological control programme. In this article, mass rearing and release techniques of *A. gifuensis* were detailed and its control efficacy and economic costs were further reviewed, showing its high potentials for control of *Myzus persicae*. However, as wider and long term release of *A. gifuensis*, some techniques of mass rearing and release should be further improved or optimized, including winter host selection of *M. persicae*, management of hyperparasitoids and timing and quantity of release. Moreover, efficacy evaluation currently focused on the decrease of aphids' population densities, but failed to consider other aspects like environmental impacts, possibly lowering the benefits of augmentative release of *A. gifuensis*. This suggested more work should be further done in this biological control programme.

Key words: Review, *Aphidius gifuensis*, *Myzus persicae*, augmentative release, biological control.

INTRODUCTION

The green peach aphid (GPA), *Myzus persicae* (Sulzer), can affect over 400 host plants, including vegetables, tobacco and fruits (Kulash 1949; Stary 1970; Lojek and Orlob 1972; Mackauer and Way 1976; Liu 1991; Chen *et al*. 1994; Kanavaki *et al*. 2006). It is widely distributed and one of the most destructive pest insects on various crops in China. In Yunnan Province, southwest of China, GPA severely damaged tobacco and its infestations have caused big economic losses (Zhao 1981). In the past, farmers controlled this pest insect by intensively spraying chemical pesticides. However, populations of *M. persicae* did not decrease due to its high resistance to chemical pesticides (Wu *et al*. 2004; Wu and Song 2007). Moreover, overuse of pesticides has caused negative impacts on environment and human health.

To reduce pesticide use and effectively control GPA, a biological control programme -augmentative release of *Aphidius gifuensis* Ashmead (Hymentoptera: Aphidiidae) was initiated by Yuxi Tobacco Company in Hongta District, Yuxi Prefecture of Yunnan Province in 1997 and 1998. *A. gifuensis*, distributed widely in Asian countries, such as China, Japan and Korea, is a promising biocontrol agent for various aphids (e.g. *M. persicae*, *Brevicoryne brassicae*, *Lipaphis erysim* and *Macrosiphum avenae*) (Zhao *et al*. 1980; Xin 1986; Chen, 1994; Ohta and Ohtaishi 2005; Wei *et al*. 2005). In Japan, this parasitoid has been attempted to control *M. persicae* in small experimental greenhouses and showed its high potential for aphid control (Ohta and Ohtaishi 2005). In China, the mass rearing techniques of *A. gifuensis* were well developed and the parasitoid has been widely released for aphid control in tobacco fields and greenhouses (Zhao *et al*. 1980; Xin 1986; Xin *et al*. 2001; Li *et al*. 2002; Jiang *et al*. 2003; Wei *et al*. 2003; Yang, Yang *et al*. 2009). However, large-scale application of *A. gifuensis* was only reported in Yuxi Prefecture, Yunnan Province of China. After augmentative release in Yuxi Prefecture of Yunnan Province, this parasitoid has demonstrated effective control in tobacco fields by decreasing population of *M. persicae*, lowering costs and reducing pesticide use level (Wu, Zhao *et al*. 2000; Wei 2003; Yang, Yang *et al*. 2009; Yang *et al*. 2010). Currently, *A. gifuensis* release is being promoted throughout Yunnan Province. The total area of *A. gifuensis* release was about 46,000 ha and 128,000 ha respectively in Yuxi Prefecture and the whole Yunnan Province in 2010. Without exaggeration, it can be considered as one of the largest pest biocontrol practices in the world.

In the past years, mass rearing techniques of *A. gifuensis* kept improved in Yunnan. Now, the parasitoid can be produced both in big greenhouses and small nylon greenhouses (Wei *et al*. 2001; Wei *et al*. 2003; Deng *et al*. 2006; Deng *et al*., 2010). Big greenhouses are used not only for mass rearing but also for maintenance of seed aphids and parasitoids. Small greenhouses are widely applied in rural communities due to the lower cost and flexibility. These two rearing systems are complementary and essential to the large-scale extension of *A. gifuensis* (Deng *et al*. 2010). Furthermore, much work has been done for the evaluation of control effectiveness of parasitoid release (Wu, Zhao *et al*. 2000; Wei 2003; Yang, Yang *et al*. 2009; Yang *et al*. 2010). The results were positive and the wider application has been greatly encouraged by different levels of government. In addition, trainings of mass rearing and release techniques for technicians and farmers have been organized in past years (Yang, Yang *et al*. 2009; Deng *et al*. 2010). This is important to the further application of *A. gifuensis* as well.

Now, the adverse impacts of chemical pesticides on health, environment, biodiversity and food safety have been gradually recognized by governments and the public. People are trying to find out effective environment-friendly alternatives for pest management such as biological control and ecological management. The practice of *A. gifuensis* release in Yunnan Province may provide some valuable information on the promotion of biological control to other countries. In this paper, we reviewed *A. gifuensis* application in Yunnan Province focusing on overall situation of release, mass

rearing and release techniques, control efficacy and economic cost comparison. In addition, how to further improve the effectiveness of *A. gifuensis* was also proposed with an attempt to promote its wider application in agricultural production.

The release situation of *Aphidius gifuensis* in Yunnan Province

In 1997 and 1998, Yuxi Tobacco Company made efforts in the study on mass rearing techniques of *A. gifuensis* in big greenhouses. However, limited parasitoids were collected and just released into very small tobacco fields due to limited numbers of greenhouses and unsatisfactory rearing technique. After Wei *et al*. (2001) and Wei (2003) developed a more applicable and effective method for mass rearing *A. gifuensis* in big greenhouses, a little bigger release began in 2000 with the area of 66.67 ha in Hongta District of Yuxi Prefecture. As the further improvement and number increase of big greenhouses, the release area also increased by 400 ha in this region, 2001(Deng *et al*. 2010). Parasitoid release was extended more widely to rural villages and total release area reached > 5,746 ha in Yuxi Prefecture, 2002 due to the introduction of mass rearing technique in small greenhouses (Wei *et al*.,2003; Deng *et al*. 2006). After that, the release has been kept increasing. In 2010, this augmentative release has covered all tobacco lands of 46,000 ha in Yuxi Prefecture. The release situation of *A. gifuensis* in Yuxi was listed in Fig.1. Moreover, other tobacco planting regions in Yunnan (e.g. Chuxiong and Dali) began to introduce this technique for *M. persicae* control in 2007. With the strong encouragement and promotion, the release area totaled up 128,000 ha in Yunnan, 2010. It is expected that the application of *A. gifuensis* will cover 0.2 million and 0.3 million ha of tobacco fields in Yunnan Province respectively in 2011 and 2012.

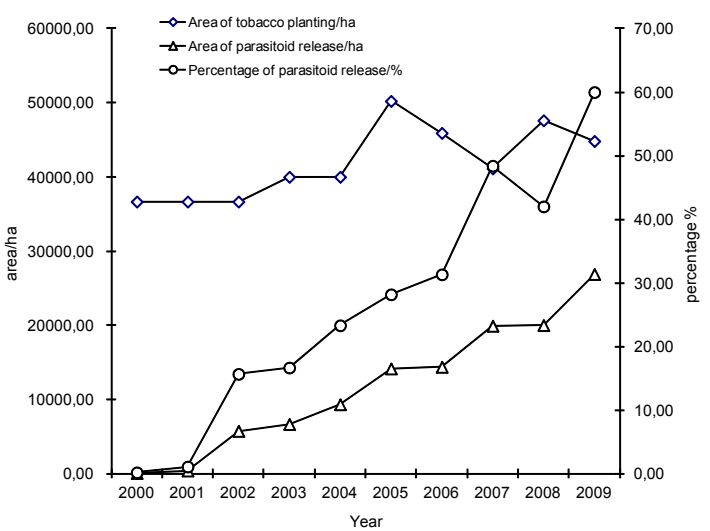

Fig. 1. Release situation of *A. gifuensis* in Yuxi, Yunnan Province(2000-2009)
(Note: Percentage of parasitoid release % = Area of parasitoid release / Area of tobacco planting × 100%)

Mass rearing and release techniques

Mass rearing techniques

Currently, *A. gifuensis* is produced in big greenhouses or small greenhouses in Yunnan. The mass rearing of parasitoid in big greenhouses (Length×Width×Height: 5×10×2.5m) was first reported by Wei *et al*.(2001). The big greenhouse could be glass or plastic. With effective management, maximum parasitoid production per generation was about 2.5 million mummified aphids for one large glass greenhouse (Wei *et al*., 2001; Wei, 2003). To meet the demands of large-scale production, big greenhouses were further improved by increasing total area (Length×Width×Height: 50×12×3m) (Deng *et al*., 2010). In the middle of greenhouse, there was a 50m long and1.5m wide aisle. On each side of the aisle, there were 17 nylon chambers (small rooms). The sizes of chambers on both sides were about 6 × 3 × 1.8m (Room A) and 4.5 × 3 × 1.8m (Room B) respectively. 90 and 70 tobacco seedlings can be planted respectively in Room A and Room B, largely increasing the scale and numbers of parasitoid rearing. This big greenhouse was costly and increased the cost of parasitoid rearing, but it was helpful to the maintenance of seed parasitoids and aphids. Therefore, these big greenhouses were applied as regional or county-level bases, which can strongly support the system of mass rearing parasitoids at township or community levels. Moreover, it can be utilized for vegetables or flowers cultivation after mass rearing of *A. gifuensis*, getting more additional benefits.

However, the cost of big greenhouse establishment was unaffordable to farmers and it was impossible to widely extend in rural villages. Wei *et al*. (2003) produced *A. gifuensis* by adopting small glass-topped greenhouses (1.7 × 3 × 3m) or plastic greenhouses (Wei *et al*., 2001). 125,000 and 45,000 mummified aphids for per generation can be produced respectively in glass-topped greenhouses or plastic ones (Wei *et al*., 2001). However, glass-topped greenhouses were inconvenient for transportation and not flexible to the tobacco-rotating system in Yunnan Province. Therefore, Deng *et al*. (2010) finalized this technique. The greenhouse (3 × 3× 2m) consists of detachable steel poles and nylon net. It can be easily transported, fixed according to the tobacco planting situation and detached immediately after parasitoid production. In this small greenhouse, 28-30 tobacco seedlings can be planted and totally 140,000-210,000 mummified aphids produced, which can cover 3-4ha of tobacco fields. Moreover, the greenhouse can be used at least for 10 years, keeping the cost at a low level.

More detailed information was given on different types of greenhouses in Table 1. Up to now, both big and small greenhouses developed by Deng *et al*.(2010) were widely adopted in Yunnan Province. Parasitoids produced in two types of greenhouses can cover respectively about 600ha and 3-4ha annually. Materials and cost for both greenhouses were listed in Table 2.

Regardless of types of greenhouses, the process for mass rearing of *A. gifuensis* included three steps, namely production of host plant -tobacco, mass rearing of *M. persicae* and *A. gifuensis*. Firstly, tobacco seedlings were transplanted into big greenhouses or small greenhouses (70-80 days after seeding). When they had 9-12

true leaves (normally 25-30 days after transplantation) (Wei *et al*. 2003; Deng *et al*. 2010), 20-30 apterous individuals of *M. persicae* were inoculated on leaves of each tobacco seedling. After 15-20 days, mummified aphids or adult parasitoids are introduced into greenhouses. The ratio of parasitoid to aphids was maintained at 1:50 or 1:100 according to population density of aphids. In general situation, abundant mummified aphids and adult parasitoids could be produced 15 - 20 days later (Deng *et al*., 2010). In Yunnan, cultivation of tobacco has a long history and it is very easy to produce enough seedlings for aphid production. During mass rearing, maintenance of environmental conditions was very important to the development and reproduction of aphids and parasitoids (Barlow 1962; Liu 1991; Liu and Wu 1994; Lu *et al*. 1994; Li *et al*. 1963; Wu, Li *et al*. 2000; Ohta *et al*. 2001; Ohta and Ohtaishi 2004). Practically, 22 - 28°C and 50 - 70% RH was suggested as the suitable environment for development of aphids and parasitoids in greenhouses (Wei *et al*. 2001, 2003; Deng *et al*. 2010). Moreover, black ventilated nets, electronic (exhausted) fans and air humidifiers were used to adjust the environment inside greenhouses (Wei *et al*. 2003; Deng *et al*. 2010). However, the prevention and control of tobacco diseases was necessary due to the high density planting pattern of tobacco seedlings in greenhouses. In addition, management of other pest insects was also important and no more chemical insecticides could be sprayed after inoculation of aphids (Deng *et al*. 2010).

To produce enough parasitoids next year, the maintenance of seed aphids and parasitoids in winter are essential. Seed aphids can be kept on tobacco seedlings in greenhouses. Meanwhile, *M. persicae* can be collected next spring from the fields as well (Wei *et al*., 2003). Seed parasitoids can been maintained in two ways:1) cold storage of mummified aphids in a refrigerator at 3 - 5°C (Chen *et al*. 2005); 2) maintenance of parasitoids in greenhouses. The techniques of maintenance of seed aphids and parasitoids in greenhouses are similar to those of mass rearing of aphids and parasitoids mentioned above with an expectation of limitation of scale and numbers (Deng *et al*. 2010).

Release techniques

Releases of mummified aphids and *A. gifuensis* adults were widely applied in Yunnan. While a large number of mummified aphids and adult parasitoids emerged, they were collected and released into fields timely. At beginning, release of mummified aphids was the main method due to low mortality and easy transportation. The tobacco leaves with abundant mummified aphids were cut down and hung directly in tobacco fields. Release of adult parasitoids was used as a complementary way because sufficient quantity of adults can not be obtained constantly in greenhouses described by Wei *et al*. (2003), the collection and maintenance of adult parasitoids was laborious work and the longevities of parasitoids could decrease by aspirating. In this situation, release of mummified aphids was more suitable (Wei *et al*. 2003). However, this release may become the new source of aphids in tobacco fields due to the fact that *A. gifuensis* females preferred to oviposit on second and third instars of aphids (Takada 1975; Bi and Ji 1994). As the development of mass rearing technique

in bigger greenhouses, abundant adult parasitoids can emerge in a short period. Moreover, adult parasitoids always aggregated at the top parts of chambers at daytime due to their phototaxis and up-position taxis. Therefore, the collection and release of adult parasitoids was more reasonable. Practically, a mini-vacuum was developed for collection. This vacuum can effectively collect adult parasitoids at a low mortality.

Adult parasitoids should be transferred into nylon cages (15.0×25.0 cm; diameter × height; 100 holes per cm^2) and transported to target fields immediately after collection. During transportation, it was suggested to feed parasitoids with honey juice or water to maintain their energy (Deng *et al*. 2010).

Timing and quantity of release are very important to augmentative biological control (Collier and van Steenwyk 2004). Firstly, the monitoring of *M. persicae* population was very necessary. Based on aphid occurrence in tobacco fields, three releases were made at different growth stages of tobacco. The releases were made respectively 15-20 days, about 30 days and 40-60 days after transplantation. The ratio of parasitoids to aphids was 1:30-100 and the ratio should change with the population densities of aphids in the field (Deng *et al*. 2010). In Yuxi Prefecture of Yunnan Province, two to three releases were made annually from May to July, at a rate of 15,000 adults per ha due to the lower population density of *M. persicae* after the long-term release of parasitoids (Yang, Yang *et al*. 2009). In any case, while releasing, the mouth of nylon cage should be up-positioned and opened, letting parasitoids naturally fly outside. Shaking of container is not allowed due to the possible hurt to parasitoids. Furthermore, the release should be accomplished before noon on good weather days (Wu, Zhao *et al*. 2000; Wei 2003).

Agro-chemicals may be highly toxic to different development stages and can increase mortality and decrease emergence, longevity and host parasitism of *A. gifuensis* (Chen *et al*. 1989; Kobori and Amano 2004). Strictly, insecticides sprayings are not permitted 2-3 days before and after parasitoid release (Chen *et al*. 1989; Deng *et al*. 2010). Therefore, unifying farmers' actions is essential to increase control effect of *A. gifuensis*. Moreover, during the whole season, reduction of chemical pesticides for other pest insects (e.g. tobacco cutworm) is also needed, indicating the importance of developing more alternatives for pest management in tobacco field.

Control efficacies

Zhao *et al*. (1980) firstly reported the control efficacy of *A. gifuensis* release on *M. persicae* in tobacco fields. The results showed that the parasitism rate increased from 0 to 95% and aphid population density decreased from 34.3/plant to 0.1/plant in parasitoid release fields within 60 days. However, in control (blank) fields, the parasitism rate increased from 0.1 to 38.8%, but aphid population density increased from 33.2/plant to 51.2/plant on average. Wu, Zhao *et al*. (2000) demonstrated that the control effect of *A. gifuensis* release on aphids in the late season can reach 93-93.5% in tobacco fields. The two studies above were just conducted in small-scale tobacco fields over short intervals. Using historical data collected in Hongta District of Yuxi Prefecture, Yang, Yang *et al*. (2009) examined the efficacy of *A. gifuensis*

for *M. persicae* control after its long-term and large-scale release. It was reported that in the years without release of *A. gifuensis*, the mean population densities of *M. persicae* were significantly higher than those in the years with parasitoid release. In years of without *A. gifuensis* release, *M. persicae* population increased rapidly and the population densities exceeded the action threshold during most of the growing season. However, in the years of parasitoid releases, the increase of *M. persicae* population was lower and the population density was much closer to the action threshold even at their highest population densities. Moreover, compared the data on pesticide application for *M. persicae* control before parasitoid release, the spraying times of insecticide application maintained a lower level after augmentative release of *A. gifuensis*. In addition, tobacco farmers in Hongta District reported the decrease of *M. persicae* population after release of *A. gifuensis* and recognized the effectiveness of *A. gifuensis* for *M. persicae* control. These further suggested the control efficacy of *A. gifuensis*. More important, farmers' recognition is very important to the further extension of this biocontrol technique to other tobacco planting regions in Yunnan Province.

Economic costs

Costs of mass rearing and release of parasitoids

In the big greenhouse reported by Wei (2003), the recurring cost of mass rearing 1000 mummified aphids of *A. gifuensis* was US$ 0.125. In a small glass-topped and a plastic greenhouse, recurring cost for 1,000 mummified aphids was US$ 0.06 and US$ 0.096 respectively (Wei *et al*., 2003) (Table 1). If three releases were made annually (15,000 mummified aphids per ha for each release), the total cost of parasitoid release ranged US$ 2.7 to US$ 5.63 per ha (Wei *et al*., 2001; Wei, 2003). However, the nonrecurring costs including the cost of greenhouse establishment, land renting cost, etc., were excluded and the cost of mass rearing and release of parasitoids was relatively low.

As the development and improvement of big greenhouse and small nylon greenhouse as well as cost increase of construction materials, the cost of mass rearing and release changed. Both big greenhouse and small greenhouse can be used for 10 years. However, cover nets would change every two years (Deng *et al*. 2010). The undepreciated cost should be calculated in the whole cost of mass rearing. Besides nonrecurring costs, the cost of mass rearing of *A. gifuensis* was US$ 0.24 and US$ 0.235 per 1,000 adult parasitoids respectively in big greenhouse and small greenhouse (Table 1). Annually, 2-3 releases of parasitoid were made at a rate of 15,000 adults per ha each time. Moreover, based on practices, the cost of labor input of one parasitoid release was US$ 6.62 per ha, and the total cost of parasitoid release ranged US$ 20.44 -30.66 annually (Deng *et al*. 2010) (Table 3).

Pesticide use and cost

Without parasitoid release, pesticide spraying ranged 5 to 6 times for *Myzus persicae* control per year (Wei 2003; Yang, Yang *et al*. 2009). However, the average spraying decreased to 2.14 times after long-term release of *A. gifuensis* (Yang, Yang *et al*. 2009).

Table 1. Information on mass rearing of *Aphidius gifuensis* in different types of greenhouses.

Type of greenhouse	Size	No. of tobacco seedlings[1]	Mummified aphids or parasitoid adults produced per generation[3]	Cost for 1000 mummified aphids or adult parasitoid US$[4]
Big greenhouse by Wei et al.(2001, 2003)	5×10×2.5m	180 large pots or 400 medium pots	2,500,000	0.125
Small plastic greenhouse by Wei et al.(2001, 2003)	1.7 × 3 × 3m	50 medium pots	45,000	0.096
Small glass-topped greenhouse (Wei et al., 2001)	1.7× 3 × 5m	500 small pots	125,000	0.06
Big greenhouse by Deng et al. (2010)	50×12×3m	2720[2]	> 25,000,000	≈0.24
Small greenhouse by Deng et al. (2010)	3×3×2m	28-30	140,000-210,000	≈0.235

[1]In Wei *et al*. (2001, 2003) system, different developmental stages of tobacco seedlings were adopted for aphid production and parasitoid rearing. In other systems, large pots or tobacco seedlings were used.
[2]17 bigger and 17 smaller chambers in one greenhouse. 90 and 70 tobacco seedlings were planted in each bigger and smaller chamber respectively.
[3]Each greenhouse can produce 3 generations of parasitoid per year.
[4]In greenhouses described by Wei *et al*. (2001, 2003), only recurring cost was analyzed.

Table 2. Materials and cost of big and small greenhouses by Deng *et al*. (2010)

Greenhouse type	Materials and cost / US$ per year						
	Greenhouse construction cost [1]	Cover nets	Land rental[2]	Tobacco seedling cultivation materials	Fertilizer	Pesticide	Total
Big greenhouse	2941	610	220	1198	420	50	5439
Small greenhouse	3.8	3.8	-	0.44	0.44	0.44	8.92

[1]Cost of greenhouse construction and cover nets were the undepreciated.
[2]Small greenhouse can be constructed near tobacco fields in rural communities.

Table 3. Cost comparison between parasitoid release and chemical control for *Myzus persicae* control[1]

Cost analysis	Parasitoid release (US$ per ha)	Chemical control (US$ per ha)	Remark
Cost of parasitoid rearing / time	3.6	-	The cost of parasitoid rearing in big greenhouse. The number of parasitoid released was 15,000 per time.
Labor input of parasitoid release/ time	6.62	-	
Times of parasitoid release	2-3	-	
Annual cost of parasitoid release	20.44 -30.66	-	
Cost of pesticide purchasing/time	7.5	7.5	Currently, imidacloprid is commonly used for aphid control in Yuxi of Yunnan Province.
Labor input of pesticide spraying and mixing/time	17.64	17.64	
Times of pesticide spraying	2-3	5-6	With parasitoid release, spraying times were 2 -3. In mere chemical control, pesticides were applied 5 -6 times annually.
Annual cost of pesticide spraying	50.48 – 75.72	126.2 – 151.44	
Total cost[2]	70.92 – 106.38	126.2 – 151.44	Cost comparison: total cost of mere chemical control -total cost of parasitoid release = US$ 19.82 – 80.52 per ha.

[1]Data resources: Deng *et al.,* (2010) and Yang, Yang *et al*., (2009)
[2]Total cost = annual cost of parasitoid release + annual cost of pesticide spraying.

Compared with the cost of US$ 83.94 per ha by mere chemical control, the total cost for aphid control was US$ 29.54 - 31.68 per ha by adoption of parasitoid release. However, only recurring cost of mass rearing of parasitoids and cost of pesticide were used in this comparison and labor inputs were ignored (Yang, Yang *et al*. 2009). Actually, the

average cost for pesticide and the labor cost of pesticide mixing and spraying per time was respectively US$ 7.5 per ha and US$ 17.64 per ha (Deng *et al*., 2010) (Table 3).

Cost comparison

The economic cost of a pest management approach is a key factor influencing farmers' further adoption, especially the small-scale farmers in developing countries like China. Therefore, it is essential to analyze the economic cost of parasitoid release for *M. persicae* control. Deng *et al*. (2010) compared the direct economic costs of augmentative release of *A. gifuensis* for *M. persicae* control, mainly including cost of mass rearing and quantities of parasitoid release, labor input of parasitoid release, cost of pesticide application and labor input of pesticide mixing and spraying. Compared with mere chemical control, totally US$ 19.82 – 80.52 per ha can be saved by parasitoid release (Table 3), indicating farmers can get more economic benefits with the adoption of this biological control method. Moreover, farmers can also add benefits by less exposure to chemical pesticides and higher quality of products, but it is difficult to quantify this as direct economic benefit.

Future trends

Mass rearing and release technique

Hyperparasitoids have normally negative impacts on biological control programmes (Sullivan, 1987). Some hyperparasitoids of *M. persicae*, feeding on *A. gifuensis*, have been identified both in greenhouses and tobacco fields. Among them, *Pachyneuron aphidis* is the dominant species (Wei *et al*., 2003; Chai *et al*., 2005; Chai *et al*., 2008; Zhao *et al*. 2009). At the beginning of mass rearing of *A. gifuensis*, hyperparasitoids were not a problem (Wei *et al*., 2003), but environmental conditions in big greenhouses are suitable to the reproduction and survival of hyperparasitoids, several years later, hyperparasitoid populations increased and caused high mortalities of *A. gifuensis*, negatively influencing mass rearing of this parasitoid. In some big greenhouses in which parasitoids have been produced for a long time, the highest parasitism rate of hyperparasitoids was 65% in the late stage of mass rearing of *A. gifuensis*, which greatly affected the emergence of adult parasitoids (Chai, 2005).

Collection and release of the mixture of hyperparasitoid and parasitoids can decrease the effect of parasitoids in field in the current or following year. Chai *et al*. (2005) reported that the hyperparasitism can reach 37.86% in tobacco fields and Zhao *et al*. (2009) had the similar results. These suggested the importance of hyperparasitoid management during mass rearing and release of *A. gifuensis*. It is unfeasible to control hyperparasitoids by spraying chemical insecticides due to their feeding inside mummified aphids, causing damages to *A. gifuensis*. Manual removal of hyperparasitoids (e.g. aspiration) (Wei *et al*., 2003) was the common used approach to decrease their populations during mass rearing procedure and collection of adult parasitoids. However, it is laborious work due to huge numbers of hyperparasitoids and difficulty in identifying them. Moreover, there are still large numbers of hyperparasitoid larvae or pupae inside mummified aphids and their populations increase after several

generations, continuing to lower the production and control effect of parasitoids. Therefore, currently, development of effective approaches to decrease or prevent the impacts of hyperparasitoids (where they have high populations) in greenhouses is essential to wider application of *A. gifuensis*.

In current mass rearing system, only tobacco seedlings are used as host plants for *M. persicae*, even in the process of maintenance of aphid population in winter (Wei *et al*., 2003; Deng *et al*., 2010). However, tobacco is a summer crop and it grows relatively slowly even in greenhouses in winter, influencing the maintenance and quality of overwintering *M. persicae*. In addition, compared with cultivation of winter crops, that of tobacco seedlings in winter may cost more labor inputs, increasing the total cost of this biological control programme. *M. persicae* has a wide host range and can damage throughout the year in Yuxi Prefecture. Therefore, it is possible to find suitable winter hosts for maintenance of overwintering aphid population.

Both release of mummified aphids and adult parasitoids were adopted at the beginning. However, as the increase of hyperparasitoid population and its negative impacts on control effectiveness, release of adult parasitoids instead of mummified aphids is currently the most common method adopted due to visibility and possible removal of hyperparasitoids. Moreover, release technique (e.g. release timing and methods) may be crucial to the effectiveness of augmentation (Stiling, 1993; Collier and van Steenwyk, 2004). In many cases, early releases of natural enemies were more effective than later releases (Trouve *et al*.,1997; Cambell and Lilley 1999). However, the early release of quantitative *A. gifuensis* adults did not provide adequate control of *M. persicae* (Wu, Zhao *et al*., 2000), possibly causing waste of biocontrol agents and increase of control cost. This may be due to many reasons, including improper timing of release or that low aphid infestation at the early stage may affect host foraging behavior of *A. gifuensis* (Yang, Xu *et al*. 2009). In any case, release technique of *A. gifuensis* should be further optimized. Moreover, not only insecticides but fungicides have negative impacts on parasitoids and limit their effectiveness (Chen *et al*., 1989; van Driesche *et al*., 1998; Kobori and Amano 2004). It was reported that ingestion with the fungicide, copper oxychloride, can cause 46.7 % mortality of female adults of *A. gifuensis* (Kobori and Amano, 2004). However, in Yunnan Province, farmers sprayed additional pesticides for control of lepidopteran pest insects and diseases in tobacco fields. It was suggested that influence of pesticides on *A. gifuensis* and synergy of chemical control and release of *A. gifuensis* should be further studied.

Evaluation of efficacy

Efficacy of biological control was one of the key reasons for farmers' adoption, further influencing its wide application (van Mele and Cuc, 2001). However, efficacy of biological control programme included many aspects, involving both direct and indirect efficacy (Collier and van Steenwyk, 2004). Generally, the suppression of pest density or damage by release of natural enemies was applied to evaluate their direct effectiveness. It was reported that release of *A. gifuensis* can maintain population densities of *M. persicase* at a low level both in field experiments and long term

practice, indicating the direct efficacy of this biological control programme (Yang, Yang *et al*., 2009). However, previous studies have neglected to evaluate the indirect efficacies of *A. gifuensis* release (e.g. effects on arthropod communities, prevention or postponement of pesticide resistance). Biocontrol agents may also cause some impacts on other organisms in augmentation programme (van Driesche and Bellows, 1996). However, no study has been conducted on the relation between *A. gifuensis* and other organisms (e.g.natural enemies) after its long term release. Unlike chemical control, biological control generally has a slower, but sustainable effectiveness and is more environment-friendly. Unfortunately, the indirect efficacy was ignored or not considered in many biological control programmes by lowering their efficacies.

As known, *A. gifuensis* can attack many aphids (Zhao *et al*., 1980; Xin, 1986; Ohta and Ohtaishi, 2005; Wei *et al*., 2005). The long term release of this parasitoid may lead a decrease of aphid population in the whole region, indicating more studies should be conducted to evaluate efficacy of *A. gifuensis* release in near future.

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