Life history parameters during immature stage of *Aphidius gifuensis* Ashmead (Hymenoptera: Braconidae) on green peach aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae)

Izumi Ohta,* Kazuki Miura and Masahiro Kobayashi

Laboratory of Insect Pest Control, Chugoku National Agricultural Experiment Station, Fukuyama, Hiroshima 721–8514, Japan

(Received 24 April 2000; Accepted 8 September 2000)

Abstract

In order to evaluate the efficiency of an indigenous aphid parasitoid *Aphidius gifuensis* as a biological control agent against *Myzus persicae*, its oviposition rate, developmental time and survival rate on *M. persicae* were investigated in the laboratory. The oviposition rate was 84.9% at 25°C, and no aphids in which more than one *A. gifuensis* progeny were oviposited by one *A. gifuensis* female were observed. The survival rates and developmental times of immature *A. gifuensis* were examined at four constant rearing temperatures of 15, 20, 25 and 30°C with a photoperiod of 16L–8D. The survival rates from egg to adult emergence were more than 80% at all temperatures tested. The developmental times decreased with increasing temperatures in both sexes, except that the periods at 30°C were slightly longer than those at 25°C. The lower developmental threshold (T_0) and total effective temperature (K) of *A. gifuensis* were 5.5°C and 188.6 degree-days for the females, and 5.7°C and 181.0 degree-days for the males. The oviposition rate, survival rates and the developmental times were similar to those of commercially produced *Aphidius colemani*.

Key words: *Aphidius gifuensis*, *Myzus persicae*, developmental time, oviposition rate, survival rate

INTRODUCTION

The green peach aphid, *Myzus persicae* (Sulzer), is an outstanding pest because of its wide distribution, wide host plant range and high transmission of over 100 virus plant diseases to many major crops (van Emden et al., 1969). In Japan, *M. persicae* has developed resistance to several common insecticides (Morishita and Azuma, 1990), and alternative control methods without use of chemical insecticides are required. Therefore, an exotic aphid parasitoid *Aphidius colemani* Viereck has been commercially introduced into Japan as a biological control agent against *M. persicae* and *Aphis gossypii* Glover since 1998.

A. colemani has been released widely throughout the world due to its high ability to parasitize *M. persicae* and *A. gossypii* (van Steenis, 1993, 1995; van Tol and van Steenis, 1994). However, Takada (1998) pointed out that the effect of the introduction on the aphid parasitoid fauna in Japan might become a problem because *A. colemani* did not originally inhabit Japan (Starý, 1975).

On the other hand, *Aphidius gifuensis* Ashmead is an aphid parasitoid distributed in the Far East

Asia including Japan, China, Korea and Taiwan (Takada, 1992). *A. gifuensis* has been marked as a candidate for an indigenous biological control agent against *M. persicae*. Takada (1976a) reported that *A. gifuensis* dominantly parasitized *M. persicae* at potato and tobacco fields in Japan. Yamamoto (1997) also observed that a lot of *M. persicae* were parasitized by *A. gifuensis* in domestic greenhouse eggplants.

At introductory evaluation of natural enemies, it is important to determine their intrinsic rates of population increase (r_m) because the values directly affect not only their efficiency as biological control agents but also their releasing methods in the programs, that is to say, inoculative, seasonal inoculative or inundative release (van Lenteren, 1986). The r_m depends upon several life history parameters such as developmental time, survival rate, fecundity, longevity and sex ratio (Andrewartha and Birch, 1954). In particular, development time has a great effect on r_m (Lewontin, 1965). Although some parameters of indigenous *A. gifuensis* have been examined by Takada (1976b), Takada and Takenaka (1982), Fukui and Takada (1988) and Kaneko et al. (1992), their studies have not suc-

* To whom correspondence should be addressed at: E-mail: ohtaiz@cgk.affrc.go.jp

cessfully resulted in finding the value of r_m . This parasitoid has also been studied by Chao et al. (1980), Tang and Chen (1984), Bi and Ji (1993, 1994, 1996), Lu et al. (1993, 1994), Kuo (1995) and Wang and Li (1996), but all of these reports are on *A. gifuensis* derived from China or Taiwan. In the case of the other aphid parasitoid, *Diaeretiella rapae* (M'Intosh) (Hymenoptera: Braconidae), the temperature requirements for its development are known to vary with the population from which it is originally derived (Campbell et al., 1974). Therefore, some of the biological characteristics of *A. gifuensis* distributing in Japan may be different from those of the same species in the other regions (i.e. China and Taiwan etc.).

As the first step to introductory evaluation of indigenous *A. gifuensis*, this study was carried out to determine the life history parameters of immature stages, namely, developmental times and survival rates at several different temperatures. In addition, the oviposition rate of host aphids *M. persicae* by *A. gifuensis* female adults was investigated.

MATERIALS AND METHODS

Aphid and parasitoid cultures. A clonal population of *M. persicae* aphids, derived from a single apterous viviparous female obtained from a cabbage field at Chugoku National Agricultural Experiment Station in 1996, was reared on Japanese radish leaves (variety 'Tokinashi') in the laboratory controlled at $25 \pm 1^\circ\text{C}$ (humidity uncontrolled) under a 16L–8D photoperiod. *A. gifuensis* was collected from the potato field in our institute in 1996, and maintained on *M. persicae* hosts under the same condition as described for *M. persicae*.

Experiment 1—Oviposition rate. All the following treatments were conducted in the laboratory controlled at $25 \pm 1^\circ\text{C}$. A glass petri dish (ca. 6.0 cm dia., 1.5 cm depth), on the bottom of which a fresh leaf disk of Japanese radish had been attached with double-sided tape, was prepared for the test. Twenty to thirty three day old *M. persicae* aphids (approximately third nymphal stadium) were placed on the leaf disk with a wet fine brush, and then one mated female of *A. gifuensis* within 24 h after emergence was released into the petri dish. Individual *A. gifuensis* females were allowed to successively attack up to ten aphids during the observation lasting a few minutes. 'Attack' in this

study was defined as the behavior whereby an *A. gifuensis* female stings a *M. persicae* aphid's body with her ovipositor. Parasitoids which never tried to attack any aphids were removed from the arena. Attacked aphids were moved to other Japanese radish leaves to prevent superparasitism by conspecifics, and kept in a climate cabinet at $25 \pm 0.5^\circ\text{C}$, $60 \pm 10\%$ R.H. and 16L–8D. Three days after the time of parasitoid attack, the aphids were dissected under a binocular microscope to determine the number of *A. gifuensis* larvae in the aphid bodies. Oviposition rate of *M. persicae* by *A. gifuensis* was obtained by the following equation.

Oviposition rate (%)

$$= \frac{\text{No. of aphids containing parasitoid larvae}}{\text{No. of aphids dissected}} \times 100$$

Since the mortalities of the parasitoid eggs and their young larvae before the dissection were expected to be very low (Fukui and Takada, 1988), they were neglected in estimating the oviposition rate.

Experiment 2—Developmental time and survival rate. *M. persicae* aphids attacked by *A. gifuensis* parasitoids were obtained as in Experiment 1. Attacked aphids were mass-reared on Japanese radish leaves in incubators controlled at $15 \pm 0.5^\circ\text{C}$, $20 \pm 0.5^\circ\text{C}$, $25 \pm 0.5^\circ\text{C}$ or $30 \pm 0.5^\circ\text{C}$, $60 \pm 10\%$ R.H. and 16L–8D. Formed mummies were individually transferred into small glass tubes (2.1 cm dia., 4.5 cm depth) sealed with Sealon Film (Fuji Photo Film Co., Ltd.). By checking the states of aphids and mummies every 8 h until new parasitoids emerged, the developmental times from egg to mummification and mummification to emergence of the new parasitoid adults were recorded with their sexes. 'Mummification' in this experiment was defined as the change in the body forming spherical shapes with pearl color, but not translucent. The aphids which were not mummified by three days after the formation of the last mummy, and the mummies from which no parasitoid adults appeared by three days after the last emergence were excluded from the observation, but their numbers were recorded to calculate survival rates of the parasitoids.

Mummification rate of attacked aphids and emergence rate of mummified aphids were calcu-

lated as follows:

Mummification rate (%)

$$= \frac{\text{No. of mummies}}{(\text{No. of aphids attacked}) \times \left(\frac{\text{Oviposition rate (\%)}}{100} \right)} \times 100$$

Emergence rate (%)

$$= \frac{\text{No. of mummies from which new parasitoids emerged}}{\text{No. of mummies}} \times 100$$

Survival rate in immature stage of *A. gifuensis* on *M. persicae* was determined as follows:

Survival rate (%)

$$= \text{Mummification rate (\%)} \times \text{Emergence rate (\%)} \times \frac{1}{100}$$

RESULTS

Experiment 1—Oviposition rate

Table 1 shows the oviposition rate of *M. persicae* by *A. gifuensis*. We detected parasitoid larvae from 84.9% of aphids stung by *A. gifuensis*. No aphids containing two or more than one *A. gifuensis* progeny were found in this test.

Experiment 2—Developmental time and survival rate

Developmental times of *A. gifuensis* females and

Table 1. Oviposition rate of *Myzus persicae* by *Aphidius gifuensis*^a

No. of aphids dissected	No. of parasitoid larvae in aphid bodies			Oviposition rate (%) ^b
	0	1	2≤	
73	11	62	0	84.9

^aThirteen female parasitoids were used in the test.

^bOviposition rate (%) = (No. of aphids containing parasitoid larvae / No. of aphids dissected) × 100.

Table 2. Developmental times of immature stage of *Aphidius gifuensis* at different constant temperatures with photoperiod of 16L–8D

Temperature (°C)	Sex	No. tested ^a	Developmental time (days) ^b		
			Egg to mummification	Mummification to emergence	Egg to emergence
15	Female	36	12.0±0.4NS ^c	7.9±0.4*	19.9±0.6*
	Male	87	12.2±0.5	7.3±0.4	19.5±0.8
20	Female	36	8.3±0.3NS	4.7±0.3*	13.0±0.3*
	Male	102	8.3±0.2	4.3±0.2	12.6±0.3
25	Female	27	5.9±0.2NS	3.8±0.2*	9.7±0.3*
	Male	81	5.9±0.3	3.5±0.3	9.4±0.4
30	Female	36	6.6±0.4NS	4.1±0.4NS	10.7±0.6NS
	Male	65	6.6±0.4	4.0±0.5	10.6±0.8

^aThe numbers of *A. gifuensis* female adults used to obtain the parasitized aphids at each temperature were as follows: 26 females at 15°C, 25 females at 20°C, 22 females at 25°C and 20 females at 30°C.

^bMean ± SD.

^c* and NS indicate significant differences between females and males at each constant temperature at 0.1% level (Mann-Whitney *U*-test), and no significant differences at 5% level, respectively.

Table 3. Linear regression equations for developmental rate and temperature, lower developmental thresholds and total effective temperatures of *Aphidius gifuensis* on *Myzus persicae*

Sex	Regression equation ^a	r^2	Lower developmental threshold (T_0 : °C)	Total effective temperature (K : degree-days)
Female	$Y=0.0053X-0.0292$	0.980	5.5	188.6
Male	$Y=0.0055X-0.0314$	0.985	5.7	181.0

^a Data for 15, 20 and 25°C. Y : developmental rate (day^{-1}), X : temperature (°C).

Table 4. Survival rates of immature stage of *Aphidius gifuensis* at different constant temperatures with photoperiod of 16L–8D

Temperature (°C)	No. of aphids attacked ^a	Mummification rate (%) ^b	Emergence rate (%) ^c	Survival rate (%) ^d
15	169	89.9 a	95.3 ab	85.7 ab
20	173	95.3 ab	98.6 a	94.0 a
25	135	97.7 b	96.4 a	94.2 a
30	147	92.9 ab	87.1 b	80.9 b

^a The number of *A. gifuensis* female adults used to obtain the attacked aphids are indicated in Table 2.

^b Mummification rate (%) = $[\text{No. of mummies}/(\text{No. of aphids attacked} \times \text{Oviposition rate (\%)}^e/100)] \times 100$.

^c Emergence rate (%) = $(\text{No. of mummies from which } A. gifuensis \text{ adults emerged}/\text{No. of mummies}) \times 100$.

^d Survival rate (%) = $\text{Mummification rate (\%)} \times \text{Emergence rate (\%)} \times 1/100$.

^{b,c,d} Percentages followed by the same letter are not significantly different at 5% level by Tukey-type multiple comparison test.

Data (X) were analyzed after transformation to $0.5[\arcsine(\sqrt{X/n+1}) + \arcsine(\sqrt{(X+1)/n+1})]$ (n =No. tested).

No directly proportional or parabolic relationships with statistical significance at 5% level were also obtained between mummification rate, emergence rate or total survival rate and temperature.

^e Indicated in Table 1.

males at 15, 20, 25 and 30°C are given in Table 2. The developmental times tended to decrease with increasing rearing temperatures, but the periods were slightly longer at 30°C than at 25°C. The periods from egg to mummification were not significantly different between the sexes at any of the temperatures tested ($p>0.05$, Mann-Whitney U -test). The periods of mummification to emergence and egg to emergence of *A. gifuensis* females were significantly longer than those of males at 15, 20 and 25°C ($p<0.001$), although no significant differences existed at 30°C ($p>0.05$). Significant linear regression equations shown in Table 3 could be fitted through the data of *A. gifuensis* females ($r^2=0.980$) and males ($r^2=0.985$), provided that the data at 30°C were not included in the equations because they had great effects on the regression lines. Moreover, the lower developmental threshold (T_0) and total effective temperature (K) were 5.5°C and 188.6 degree-days for the females and 5.7°C and 181.0 degree-days for the males (Table 3).

Mummification rates of attacked aphids, emergence rates of mummified aphids and survival rates

of immature *A. gifuensis* at 15, 20, 25 and 30°C are shown in Table 4. Mummification rate at 15°C was less than 90%, and significantly lower than that at 25°C ($p<0.05$, Tukey-type multiple comparison test). The emergence rate and the survival rate at 30°C were less than 90% and significantly lower than those at 20 and 25°C ($p<0.05$, Tukey-type multiple comparison test). Linear and quadratic regression analyses showed that directly proportional or parabolic relationships between mummification rate, emergence rate or survival rate and temperature were not obtained at the 5% level.

DISCUSSION

It is quite difficult to estimate survival rate during the immature stage of *A. gifuensis* because we can not immediately determine whether or not *A. gifuensis* females lay their eggs into *M. persicae*, even if we observe their oviposition behavior. Therefore, we first evaluated the oviposition rate of *M. persicae* by *A. gifuensis* females in order to extrapolate the survival rate. The oviposition rate of

84.9% revealed in the first experiment demonstrated that *A. gifuensis* could successfully parasitize *M. persicae*. The value was as high as that of *A. colemani* on *M. persicae* described by van Tol and van Steenis (1994). Also, no aphids with more than one progeny of *A. gifuensis* were found in this dissection test. This observation coincides with the study of Takada (1975), and provides evidence that *A. gifuensis* females oviposit one progeny into a host aphid *M. persicae* per attack.

In the second experiment, mummification rates, emergence rates and survival rates were found to be more than 80% at each temperature tested (Table 4). The mummification rate of *M. persicae* attacked by *A. colemani* reached around 90% (rearing temperature unknown) (van Tol and van Steenis, 1994), and survival rates of *A. colemani* on *A. gossypii* were 85.9% at 20°C and 72.2% at 25°C (van Steenis, 1993). *A. gifuensis* in our laboratory is thus considered to have as high a survival rate during the immature stage on *M. persicae* as *A. colemani*.

Kuo (1995) estimated the rates of pupation and adult emergence of *A. gifuensis* at 10, 15, 20, 25 and 30°C. The survival rates calculated with her data were as follows: 0% (10°C), 50.3% (15°C), 80.0% (20°C), 32.0% (25°C), 18.0% (30°C). These rates were all much lower than our results. Three day old *M. persicae* nymphs reared at 25°C were used in our study while one day old adults were used in Kuo (1995). It is difficult to consider, however, that the host aphid age greatly affected the survival rates of immature *A. gifuensis*, because Kaneko et al. (1992) showed that there was no effect of host age on the emergence rate of *A. gifuensis*.

Tang and Chen (1984), Kaneko et al. (1992), Bi and Ji (1993), Lu et al. (1994) and Kuo (1995) have evaluated the developmental times of *A. gifuensis* although they have not distinguished between females and males of the parasitoids. Some of their data were comparable to our results given in Table 2. However, the Taiwan strain of *A. gifuensis* completed development from egg to emergence at 15°C in 23.1 days (Kuo, 1995). This period was approximately three days longer than the corresponding *A. gifuensis* used by us. *A. gifuensis* in Sapporo in northern Japan also required a longer time (15.4–16.3 days) for the completion of development at 20°C (Kaneko et al., 1992). Campbell et

al. (1974) showed that the temperature requirement for the development of *D. rapae* collected from Berkeley in the U.S. was higher than that of the same species from Vancouver in Canada. Accordingly, some disagreements in the developmental times of *A. gifuensis* may reflect genetic diversity among different populations.

The developmental time of our *A. gifuensis* at 30°C was slightly longer than that at 25°C in both sexes. Developmental rates in insects increase linearly with temperature over the intermediate range. However, the rates decrease from a linear relationship above a certain temperature (Campbell et al., 1974). For example, the developmental period of *Aphidius smithi* Sharma and Subba Rao on the pea aphid, *Acyrtosiphon pisum* (Harris), was lengthened at constant temperatures above 25°C (Fox et al., 1967). *Aphidius matricariae* Haliday on *M. persicae* also required longer times for its development at 29.5°C than at 26.7°C (Giri et al., 1983). The result in the current study suggests that high temperatures of 30°C and above would at least delay the development of our *A. gifuensis*. On the other hand, Kuo (1995) observed no developmental retardation at 30°C in the Taiwan strain of *A. gifuensis* (Table 2). This means that the upper developmental thresholds of *A. gifuensis* may differ among local populations.

The lower developmental threshold (T_0) and total effective temperature (K) of *A. gifuensis* were calculated in this experiment (Table 3). The values of T_0 (♀ 5.5°C, ♂ 5.7°C) were quite similar to those of Taiwan *A. gifuensis* (5.8°C) (Kuo, 1995) and other *Aphidius* parasitoids, e.g. *A. matricariae* (6.0°C) (Rabasse and Shalaby, 1980), *A. smithi* (6.2°C), *Aphidius ervi ervi* Haliday (6.1°C) and *Aphidius ervi pulcher* Backer (6.1°C) (Campbell and Mackauer, 1975) although K varied with each other. This result is in accord with Kiritani's (1997) statement that T_0 of insects is a comparatively stable parameter while K can change with the strains even within the same species.

The developmental times of *A. colemani* have been described by some authors as follows: on *A. gossypii* 13.9 days at 20°C (Harizanova and Ekbom, 1997), 12.7 days (♀), 12.6 days (♂) at 20°C and 10.0 days (♀), 9.6 days (♂) at 25°C (van Steenis, 1993), on *M. persicae* 9.5 days (♀) and 9.4 days (♂) at 25°C (Ohta, unpublished). These durations are almost equal to those of our *A. gifuensis*

at 20 and 25°C (Table 2).

In order to establish an efficient method for using *A. gifuensis* as a biological control agent against *M. persicae*, the properties of the parasitoid adults should be also studied.

ACKNOWLEDGEMENTS

We thank Dr. Y. Suzuki, National Agriculture Research Center for critical reading of the original manuscript.

REFERENCES

- Andrewartha, H. G. and L. C. Birch (1954) *The Distribution and Abundance of Animals*. The University of Chicago Press, Chicago. 782 pp.
- Bi, Z. and Z. Ji (1993) Bionomics of *Aphidius gifuensis* Ashmead I. Development stages and morphology of larval stage. *J. Hebei Agric. Univ.* 16(2): 1–6 (in Chinese with English summary).
- Bi, Z. and Z. Ji (1994) Bionomics of *Aphidius gifuensis* Ashmead II. Bionomics of adult and over winter. *J. Hebei Agric. Univ.* 17(2): 38–44 (in Chinese with English summary).
- Bi, Z. and Z. Ji (1996) Bionomics of *Aphidius gifuensis* Ashmead IV. Fecundity, intrinsic rate of increase, functional response and population suppression of peach green aphids. *J. Hebei Agric. Univ.* 19(3): 1–6 (in Chinese with English summary).
- Campbell, A., B. D. Frazer, N. Gilbert, A. P. Gutierrez and M. Mackauer (1974) Temperature requirements of some aphids and their parasites. *J. Appl. Ecol.* 11: 431–438.
- Campbell, A. and M. Mackauer (1975) Thermal constants for development of the pea aphid (Homoptera: Aphididae) and some of its parasites. *Can. Entomol.* 107: 419–423.
- Chao, W., C. Ting, T. Dong, Y. Wang and W. Chang (1980) The bionomics of *Aphidius gifuensis* Ashmead and its utilization for the control of tobacco aphid *Myzus persicae* Sulzer. *Zool. Res.* 1: 405–415 (in Chinese with English summary).
- Fox, P. M., B. C. Pass and R. Turston (1967) Laboratory studies on the rearing of *Aphidius smithi* (Hymenoptera: Braconidae) and its parasitism of *Acyrtosiphon pisum* (Homoptera: Aphididae). *Ann. Entomol. Soc. Am.* 60: 1083–1087.
- Fukui, M. and H. Takada (1988) Fecundity, oviposition period and longevity of *Diaeretiella rapae* (M'Intosh) and *Aphidius gifuensis* Ashmead (Hymenoptera: Aphidiidae), two parasitoids of *Myzus persicae* (Sulzer) (Homoptera: Aphididae). *Jpn. J. Appl. Entomol. Zool.* 32: 331–333 (in Japanese with English summary).
- Giri, M. K., B. C. Pass and K. V. Yeagan (1983) The effects of temperature on the rate of development of *Aphidius matricariae* Haliday (Hymenoptera: Aphidiidae). *Trans. Ky. Acad. Sci.* 44: 145–147.
- Harizanova, V. and B. Ekbom (1997) An evaluation of the parasitoid, *Aphidius colemani* Viereck (Hymenoptera: Braconidae) and the predator *Aphidoletes aphidimyza* Rondani (Diptera: Cecidomyiidae) for biological control of *Aphis gossypii* Glover (Homoptera: Aphididae) on cucumber. *J. Entomol. Sci.* 32: 17–24.
- Kaneko, J., N. Sugawara and T. Endou (1992) Influence of parasitism by *Aphidius gifuensis* Ashmead (Hymenoptera: Aphidiidae) on the reproductive ability of peach-potato aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae). *Jpn. J. Appl. Entomol. Zool.* 36: 137–139 (in Japanese with English summary).
- Kiritani, K. (1997) The lower developmental threshold and the thermal constant in insects, mites and nematodes in Japan. *Misc. Publ. Natl. Inst. Agro-Environ. Sci.* 21: 1–72 (in Japanese with English summary).
- Kuo, M. H. (1995) Development of green peach aphid parasitoid *Aphidius gifuensis* Ashmead and hyperparasitoid *Pachyneuron aphidis* (Bouche) at various temperatures. *Plant Prot. Bull.* 37: 393–401 (in Chinese with English summary).
- Lewontin, R. C. (1965) Selection for colonizing ability. In *The Genetics of Colonizing Species: Proceedings of the First International Union of Biological Sciences Symposia on General Biology* (H. G. Baker and G. Ledyard Stebbins eds.). Academic Press, New York, pp. 77–94.
- Lu, H., B. Shi, Y. Niu and Z. Zhang (1994) Development thresholds and thermal constants of *Aphidius gifuensis* and *Diaeretiella rapae*. *Acta Agriculturae Boreali-Sinica* 9(3): 72–75 (in Chinese with English summary).
- Lu, H., B. Shi and Z. Zhang (1993) Studies on the fecundity of *Aphidius gifuensis* Ashmead. *Acta Agriculturae Boreali-Sinica* 8(1): 76–79 (in Chinese with English summary).
- Morishita, M. and K. Azuma (1990) Decreased susceptibilities of the green peach aphid (*Myzus persicae* Sulzer) to some synthetic pyrethroids. *Jpn. J. Appl. Entomol. Zool.* 34: 163–165.
- Rabasse, J. M. and F. F. Shalaby (1980) Laboratory studies on the development of *Myzus persicae* Sulz. (Hom., Aphididae) and its primary parasite, *Aphidius matricariae* Hal. (Hym., Aphidiidae) at constant temperatures. *Acta Oecologia Oecol. Applic.* 1: 21–28.
- Starý, P. (1975) *Aphidius colemani* Viereck: its taxonomy, distribution and host range (Hymenoptera, Aphidiidae). *Acta Entomol. Bohemoslov.* 72: 156–163.
- Takada, H. (1975) Differential preference for *Myzus persicae* (Sulzer) of two parasites, *Diaeretiella rapae* (M'Intosh) and *Aphidius gifuensis* Ashmead. *Jpn. J. Appl. Entomol. Zool.* 19: 260–266 (in Japanese with English summary).
- Takada, H. (1976a) Studies of aphids and their parasites on cruciferous crops and potatoes. I. Parasite complex of aphids. *Kontyû* 44: 234–253 (in Japanese with English summary).
- Takada, H. (1976b) Studies of aphids and their parasites on cruciferous crops and potatoes. II. Life-cycle. *Kontyû* 44: 366–384 (in Japanese with English summary).
- Takada, H. (1992) Aphid parasitoids as biological control agents of vector aphids of papaya ring spot virus and banana bunchy top virus. *FFTC Tech. Bull.* 132: 1–11.
- Takada, H. (1998) A review of *Aphidius colemani* (Hymenoptera: Braconidae; Aphidiinae) and closely related species indigenous to Japan. *Appl. Entomol. Zool.* 33: 59–66.

- Takada, H. and Y. Takenaka (1982) Parasite complex of *Myzus persicae* (Sulzer) (Homoptera, Aphididae) on tobacco. *Kontyû* 50: 556–568 (in Japanese with English summary).
- Tang, Y. and Z. Chen (1984) Preliminary study on the biology and the ecology of *Aphidius gifuensis* (Ashmead). *J. Fujian Agric. College* 13(2): 119–125 (in Chinese with English summary).
- van Emden, H. F., V. F. Eastop, R. D. Hughes and M. J. Way (1969) The ecology of *Myzus persicae*. *Ann. Rev. Entomol.* 14: 197–270.
- van Lenteren, J. C. (1986) Parasitoids in the greenhouse: Successes with seasonal inoculative releases systems. In *Insect Parasitoids* (J. Waage and D. Greathead eds.). Academic Press, London, pp. 341–374.
- van Steenis, M. J. (1993) Intrinsic rate of increase of *Aphidius colemani* Vier. (Hym., Braconidae), a parasitoid of *Aphis gossypii* Glov. (Hom., Aphididae), at different temperatures. *J. Appl. Entomol.* 116: 192–198.
- van Steenis, M. J. (1995) Evaluation of four aphidiine parasitoids for biological control of *Aphis gossypii*. *Entomol. Exp. Appl.* 75: 151–157.
- van Tol, S. and M. J. van Steenis (1994) Host preference and host suitability for *Aphidius matricariae* Hal. and *A. colemani* Vier. (Hym.: Braconidae), parasitizing *Aphis gossypii* Glov and *Myzus persicae* Sulz. (Hom.: Aphididae). *Med. Fac. Landbouww. Univ. Gent* 59/2a: 273–279.
- Wang, W. and Q. Li (1996) Effect of host density on reproductive rate of *Aphidius gifuensis*. *Acta Agriculturae Boreali-Sinica* 11(4): 52–57 (in Chinese with English summary).
- Yamamoto, M. (1997) Studies on the hymenopterous parasitoids reared from eggplant in greenhouse in Shiga Prefecture Japan. *Spec. Bull. Shiga Agric. Exp. Stn.* 20: 1–70 (in Japanese with English summary).