Acta Biologica Turcica 29 (4) 111-123, 2016 Received 10 July. 2016; Accepted 8 Sept. 2016

ACTA BIOLOGICA TURCICA

E-ISSN: 2458-7893, http://www.actabiologicaturcica.info

Life table of *Aphelinus paramali* Zehavi & Rosen, 1989 (Hymenoptera: Aphelinidae), a parasite of the melon aphid, *Aphis gossypii* Glover, 1877 (Hemiptera, Aphididae)

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Abstract: In this study, biological parameters of *Aphelinus paramali* on *Aphis gossypii* on Crimson Tide F1 watermelon variety and relationship between *A. gossypii* and parasitoid were investigated. In addition, preference of parasitoid on which stage of host, numerical and functional reactions of parasitoid were investigated. All studies carried out under laboratory conditions (25±1°C, 65±5% humidity and 16:8 h photoperiod). The fourth instar of *A. gossypii* was the most preferred by *A. paramali* in both trials (choice and no-choice). The highest parasititation was occurred as 42%. Parasitizing of *A. paramali* lasted till 24^{th} day. The mean number of developed parasitoid which lay on host during its life was 151.1 individuals. The value of intrinsic rate of increase (r_m) was determined as 0.324, the values of generation time (T_o) was determined as 18.21, and net reproduction rate (R_0) was determined as 152.5. As density of host increased, the number of parasitized aphid also increased till a certain density level, and then this level reached a stabile parasitism and showed type II.

Keywords: *Aphelinus paramali*, *Aphis gossypii*, Watermelon, Biological parameters, Biological control.

Introduction

Turkey is an important country in the world in terms of its total watermelon field, production and economic importance. According to FAO, Turkey is third country after China and Iran in terms of watermelon production and the amount of production salary (3.864.490 ton/$307.977.000) (Anonymous, 2011a). According to the amount of watermelon production, Southeast Anatolia region has an important watermelon production percentage (14.4%) in Turkey and it comes after Aegean and Mediterranean regions. Diyarbakir Province has highest production (187.623 ton/ 33.7%) in Southeast Anatolia region (Anonymous, 2011b). Also, Diyarbakir Province has special domestic watermelon varieties and it is known as a watermelon province. These watermelon varieties are symbol of the city in every street and every year watermelon festivals are arranged in the city.

However watermelon production is important for country, region and Diyarbakir Province, but like other plants, watermelon also has aphid damage problems. The cotton aphid *Aphis gossypii* Glover (Hemiptera, Aphididae) is a phytophagous cosmopolitan species and an important pest on vegetables especially on Cucurbitaceae in Southeast Anatolia in Turkey (Akkaya, 1995; Büyük and Özpınar, 1999; Bayram and Bayhan, 2012). It is a major pest of cultivated plants such as Curcurbitaceae, Rutaceae and Malvaceae in Turkey. This aphid causes economic damage to watermelon plants by giving direct injury to the plants and by carrying viral diseases giving indirect injury as a vector, such as CMV. *Aphis gossypii* populations can increase ten times a week under favorable conditions even an augmentation of 22.7 times a week has been observed (Scopes and Biggerstaff, 1976). Because of rising insecticide resistance (O'Brien and Graves, 1992; Furk and Hines, 1993; Albert and Merz, 1995; Villatte et al., 1999; Wang et al., 2001;

Ahmad et al., 2003) and destruction of natural enemies through the use of pesticides, current research is directed towards the development of management systems that use biological control methods. For plant diseases and pests controlling, it is clear that long term effective and environmentally better methods are more effectively than short term effectively, temporarily measures. For example integrated pest management, biological control, breeding some resistant or tolerant varieties are some long term and environmentally better control methods. At the present, insecticides are reliable for control of aphids in watermelon fields. The use of insect resistant varieties has been a major successful control tactic against vegetable pests, often resorted to because of the difficulty of using pesticides on these edible plants (Chambliss and Jones, 1966; Hafiz and Hagag, 1997; Howe et al., 1976; Kooistra, 1971). Beneficial arthropods often exhibit greater susceptibility to persistent insecticides than their host or prey (Croft, 1990; Ruberson et al., 1998); however they play an indispensable role in controlling various crop(s) pests worldwide (Amano and Haseeb, 2001). The integration of biological control agents for Integrated Pest Management (IPM) would be most effective if they properly could be used. Several studies have shown the possibility of integrating parasitoids into IPM due to their effective roles.

Aphis gossypii has so many natural enemies like other pests (Gücük and Yoldaş, 2000; Ölmez and Ulusoy, 2003; Satar et al., 2009). Generally for controlling *A. gossypii* so many life table studies focused on certain parasitoids such as *Aphidius colemani*, *Lysiphlebus fabarum*, *L. testaceipes* and *L. confusus* (Howard et al., 1985; Van Driesche and Bellows, 1996; Kaplan and Eubanks, 2002). One promising family of parasitoids used for biological control of the cotton aphid is aphelinids. Aphelinids are in fact a combination of parasite and predator: aphid mortality is caused by parasitization, i.e. oviposition and development of the parasitoid, but also by predation (host feeding) of parasitoid adults on aphids (Starý, 1988). In addition, they are solitary and endophagous parasitoids with the ability of parthenogenesis and tend to avoid super parasitism when sufficient numbers of host aphids are available (Mackauer, 1982; Bueno and Stone, 1987). These aphidophagous specialists have a better searching efficiency at low aphid density than predators and consequently are able to detect even small aphid colonies directly in the beginning of the pest invasion.

One candidate for the biological control of the cotton aphid is an aphelinid parasitoid, *A. paramali*. *Aphelinus paramali* is known as a parasitoid of the cotton aphid even there is evidence it can parasitize other aphid species such as *Aphis pomi* (Larsen, 2011; Darsouei et al., 2011) *Aphelinus* near *paramali* preferred cotton aphid, green peach aphid (*Myzus persicae* (Sulzer)), black citrus aphid (*Toxoptera aurantii* (Fonscolombe)), and spirea aphid (*Aphis spiraecola* Patch (Homoptera: Aphididae)) (Tang and Yokomi, 1996). Later studies revealed that *A. paramali* is more effective parasitoid than the other cotton aphid parasitoids (Godfrey, 2004). *Aphelinus paramali* was first identified in Israel (Zehavi and Rosen, 1989). Then some field studies made by Tang et al. (1995, unpublished) (Godfrey, 2004) in California, and by Godfrey (2004) in California, it was found on A. *pomi* as a first record in Iran by Larsen (2011) and Darsouei et al. (2011) and the last it was found in Diyarbakır Province in Southeastern of Turkey in 2011 by Bayram and Bayhan (2013).

Although many hosts are suitable for parasitoid development, different host species and developmental stages may vary in quality, i.e. the kind of amount of resources available to the immature parasitoid (Starý, 1988; Sequeira and Mackauer, 1994). Thus, host age as well as host species have an impact on successful biological control because the choice of suitable aphid instar or aphid species can affect considerably the population growth of both host and parasitoid (Pak, 1986; Hagvar and Hofsvang, 1991). However, detailed knowledge on the biology and ecology of *A. paramali* with *A. gossypii* as host is not available in the literatures. Therefore, the aim of the present study was to evaluate host age preference, developmental duration, longevity, fecundity, numerical and functional reaction and behaviour of *A. paramali* parasitizing different ages of the cotton aphid, *A. gossypii*. Biological parameters of *A. paramali* were determined on *A. gossypii* on Crimson Tide F1 watermelon variety under laboratory conditions and it is the first study about biological parameters of *A. paramali* on *A. gossypii*.

Materials and Methods

Plant Source: In this study, Crimson Tide F1 watermelon (*Citrillus lanatus* L.) variety was used. Crimson Tide F1 variety is a middle early grown hybrid variety which is commonly used in Turkey. Crimson Tide F1 variety was grown under controlled conditions in climatic room under long day conditions at 25±1ºC, 65±5% RH and photoperiod of 16:8 (L:D) h. Seeds of this variety planted in 15x25 diameter pots with a mixture of soil, sand, and natural fertilizer. The pots were watered on alternate days and the soil was not fertilized anytime till the end of the study. Every two weeks new plants were planted to make available leaves until the end of the study.

Aphid Source: A stock culture of *A. gossypii* was established with individuals obtained from watermelon field in the Plant Protection Research Station in Diyarbakır, and it was reared on watermelon plants in controlled climate chambers and climatic room at 25±1°C temperature, 65±5% RH and a photoperiod of 16:8 (L:D) h. For this study, two lattices were established. Cotton aphids were transferred into these lattices until reproduced to begin study. After melon aphid (cotton aphid) reproduced, adopted this variety and generated new generation then transferred to 9 cm diameter plastic petri dishes on watermelon leaves in an environmental chamber. Four different instar stages of the cotton aphid and adults were utilized in the experiments. They were obtained by using freshly excised watermelon leaf discs, about 4.5 cm in diameter, which were placed downside on the top of blotting papers in round petri dishes. The petri dishes were about 9 cm in diameter and 3.5 cm in height and had three mesh-covered holes in the lid to allow air exchange. Up to twenty young adult *A. gossypii* females were placed gently in each petri dish with a moistened brush. The females were left in the petri dishes for nymphs lying for 24 hours. Then newly laid nymphs were further reared until the desired age.

Parasitoid Source: The stock culture of *A. paramali* was initiated with few individuals obtained from parasitized cotton aphids in the same watermelon field in Diyarbakır Province. When field studies were conducted in 2010, some mummified cotton aphid adults were found on watermelon plants. These samples were taken under climatic room conditions and from which so many parasitoid adults emerged. Some of these adults were put into eppendurf with 70% ethanol and sent to Dr. Mohammad HAYAT (Aligarh Muslim University Department of Zoology, India) to be identified. The result showed that all samples were *A. paramali* and it was first record for Turkey. The parasitoids were reared in climate room on *A. gossypii*, which were feeding on Crimson Tide F1 variety under lattices and under the same climatic conditions described above. For the experiments, a few *A. paramali* females were taken from stock culture and transferred to an *A. gossypii* culture feeding on watermelon to reproduce till desired number of parasitoids. After few generations, mummified aphids were put individually into small glass vials (1 cm in diameter x 7 cm in height) sealed with Parafilm® M and checked for adult emergence every day. The emerged parasitoids (0-24 hrs old) were sorted by sex, and before starting the experiments females were mated for 6 hrs in the same test tubes as described above. For food requirement of parasitoids, thin strip of the honey has been given inner side of the small glasses.

Determination of relationship between A. paramali and A. gossypii: All experiments were conducted in controlled climate chambers at 25±1°C temperature, 65±5% RH, and a photoperiod of 16:8 h (L:D) on Crimson Tide F1 hybrid watermelon variety and on *A. gossypii*. Biological parameters, life table, numerical and functional reaction and host stage preference of *A. paramali* were determined in this study.

Determination of Host Stage Preference of A. paramali on A. gossypii: In order to determine which stage of *A. gossypii* more preferred by *A. paramali* for laying its eggs, two paired-choice trials were conducted. Each treatment was replicated ten times.

For the no-choice experiment, 100 aphids each of the 1st, 2nd, 3rd and 4th instars and apterous adult groups were transferred respectively to petri dishes on watermelon leaves separately so as to control for the confounding effect of host instar. For this study, one day adult age group of *A. paramali* were used. A mated *A. paramali* couple (one ♀ and one ♂) was introduced into each petri for 24 hrs parasitization period. After removal of the parasitoid the aphids were kept in a climate chamber at constant climatic conditions as described above and checked daily for mummification. Mummified aphids were transferred to small glass vials like those used for rearing until adult emergence at the same treatments.

For the choice experiment, the experimental procedures and replicates were the same as described for the no-choice experiment with the exception of providing a couple mated *A. paramali* with 25 individuals each from instars 1-4, and apterous adults at the same time on the same petri dishes (9x3.5 cm in diameter). After 24 hrs, the parasitoid was removed and the aphids were separated according to developmental stages and transferred respectively onto five petri dishes for daily observations.

Determination of number of parasitoid on preferred Stage of A. gossypii: In order to determine life table parameters of *A. paramali*, such as longevity, fecundity, development time, adult longevity and number of parasitoid on preferred stage of host, twenty mated females (0-24 hrs old) were released daily (for 24 hrs) into round Plexiglas Petri dishes (9x3.5 cm) on watermelon leaf discs containing 100 individuals of fourth instar of *A. gossypii* individuals throughout its life span. *Aphelinus paramali* females were transferred daily into new round Plexiglas Petri dishes with fresh host individuals. The old Plexiglas Petri dishes were returned to climate chambers and after 3-4 days all aphids were controlled and counted daily till adult emergence at the same treatments. For food requirement of parasitoids thin strip of the honey has been given inner side of the petri dishes. This treatment was replicated twenty times, but only those individuals that completed development to the adult stage were included in nymphal development time calculations, and individual adults that escaped or were damaged during transfer were excluded from reproduction and survival rate analyses.

Determination of parasitism power of A. paramali depending on the intensity of A. gossypii: This experiment was established to determine which intensity of host is more suitable for *A. paramali*, to determine numerical reaction effect of parasitoid on its host. For this trial 5, 10, 20, 40, 80 and 160 individuals of fourth instar of *A. gossypii* were given female (0-24 hrs old) parasitoids separately into round Plexiglas Petri dishes (9x3.5 cm) on watermelon leaf discs for 24 hrs. After removal of the parasitoid, the aphids were kept in a climate chamber at constant climatic conditions as described above and checked daily for mummification. Mummified aphids were transferred to small glass vials like those used for rearing until adult emergence at the same treatments. For food requirement of parasitoids, thin strip of the honey has been given inner side of the petri dishes. This treatment was replicated five times for each certain number of hosts. At the end of this trial parasitizing rate of parasitoid on each determined density were investigated.

Data analysis: Data analyses and statistics effect of different host instars and adults on biology of the *A. paramali* were assessed by constructing a life table, using age-specific survival rates (l_x) and fecundity (m_x) for each age interval (x) per day. The intrinsic rate of increase (r_m) was calculated by iteratively solving the equation $\sum e^{-mrx} L_x m_x = 1$; where the age-specific survival rate (l_x) is the proportion of individuals in the original cohort alive at age x, and the age-specific fecundity (m_x) is the mean number of female progeny produced per female alive in the age-interval x. The net reproductive rate, $R0 = \sum l_x m_x$, were also calculated according to Birch (1948), Howe (1953) and Watson (1964). The values of generation time ($_{To}$) was determined with the equation $T = \sum x.l_x.m_x / \sum l_x.m_x$. In addition, life table parameters of *A. paramali* were calculated by TWOSEX software (Chi, 2015). Data on development period, adult life span, fecundity, and daily reproduction of *A. paramali* on *A. gossypii* on wateremlon Crimson Tide F1 variety were analyzed using SPSS-13.0 G (SPSS Inc., Cary, NC, USA, 1999). A one-way analysis of variance (ANOVA) was conducted for statistical comparison among means of developmental duration, longevity, fecundity, numerical and functional reaction of parasitoid. Significant differences between host age groups were determined by Least Significant Difference (LSD) Test a probability level of $P \leq 0.05$. For the statistical comparison of an average of female longevity was calculated.

Results and Discussion

Determination of host stage preference of A. paramali to parasitizing A. gossypii: First study was performed on each stage of *A. gossypii* instars and adults separately (no-choice). The results of parasitizing situation of *A. paramali* under no-choice trial conditions were given in Table 1. It was determined that when each biological stage of *A. gosyypii* individuals separately were given to *A. paramali*, they were parasitized by *A. paramali* in all stages including adults and in all situations adult emerging was occurred comparatively. Parasitizing situation from the least to the most level were ordered as; first, second, third stages, adults and fourth stage with 17.9% the most parasitizing rate. According to statistical analysis there was not any difference between third, fourth instars and adults in terms of parasitizing rate of host preference, but even was not difference comparatively fourth instar stage more preferred than the others (Table 1).

Second study was performed on all stages of *A. gossypii* instars and adults together with (choice) the same petri dishes to evaluate which biological stage of *A. gossypii* was preferred by parasitoid. The results of parasitizing situation of *A. paramali* under choice trial

Table 1. Parasitizing performance of *Aphelinus paramali* adults on each stage and adults of *Aphis gossypii* which were given separately (no-choice) (%), and together (choice) (%).

Trials	Stage of *Aphis gossypii*	Number of *Aphelinus paramali* (n)	Number of *Aphis gossypii* (n)	Number of Parasitized *Aphis gossypii* (n)	Percentage of Parasitized *Aphis gossypii* (%)
No-choice	First instar	1♀ 1♂	100	5.1±1.10 a	5.1
	Second instar	1♀ 1♂	100	10.3±1.64 b	10.3
	Third instar	1♀ 1♂	100	15.8±2.49c	15.8
	Fourth instar	1♀ 1♂	100	17.9±2.28 c	17.9
	Adults	1♀ 1♂	100	16.8±2.20 c	16.8
	LSD			4.22	
Choice	First instar	1♀ 1♂	25	2.5±0.53 a	10.0
	Second instar	1♀ 1♂	25	5.3±1.16 b	21.2
	Third instar	1♀ 1♂	25	8.1±0.99 c	32.4
	Fourth instar	1♀ 1♂	25	10.5±1.58 d	42.0
	Adults	1♀ 1♂	25	7.7±1.16 c	30.8
	LSD			1.59	

* Means within a row sharing the same letter are not significantly different (P≤0.05, Least Significant Difference (LSD) test).

conditions were given in Table 1. It was determined that when all biological stages and adults of *A. gosyypii* individuals together were given to *A. paramali*, they were parasitized by *A. paramali* in all stages including adults and in all situations adult emerging of parasitoid was occurred comparatively (Table 1). According to the results, when all biological stages and adults of *A. gosyypii* individuals together were given to *A. paramali*, there was an important difference between parasitizing rate of host preference between fourth instar and the other instars including adults. But like the first treatment the least parasitizing was occurred on the first instar of *A. gossypii*, then ordered second instar, adults, third instar and the most parasitizing rate was on the fourth instar as 42% (Table 1). There was no difference between third instar and adults, while first, second and fourth instars took place as a different group (Table 1). Both experiments showed that fourth instar was preferred more than the other stages and the most preferred biological stage of *A. gossypii*.

The most parasitizing rate of *A. paramali* that preferred as fourth stage of aphids when they were given in no-choice conditions occurred as nearly 18% (Table 1), but when they were given in choice conditions the rate of parasitizing was increased as 42% (Table 1). According to some earlier studies that carried out on *A. gossypii*; parasitizing rate of *A. colemani* on *A. gossypii* is 70-80% (Gücük and Yoldaş, 2000); the highest parasitizing rate of *Lysiphlebus confusus* at 22°C temperature 53.9%, the highest parasitizing rate of *L. fabarum* at the same temperature 41.2% and the highest parasitizing rate of *L. testaceipes* at 17°C temperature 69.1% (Satar et al., 2009); parasitizing rate of *L. testaceipes* 65% and the rate of adult emerging 62% (Rodrigues et al., 2004). There is no similarity between this study and literatures due to using different parasitoids, different stage of host and different conditions.

As it was stressed before, the most preferred stage of *A. gossypii* by *A. paramali* was fourth stage both, choice and no-choice trials. Host stage preferences of parasitoid vary from parasitoids to parasitoids and from host to host. According to some literatures, parasitoids preference of *Ephedrus cerasicola* on *Myzus persicae* (Hofsvang and Hagvar, 1986); parasitoids preference of *Aphidus matricariae* on *M. persicae* and parasitoids preference of *A. colemani* on *Pentalonia nigronervosa* (Hagvar and Hofsvang, 1991) were middle age of aphids than young and old aphids. Parasitoids preference of *Diaeretiella rapae* on *Brachycorynella asparagi* (Hayakawa et al., 1990) and parasitoids preference of *D. rapae* on *Diuraphis noxia* were third and fourth stages than the other stages (Bernal et al., 1994); while the same parasitoit preferred second and third stages of *Brevicoryne brassicae* (Ölmez Bayhan and Ulusoy, 2004) or *A. colemani* more preferred first stages of *A. gossypii*, but parasitized the other stages as well, and no difference between trials (Dionyssios et al., 2004). *Aphidius colemani* more preferred fourth stage and the adults of aphid, it parasitized easily *A. gossypii* and adult emerging and reproducing were successfully occurring in the third stages and larger individuals of aphid (Van Steenis and El-Khawass, 1995).

Nymphal stage of aphid selection by parasitoids in biological control period is one of the most important factors in reducing aphid populations. Many aphids may be suitable for parasitoid, but the quality of different hosts and different development period of hosts could affect parasitoids such as parasitoid size, feeding, sex ratio, longevity, fecundity and the development of parasitoid larvae (Mackauer, 1982; Stary, 1988; Sequeira and Mackauer, 1994; Pandey and Singh, 1999). In this study, less preference of the first and second stages of *A. gossypii* and more preference of larger instars and newly adult aphid individuals formed opinion that it was due to the quest to meet the nutritional needs to continue its generation. The selection of host significantly affects both pest population and parasitoid population, and it gives a certain belief about if potential pest could be controlled successfully or not (Pak, 1986; Hagvar and Hofsvang, 1991). The theory of optimum nutrition proposes to maximum benefit of the next generation of parasitoid and selection of host accordingly (Hubbard and Cook 1978; Pyke 1984). Therefore, survival of female parasitoids individuals must be protected, their life and reproduction should be obtained (Mackauer et al., 1996). The parasitizing of all biological stages of *A. gossypii* by *A. paramali* is a positive and desirable feature in terms of biological control. The feature of parasitizing all biological stage of *A. gossypii* and suppression of its life showed that *A. paramali* could be a beneficial with a view to biological control. Several authors mentioned that host age and size affect the parasitoids perception of host suitability: in general, a parasitoid's growth and development are enhanced when older hosts that are larger and nutritionally richer are parasitized than when younger hosts are selected for parasitization; but nevertheless the effect of host age depends on the parasitoid-host system (Smilowitz and Iwantsch, 1973; Hu et al., 2002). Starý (1988) suggested that the developmental duration of aphelinid parasitoids is partially influenced by host species could be confirmed with the current experiments. The present study revealed that development period of *A. paramali* on *A. gossypii* is getting decrease by increasing of host age.

The advantage is that aphids parasitized at the first or second instar stages fail to develop into adulthood (Tsai and Wang, 2002) even though it is disadvantage for parasitoid because some time could not develop inside aphids. The parasitizing ability of *A. paramali* on all biological stages of *A. gossypii* and suppression of its life is a positive and desirable feature in terms of biological control.

The larva develops as a solitary endoparasite and pupation takes place inside the dead host, which is transformed into a bluish-black mummy. Thus, the developmental period from egg to mummification reflects the larval development and the developmental period from mummification to adult emergence referred to pupal development. Mummification in this experiment was defined as hardening and blackening of the body.

Aphelinus paramali parasite mummies (i.e., mummified aphids containing parasite pupae) could be found about 5-7 days after adult parasites were introduced, and new adult parasites began to emerge from the mummies about 3-5 days. Approximately 55-60% of all *A. paramali* mummies produced adults within 6-7 days of the first adult emergence. According to Godfrey (2004), *A.* near *paramali* parasite mummies could be found about 7 days after adult parasites were introduced into a cage and new adult parasites began to emerge from the mummies about 3-5 days. Approximately 56% of all *A.* near *paramali* mummies produced adults within 7 days of the first adult emergence. Even different type of *A. paramali* (*A.* near *paramali*) was used these results are compatible with Godfrey (2004) because of using the same species of parasitoid.

Preferred stage of A. gossypii and obtained number of parasitoid on this stage parasitized by A. paramali: The number of parasitized aphids that obtained on the fourth stage of *A. gossypii* was given on Figure 1. The mean total fecundity of *A. paramali* (number of one female of *A. paramali* laying eggs throughout its life and developing parasitoids) on *A. gossypii* was 151.1 eggs. According to earlier studies that all carried out on *A. gossypii* as host; *A. colemani* 388.1 eggs; (Van Steenis, 1993), *L. testaceipes* 180 eggs (Van Steenis, 1994), *A. varipes* Förster 207.5 eggs (Van Steenis, 1995), *Aphelinus*

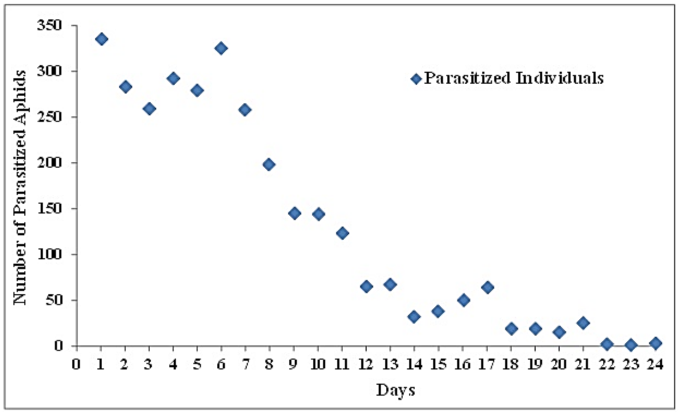

Figure 1. Average number of parasitoid that developed on *Aphis gossypii* throughout *Aphelinus paramali*'s life.

gossypii 57 eggs (Tokumaru and Takada, 1996); *A.* near *paramali* 120 eggs (Godfrey, 2004 referred to Tang et al., in 1995 unpublished), *A. colemani* 250 eggs (Gücük and Yoldaş, 2000), *A. asychis* (Walker) 232.3 eggs (Şengonca et al., 2007), *A. colemani* 420 eggs (Torres et al., 2007) and *Lipolexis oregmae* (Gahan) 115.8 eggs (Singh et al., 2009). There are difference between this study and literatures in terms of reproduction; however, this could probably be caused by different experimental designs, different host ages and different parasitoid strains.

It was determined that *A. paramali* lays eggs from the beginning of adult period until the end of life. Eggs laying performance and the number of eggs are decreased when it getting older day by day, but still continues to lay eggs. Mean daily fecundity of *A. paramali* with *A. gossypii* as host in the same study was 13.6/ eggs/day. Moreover *A. paramali* is active as an adult nearly 24 days long period. Daily fecundity in the present study reached a maximum level one week after emergence of the female parasitoid and it lasted over one week and then decreased, however, sometime the last days daily fecundity increased more than before. *Aphelinus paramali* completed its development period on *A. gossypii* averagely as 11.7 days. According to earlier studies that carried out on *A. gossypii*: *A. colemani* 11-13 days (Gücük and Yoldaş, 2000); *L. testaceipes* 11.3 days (Rodrigues et al., 2004); *A.* near *paramali* 10-12 days (Godfrey, 2004 unpublished study of Tang et al., in 1995); *A. colemani* 12 days (Torres et al., 2007); *A. colemani* 10 days and *A. matricae* 11.9 days (Zamani, 2007). Concerning the developmental period of *A. paramali*, on *A. gossypii* the present results are similar to those in earlier studies except for slightly difference. It may be regarded due to using the same host species, taking into consideration the differences in temperatures, host stages and different parasitoids. As soon as *A. paramali* emerged from pupae the same day it could lay eggs and continues to till the end of its life. Therefore, its pre- oviposition and post-oviposition period too short that it could be said there is not any pre-oviposition and post-oviposition period. Even the longevity of parasitized and not parasitized aphid individuals the same, but fecundity of parasitized aphid individuals lower than not parasitized ones.

Regarding the adult longevity, current experiments revealed that mean adult longevity of *A. paramali* on *A. gossypii* was 12.25 days. According to earlier studies that carried out on *A. gossypii*: adult longevity of *A.* near *paramali* 10-20 days (Godfrey, 2004 unpublished study of Tang et al., in 1995); *Aphelinus goossypii* 5-17 days (Tokumaru and Takada, 1996); *A. colemani* 5-9 days (Torres et al., 2007) and *L. oregmae* 8.1 days (Singh et al., 2009). There are difference between this study and literatures in terms of adult longevity. It is due to using different parasitoid species and different conditions.

Mean total longevity of *A. paramali* was determined as 23.95 days. According to earlier studies; *A. mali* 20-25 days (Lundie, 1924); *A. mali* 19-22 days ((Barlett, 1978; Almatni, 1997); *A. semiflavus* Howard 19 days (Mackauer, 1982); *L. oregmae* 23.5 days (Singh et al., 2009). It could be said *A. paramali* had lived longer than other aphelinids such as *Aphelinus gossypii* or *A. spiraecolae*, whose longevity ranged between 5 and 17.8 days (Tang and Yokomi, 1996; Tokumaru and Takada, 1996) except for *Aphelinus asychis* (Walker) 25.2 or 24.2 days (Şengonca et al., 2007). A change in longevity may affect fecundity and led to change in the population dynamism (Croft, 1990). Therefore, adult longevity and the total progeny number of *A. paramali* were significantly affected. As to total longevity of parasitoid, generally there are difference between this study and literatures due to using different parasitoid species and different conditions.

Life table of A. paramali: Life table of *A. paramali* on *A. gossypii* was given on Figure 2. In order to understand population dynamics of a beneficial insect, fecundity and life table of this beneficial insect should be determined. Life table, intrinsic rate of increase (r_m) and fecundity of beneficial insect give strategies to develop how pests could be controlled (Torres et al., 2007).

The net reproduction rate (R0) of *A. paramali* on

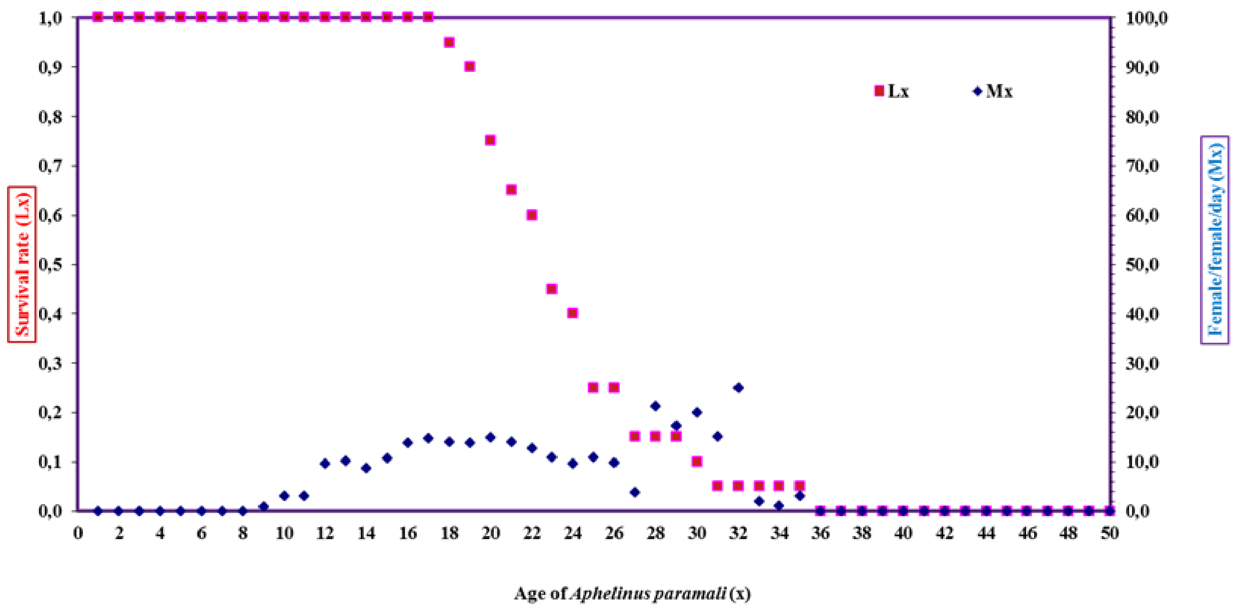

Figure 2. Life table of *Aphelinus paramali* under laboratory conditions (25±1°C temperature 16:8 L:D h and 65±5% humidity).

A. gossypii was 152 females/female/generation. According to earlier studies net reproduction rate (R_0) of *A. colemani* on *A. gossypii* 194.8 (Torres et al., 2007) and net reproduction rate (R_0) of *L. oregmae* on *A. gossypii* 75.4 (Singh et al., 2009).

The value of generation time (T_o) of *A. paramali* on *A. gossypii* was 18.2 days. According to earlier studies mean generation time (T_o) of *A. colemani* on *A. gossypii* was 13.7 days (Torres et al., 2007).

The intrinsic rate of increase (r_m) alone adequately summarizes the physiological qualities of an animal in relation to capacity to increase (Andrewartha and Birch, 1954). One of the most important parameters of reproduction power is the intrinsic rate of increase (r_m) and it has been found as 0.324. According to literatures the intrinsic rate of increase (r_m) of *A. colemani* on *A. gossypii* 0.384 (Torres et al., 2007); the intrinsic rate of increase (r_m) of *L. confusus*, *L. fabarum* and *L. testaceipes* on *A. gossypii* found that 0.228, 0.156 and 0.290, respectively (Satar et al., 2009); intrinsic rate of increase (r_m) of *L. oregmae* on *A. gossypii* 0.346 (Singh et al., 2009).

Compared to literature, the results that obtained of this study such as; the values of generation time (T_o), the intrinsic rate of increase (r_m) and net reproduction rate (R_0) parameters were found different from earlier studies. However, this could probably be caused by different experimental designs, different host species, host ages and different parasitoid strains or conditions. Survivorship rate and fecundity at early period of adults are important parameters that affect the intrinsic rate of increase (r_m) (Levontin, 1965). Therefore total number of eggs is not alone important, short development period and the most daily fecundity level in which age occurred are important as well because increase of intrinsic rate of increase (r_m) depend on these parameters (Levontin, 1965).

Determination of parasitism power of A. paramali that depending on the intensity of A. gossypii: This trial was carried out with a view to determine numerical reaction response of parasitoid in any given host number. Parasitizing performance of *A. paramali* and the number of parasitized individuals according to intensity of aphids given on Table 2 and Figure 3. It was determined that as the intensity of aphids increased the number of parasitized individuals also increased. However, parasitizing rate was found that in low intensity of host as high rate, while in high intensity of host parasitizing rate was lower (Table 2 and Fig. 3).

Functional and numerical reaction response of *A. paramali* showed similarity with the other parasitoids that as pointed out in earlier studies. When intensity of aphids increased, the number of parasitized individuals by *A. paramali* increased at the beginning (at the intensity of 5-40 host individuals), but after 80 individuals intensity increasing of parasitizing stopped and transformed into a flat plateau and showed similarity of Holling (1959) type

Table 2. Parasitizing power of *Aphelinus paramali* depending on intensity of *Aphis gossypii* (fourth instar stage).

Number of *Aphelinus paramali*	Replication	Intensity of *Aphis gossypii* (Number of Aphids)	Number of Parasitized *Aphis gossypii*	Rate of parasitized *Aphis gossypii* (%)
1♀ 1♂	5	5	4.6	92
1♀ 1♂	5	10	8.6	86
1♀ 1♂	5	20	10.6	53
1♀ 1♂	5	40	17.0	43
1♀ 1♂	5	80	19.0	24
1♀ 1♂	5	160	22.4	14

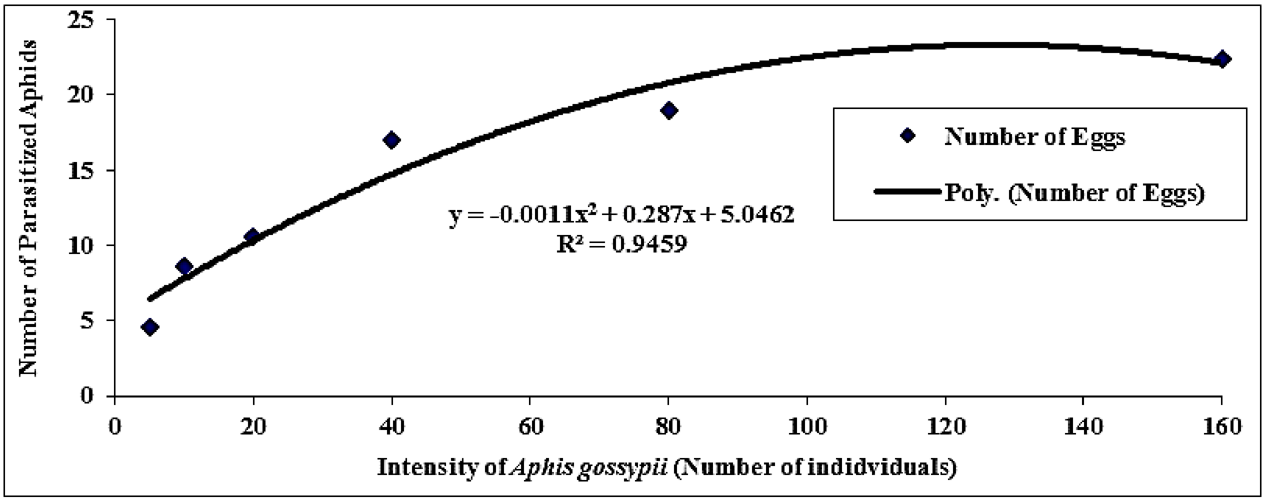

Figure 3. Parasitizing power of *Aphelinus paramali* at increasing density of *Aphis gossypii* (Functional reaction).

II functional and numerical reaction response (Fig. 3). This situation showed that when intensity of aphids increased parasitizing rate of *A. paramali* also increased in a certain level, but this increasing was unprogressive. Similarly Bernal at al. (1994) emphasized that when intensity of aphids increased parasitizing performance of *A. mali* on *Diuraphis noxia* (Mordvilko) increased and parasitizing rate and food consuming of parasitoid showed Holling, type II. In addition, so many scientists pointed out that many parasitoids of aphids generally showing Holling, type II feature (Messenger, 1968; Dransfield, 1979; Collins and Dixon, 1981; Chua et al., 1990; Ölmez Bayhan and Ulusoy, 2004; Bayram and Bayhan, 2012).

Parasitoid behavior is compatible with Holling, type II, so it could be understood that *A. paramali* would not control *A. gossypii* by itself naturally. Some scientist explained this type parasitoids could not control their hosts naturally, only by supporting release of them they could successfully be used (Messenger, 1968; Murdoch and Oaten, 1975; Hassel, 2000). The result showed that there is similarities between this study and literatures about parasitoid behavior.

Conclusion

The present study confirmed that *A. paramali* was able to develop and reproduce with *A. gossypii* as host. Due to the surplus of aphids offered, the opinion on super-parasitism was rare, consistent with earlier reports on *Aphelinus* species (Mackauer, 1982; Wahab, 1985; Bai and Mackauer, 1990). The results that obtained from this study will contribute important data to control cotton aphid and to use this wasp as a biological agent or as a component of IPM. Therefore, integrated pest management programs is becoming increasingly important, in order to keep the pest population below the economic injury level, aiming at minimizing the number of pest without eradicate their generation and especially in the agro-ecosystem without destroying other species and pollution of the environment. In integrated pest management programs, biological control method has a very important role, due to its natural balance, preventive and long term solution features. It is thought that it would be useful to benefit from this wasp and integrate it with IPM program. These findings might also be considered as basic information and first step for further investigations on the biology and ecology of this parasitoid. However, we recommend further testing under more realistic conditions, to totally ascertain its parasitizing effects on aphids. Except for *A. gossypii,* the presence of other hosts such as *Aphis pomi* (Larsen, 2011), *A. spiraecola* (Patch), *Myzus persicae* and *Toxoptera aurantii* (Fonscolombe) (Godfrey and McGuire, 2004) give advantage parasitoid to produce new generations. As it has more alternative hosts, the short developmental duration, long adult period, high proportion of females, high fecundity of every adult day, ability of overwinter in suitable areas and its adaptable features to natural conditions for establishing (Godfrey and McGuire, 2004) concluded that, it could be effective and interesting alternative in terms of biological control and IPM.

Acknowledgements

We are indebted to M. Hayat (Aligarh Muslim University-Aligarh/ India) for his incredible effort and assistance to identification of parasitoid and H. Chi for his personal assistance and using his life table program “Age Stage, two sex life table analysis”. This study is a part of PhD thesis. We are also thankful for providing us to carry out this project for their assistance and supporting “Scientific Research Projects Coordination of Dicle University” (DUSRPC Project No: 10-ZF-08) and “General Directorate of Agricultural Research and Policies of Ministry of Food, Agriculture and Livestock” (GDAR Project No: 10 / 10-01 / 01-06).

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