



Demography and life history of the egg parasitoid, *Trichogramma brassicae*, on two moths *Anagasta kuehniella* and *Plodia interpunctella* in the laboratory

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Abstract

The egg parasitoid, *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) is the most important and widely distributed species of *Trichogramma* in Iran. It attacks eggs of several lepidopterous pests, and is a major biological control agent. Rearing parasitoids is necessary for experimental work, and, potentially, for mass release in the field. Selecting a suitable host is critical for developing a successful rearing method. If other conditions are the same, the rate of population increase will be a suitable indicator of parasitoid performance on different hosts. However, conclusions based on a single generation can be misleading because of the learning ability of parasitoids. Life history parameters of *T. brassicae* were studied on two hosts easily reared in the laboratory, *Anagasta kuehniella* Zeller, and *Plodia interpunctella* Hübner (Lepidoptera: Pyralidae). All the experiments were carried out at $24 \pm 1^\circ\text{C}$, $65 \pm 10\%$ RH, and 16:8 L:D photoperiod. Eight parameters including gross and net reproductive rates (GRR and R_0 respectively), intrinsic rate of natural increase (r_m), finite rate of population increase (λ), intrinsic birth and death rates (b and d respectively), cohort generation time (T), and doubling time (DT) were compared between two hosts for two generations. All parameters showed a highly significant difference ($\alpha = 0.01$) between hosts. GRR, R_0 , r_m , λ , and b were higher, while d, T, and DT were lower in *Anagasta* than *Plodia*. The intrinsic rate of natural increase was 0.2912 and 0.2145 female/female/day and net replacement rate was 45.51 and 19.26 female/female/generation in *Anagasta* and *Plodia* respectively. Differences between generations were significant except for r_m , λ , and d. The net replacement rate was 28.56 and 39 in the 1st and 2nd generations respectively. These results showed that *A. kuehniella* was a better host than *P. interpunctella*. Higher reproduction occurred in the second generation that may be due to increased adaptation to experimental conditions.

Keywords: intrinsic rate of natural increase, net replacement rate, fertility-life table

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Introduction

Insect eggs belonging to 11 orders are attacked by different species of Trichogrammatidae parasitoids. Lepidopterous insects are the most preferred hosts (Sorokina 1999). Augmentation of parasitoids is used against some serious pests throughout the world (Li 1994; Smith 1996). *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) is the most important and widely distributed species of *Trichogramma* in Iran (Ebrahimi et al. 1998). Many *Trichogramma* species can be easily reared on laboratory hosts such as *Anagasta kuehniella*, *Sitotroga cerealella*, *Plodia interpunctella*, *Galleria mellonella*, and *Corcyra cephalonica* (Smith 1996; Shojai et al. 1998; Ebrahimi 2004). Furthermore, major crop pests such as the rice stem borer *Chilo suppressalis*, the European corn borer, *Ostrinia nubilalis*, the cotton bollworm *Helicoverpa armigera*, and some related species are target hosts of *T. brassicae* and related species (Li 1994; Dutton et al. 1996; Greenberg et al. 1998; Ebrahimi et al. 1998).

Success in biological control by *Trichogramma* depends on identification of the best host species, as well as a good understanding of the ecological requirements of the parasitoid wasp (Parra et al. 1987; van Lenteren et al. 1997). One of the most important aspects in ecology of the parasitoid is a suitable host. The size and age of the species chosen are important characteristics that determine the quality of a host (Hiehatata et al. 1976; Houseweart et al. 1982; Bourmier 1982; Brower 1983; Ahmad and Sivapragasam 1984; Pak 1986; Lewis and Redlinger 1989; Hintz and Andow 1990; Reznik and Umarova 1990; Ruberson and Timothy 1992; Monje et al. 1999; Jeffry and Robert 2000; Mansfield and Mills 2002; Roriz et al. 2006; El-Wakeil 2007). There are a few ecological studies on local populations in Iran that show trichogrammatids are affected by these factors (for example Karimian 1999; Attaran et al. 2000; Dadpour Moghanlou 2002; Haghani and Fathipour 2004; Alizadeh and Ebrahimi 2004; Karimi Malati et al. 2004; Shirazi 2004; Hosseini Bai et al. 2006). However demographic traits such as the intrinsic rate of natural increase or net reproductive rate have been estimated only in a few studies (Dadpour Moghanlou 2002; Haghani and Fathipour 2004). According to Andrewartha and Birch (1954) demographic parameters are the best indicators of fitness of a population and are suitable criteria for comparing physiological states of different species, populations, etc. or even as bioclimatic or nutritional indices (Messenger 1964; Dent and Walton 1997). Also, in biological control programs, population growth rate is an essential criterion for preliminary screening and choice of potential biocontrol agents (van Lenteren and Woets 1988).

To achieve a successful laboratory culture of *T. brassicae* it is necessary to study the effects of different ecological factors on important biological parameters of local populations of *T. brassicae*. As van Driesche and Bellows (1996)

point out, rearing natural enemies on natural hosts is often difficult and expensive. Augmentation using alternative hosts is therefore usually necessary. Stored products moths often have been used traditionally for rearing *Trichogramma* species (Smith 1996). *S. cerealella*, *A. kuehniella*, and *P. interpunctella* are not only alternative hosts but also obvious target pests (Smith 1996; Shojai et al., 1998; Ebrahimi 2004). Availability due to worldwide distribution, as well as an inexpensive rearing method (Sepasgozarian 1966; Behdad 2002) are the most important advantages of these species for mass production purposes.

Natural enemies are able to learn (Bigler 1994; van Driesche and Bellows 1996). This ability allows them to improve their response to their host when they are reared sequential generations on a host (van Driesche and Bellows 1996). This occurs via enhancing their skills in orientation, host finding, host detection and acceptance (Noldus et al. 1990). Van Bergeijk et al. (1989) observed different responses in *T. brassicae* to European corn borer when it was reared previously on the same host compared to *A. kuehniella*.

In this study, life history statistics are examined for *T. brassicae* on two laboratory hosts, *A. kuehniella*, and *P. interpunctella* in order to explore if there is any advantage to each one. As the null hypothesis we assumed that no differences were present between these hosts so that both are similar in quality for their host. If this is the case, then either host can be used equally well for production purposes, assuming all other conditions are the same. Rejection of the null hypothesis means that the hosts are not of the same value for rearing and the best host can be used. As mentioned earlier, continuous rearing on a host can improve the impact of a parasitoid. If this is the case, then considering only one generation in host evaluation may be misleading. For example if continuous rearing on a host leads to improvement in parasitoid performance on one of the hosts, then it may be recommendable using it in sequential cultures in spite of its initial low performance. Thus the second null hypothesis is that the parasitoid has equal performance in sequential generations.

Materials and Methods

Host cultures

A culture of the Indian meal moth, *Plodia interpunctella* Hübner (Lepidoptera: Pyralidae), was reared on pistachio in the Department of Plant Protection, Faculty of Agriculture, University of Tabriz. To adapt the culture to the laboratory conditions it was reared two generations on single cross hybrid of maize kernels at $24 \pm 1^\circ\text{C}$, $65 \pm 10\%$ RH, and 16:8 L:D photoperiod in an incubator. Plastic rectangular containers (20×14×6 cm) were used for rearing larvae.

A culture of the flour moth, *Anagasta kuehniella* Zeller (Lepidoptera: Pyralidae) was reared on wheat flour in the same location. It was reared two generations on wheat flour cultivar Omid under the conditions described above. Similar containers were used for this purpose.

Cylindrical containers (30cm in height, 11 cm in diameter), were used to confine moths to obtain eggs. Ten pairs of adult moths were removed by an aspirator and transferred to a cylindrical dish. The top of the dish was covered by a 10 mesh cloth net and set upside down on a piece of paper. Deposited eggs were collected every day and used in experiments.

Preparation of parasitoids for experiments

The *Trichogramma brassicae* used in this study, were collected from eggs of the cereal moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), obtained from the Agricultural Research Center of East Azerbaijan, Tabriz. These wasps had been already reared on the *S. cerealella* for five generations. To adapt it to experimental conditions it was reared for two generations under the conditions described above using *S. cerealella* eggs as the host. Honey droplets were used to feed wasps.

One-day-old eggs of both hosts were offered to newly emerged females of *T. brassicae* for 24 hours. Female wasps were then removed from host eggs and they were held under the same conditions until symptoms of parasitism appeared. Forty parasitized eggs from each host were selected randomly and the parasitoids were reared to adults. Each surviving female was then confined with a male that had been reared under the same conditions. Males were replaced when they died. Fifty eggs of the same host species that parents had been reared on were offered daily to each pair of wasps up to the time of death of the female. The number of eggs offered daily to the wasps was determined based on a functional response experiment under the same conditions (Farazmand and Iranipour 2006) in which the maximum attack rate was 40 hosts/wasp/day obtained for *A. kuehniella*. Cohorts of the second generation were selected at the peak of oviposition.

Experimental design and data analyses

The experiment was designed as a 2×2 factorial with completely randomized design. One of the factors was host with two levels *A. kuehniella* and *P. interpunctella*. The other factor was generation with two levels. Due to unequal mortality among treatments, the analysis was converted to an imbalanced design. Eight parameters including gross reproductive rate (GRR), net replacement rate (R_0), intrinsic rate of natural increase (r_m), finite rate of increase (λ), intrinsic birth rate (b), intrinsic death rate (d), cohort generation time (T), and doubling time (DT) were calculated as described by Carey (1993). Variances and standard errors were measured using the jackknife method of Meyer et al. (1986). Analyses of variances and comparisons of means were carried out using SAS software (SAS Institute Inc.). Survivorship curves were drawn using data in column l_x and type was determined by entropy (Dimitrius 1978; Carey 1993).

Results

A summary of the analyses of variances for the eight above-mentioned statistics are shown in table 1. All the parameters differ highly significantly ($p < 0.01$) between hosts, as GRR, R_0 , r_m , λ , and b are higher while d, T, and DT are lower in *A. kuehniella* than *P. interpunctella* (Table 2). These results reveal that *A. kuehniella* is a more desirable host than *P. interpunctella* for *T. brassicae*. There are also significant differences in all parameters except for r_m , λ , and d in the second generation. All parameters but doubling time were higher in second generation (Table 2). Because R_0 and T have opposite effects on r_m , the latter parameter showed no significant difference in the two generations. These data suggest that *T. brassicae* has habituated to hosts as well as other experimental conditions during the first generation. Interactions between two factors were significant in all but three parameters (GRR, λ and d). This means that level of adaptation during the second generation was not equal between the two hosts. Components of life history statistics in each host and generation are shown in Table 3.

Table 1. Summary of analysis of variance (F and p-values) for eight life history parameters of *T. brassicae* on two host species *A. kuehniella*, and *P. interpunctella* for two generations*

Source of variation	Parameters															
	GRR		R0		rm		λ		b		d		T		DT	
	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p
Host	1265.05	<0.01	4709.94	<0.01	3618.76	<0.01	62.47	<0.01	5781.32	<0.01	7.64	<0.01	460.8	<0.01	3944.53	<0.01
Generation	6.29	0.013	450	<0.01	0.05	0.82	0.65	0.42	9.52	<0.01	3.45	0.06	863.3	<0.01	5.2	0.02
Host × Generation	1.39	0.24	52.82	<0.01	44.84	<0.01	3.32	0.07	53.78	<0.01	1.13	0.29	330.48	<0.01	56.39	<0.01

*Number of df's in all comparisons are 1 for numerator and 94 for denominator.

Table 2. Summary statistics of life history of *T. brassicae* on two hosts in two generations (mean \pm 95% confidence interval).

Parameters	Hosts		Generations	
	<i>A. kuehniella</i>	<i>P. interpunctella</i>	F1	F2
GRR	56.23 \pm 0.639	39.36 \pm 0.689	47.27 \pm 2.487	49.85 \pm 2.371
R_0	45.51 \pm 1.585	19.26 \pm 0.800	28.56 \pm 3.198	39.00 \pm 4.131
r_m	0.2912 \pm 0.0024	0.2145 \pm 0.0017	0.2526 \pm 0.0097	0.2598 \pm 0.0124
λ	1.3509 \pm 0.0031	1.2416 \pm 0.0021	1.2831 \pm 0.0125	1.3122 \pm 0.0160
b	0.2952 \pm 0.0016	0.2226 \pm 0.0017	0.2599 \pm 0.0092	0.2640 \pm 0.0116
d	0.0039 \pm 0.0026	0.008 \pm 0.0002	0.0073 \pm 0.0027	0.0041 \pm 0.0008
T	13.07 \pm 0.086	13.75 \pm 0.269	12.93 \pm 0.066	13.92 \pm 0.222
DT	2.38 \pm 0.022	3.23 \pm 0.026	2.79 \pm 0.107	2.74 \pm 0.139

Table 3. Life history statistics of *T. brassicae* in each host and generation separately (mean \pm 95% confidence interval).

Parameters	<i>A. kuehniella</i> F1	<i>A. kuehniella</i> F2	<i>P. interpunctella</i> F1	<i>P. interpunctella</i> F2
GRR	55.91 \pm 1.052	56.53 \pm 0.741	38.63 \pm 1.084	40.36 \pm 0.371
R_0	40.07 \pm 0.955	50.76 \pm 0.858	17.05 \pm 0.280	22.28 \pm 0.420
r_m	0.2870 \pm 0.0041	0.2953 \pm 0.0010	0.2182 \pm 0.0015	0.2093 \pm 0.0011
λ	1.332 \pm 0.0054	1.368 \pm 0.0482	1.247 \pm 0.0073	1.233 \pm 0.0015
b	0.2931 \pm 0.0028	0.2972 \pm 0.0010	0.2268 \pm 0.0014	0.2168 \pm 0.0010
d	0.006 \pm 0.0052	0.0018 \pm 0.0001	0.008 \pm 0.0002	0.007 \pm 0.0002
T	12.86 \pm 0.123	13.29 \pm 0.037	12.98 \pm 0.034	14.81 \pm 0.058
DT	2.41 \pm 0.040	2.24 \pm 0.008	3.17 \pm 0.025	3.30 \pm 0.020

Gross reproductive rate

The gross reproductive rate (GRR) was higher in *A. kuehniella* than *P. interpunctella* by a factor of 1.4 ($F = 1265.1$, $P < 0.01$) (Table 2).

Net reproductive rate

The net reproductive rate (R_0) of *A. kuehniella* was more than twice as high as *P. interpunctella* ($F = 4709.9$, $P < 0.01$). A 36.55% increase occurred between the first and second generations (Table 2).

Intrinsic rate of natural increase

The intrinsic rate of natural increase (r_m) was significantly higher for *A. kuehniella* than *P. interpunctella* ($F = 3618.8$, $P < 0.01$). There was no significant difference between generations ($F = 0.05$, $P = 0.82$) (Table 2).

Finite rate of population increase

The finite rate of population increase (λ) is calculated easily from the intrinsic rate of natural increase. Therefore its changes follow the same pattern.

Intrinsic birth rate and death rate

The balance between these statistics (b and d) determines population growth rate. They changed in an inverse direction, as the birth rate was higher ($F = 5781.3$, $P < 0.01$)

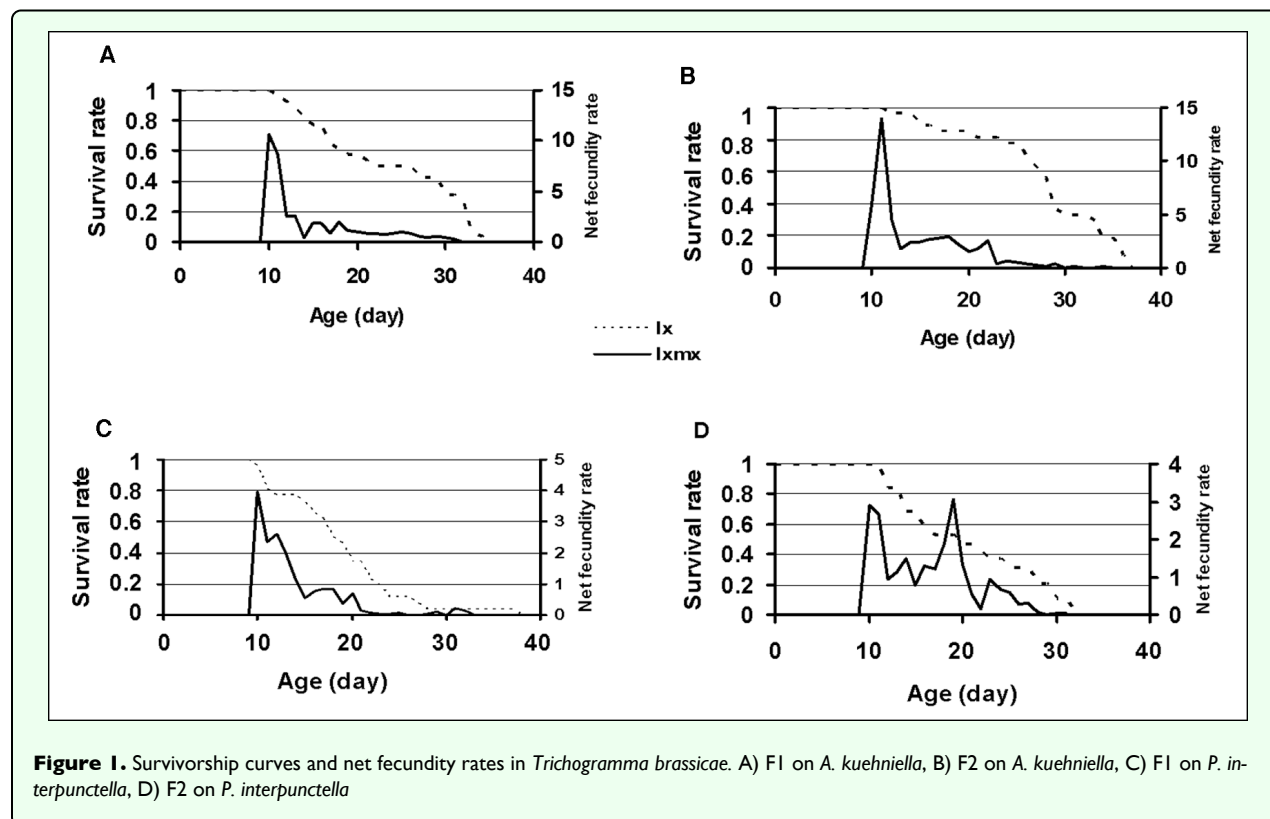
and the death rate was less ($F = 7.64$, $P < 0.01$) in *A. kuehniella* than *P. interpunctella*. So the intrinsic rate of natural increase (r_m) was higher in *A. kuehniella* (Table 2). The intrinsic birth rate also was higher in second generation ($F = 9.52$, $P < 0.01$), while the intrinsic death rate was similar in both ($F = 3.45$, $P = 0.06$) (Tables 2 and 3).

Cohort generation time

Cohort generation time (T) was significantly longer in *P. interpunctella* than *A. kuehniella* ($F = 460.8$, $P < 0.01$). There was also a significant difference between the two generations ($F = 863.3$, $P < 0.01$), as in second one was one day more (12.93 ± 0.066 vs. 13.92 ± 0.222) (Table 2). However, the differences were small and significance of such small differences means a low variance in this statistic due to the limited reproductive period.

Doubling time

In *T. brassicae* the population doubles every 2.38 ± 0.022 days for *A. kuehniella* and every 3.23 ± 0.026 days for *P. interpunctella*. The differences were significant ($F = 3944.5$, $P < 0.01$). The difference in doubling time between generations was small but significant ($F = 5.2$, $P = 0.02$) (Table 2).



Survivorship curves

A survivorship curve similar type I of Slobodkin (1980) was observed in all treatments (Figure 1). In order to determine curve type, entropy (Carey 1993) was used as a criterion. An entropy amount below 0.5 shows a survivorship curve near to type 1. During two generations, entropy was 0.28 and 0.19 in *A. kuehniella*, and 0.31 and 0.30 in *P. interpunctella*. Both survivorship and age specific fecundity are shown in Figure 1.

Discussion

The results of this study revealed that *A. kuehniella* is a more acceptable host for *T. brassicae* than *P. interpunctella*. A higher GRR, R_0 , r_m , λ , and b suggest higher reproduction of *T. brassicae* on *A. kuehniella*, whereas lower d , T , and DT may be due to an accelerated development of *A. kuehniella*. Differences in total fecundity, developmental time and other statistics related to life history have observed among hosts in different *Trichogramma* species (e.g. Shirazi 2004; Hosseini Bai 2006; Roriz et al. 2006; El-Wakeil 2007). Shirazi (2004) found a shorter developmental time, and a higher daily fecundity in females of *Trichogramma chilonis* on *Corecya cephalonica* compared to its natural host, *Helicoverpa armigera*. Larger *T. brassicae* females with higher fecundity were obtained when reared on the cereal moth compared to the Indian meal moth (Hosseini Bai et al. 2006). An average of 34.55 and 21.61 eggs were laid under non-feeding conditions respectively. Significant differences in fecundity and developmental

time were observed in *Trichogramma cordubensis* on different noctuid hosts (Roriz et al. 2006). El-Wakeil (2007) also found a higher longevity, parasitism and emergence rates on target host *H. armigera* than three factitious hosts.

The gross and net reproductive rates, and intrinsic rate of natural increase in *T. brassicae* that were found in the present study are well in the range of *Trichogramma embryophagum* and *Trichogramma pintoi* respectively as reported in the Haghani and Fathipour (2004) and Dadpour Moghanlou (2002) studies. GRR, R_0 and r_m in *T. embryophagum* were 55.24, 48.88, and 0.238 reared on the flour moth, *Ephestia kuehniella* and 41.74, 37.63, and 0.218 when reared on *S. cerealella* respectively (Haghani and Fathipour 2004). On the other hand, the above mentioned parameters in *T. pintoi* were estimated to be 46.30, 45.30, and 0.257 when reared on *A. kuehniella*, and 49.19, 45.68, and 0.281 when reared on *S. cerealella* respectively (Dadpour Moghanlou 2002).

Pratissoli and Parra (2000) calculated these statistics for *Trichogramma pretiosum* and *Trichogramma acacioi* in five constant temperatures, 15, 20, 25, 30 and 35°C. In those temperatures, R_0 was determined to be 13.98, 39.44, 31.53, 54.97, and 15.54 for *T. pretiosum* and 11.85, 62.89, 20.64, 20.42, and 9.36 for *T. acacioi* at each temperature respectively. Furthermore, r_m was calculated as 0.05, 0.21, 0.32, 0.47, and 0.36 in former species while it was 0.05, 0.22, 0.35, 0.34, and 0.30 in later species at the same temperatures respectively. Their results do not

resemble *T. brassicae* in this study totally, but there is some similarity at intermediate temperatures (20–30°C). For example R_0 in *T. acacioi* at 25 and 30 °C, as well as r_m in both species at 20 °C is near to their values in *T. brassicae* on *P. interpunctella* in the present study. Haile and Hassan (1999) found an intrinsic rate of increase of 0.309 in *Trichogramma bournier* reared on *S. cerealella* that is very near to *T. brassicae* reared on *A. kuehniella* in our study.

Birth rates in *T. embryophagum* and *T. pinto* found by Haghani and Fathipour (2004) and Dadpour Moghanlou (2002) were similar to *T. brassicae* in this study, while death rates were a little higher in our study. Both T and DT in our study resemble *T. pinto* found by Dadpour Moghanlou (2002), as one generation took 14.81 and 13.59 days on *E. kuehniella* and *S. cerealella* respectively (Dadpour Moghanlou 2002). It was considerably longer (16.37–16.49 days) in *T. embryophagum* (Haghani and Fathipour 2004). Doubling time in their studies was between 2.46 and 3.77 days in different experiments. Differences observed in all the statistics between the present study and those of the other studies may be due to variation in species and population sources of parasitoid and/or hosts, rearing background, nutritional state, physical conditions and even analytical approaches.

Lower entropy can also result in a higher survival rate when *T. brassicae* is reared on *A. kuehniella*. On the other hand, a significant increase in GRR, R_0 , and b may due to increased reproduction and adaptation of *T. brassicae* to hosts following one generation of rearing. This is in full agreement with van Bergeijk et al. (1989). It should not to be forgotten that the degree of adaptation is not equal in the two hosts and this is why interaction between host and generation was significant in reproductive rates. Absolute change in R_0 was higher in *A. kuehniella*. Indeed, the net replacement rate increased significantly with generation whereas r_m did not suffer parallel changes. This suggests a trade off between R_0 and T. In other words generation time lengthened while fecundity increased and population growth rate remained unchanged.

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References

- Ahmad A, Sivapragasam A. 1984. Parasitism by *Trichogramma australicum* Gir. on *Coryra cephalonica* Stainton eggs of various ages. *Mardi Research Bulletin* 205-210.
- Alizadeh Sh, Ebrahimi E. 2004. Investigation on biology of *Trichogramma pinto* (the egg parasitoid of winter moth) on laboratory host. *Proceedings of the 16th Iranian Plant Protection Congress*, Vol. 1: *Pests* p. 79. 28 Aug.–1 Sept. 2004, University of Tabriz, Tabriz, Iran.
- Andrewartha HG, Birch LC. 1954. *The Distribution and Abundance of Animals*. The University of Chicago Press.
- Attaran MR, Shojai M, Ebrahimi E. 2000. Effect of hosts and feeding on the longevity and the number of egg deposited by *Trichogramma brassicae*. *Proceeding of the 14th Iranian Plant Protection Congress*, Vol. 1: *Pests*, p. 173. 5-8 Sept. 2000, Isfahan University of Technology, Isfahan, Iran.
- Behdad E. 2002. *Introductory Entomology and Important Plant Pests in Iran*. Yadbood Pub, Isfahan, Iran.
- Bigler F, Wajnberg E, Hassan SA. 1994. Quality control in *Trichogramma* production. 1-36. *Biological Control with Egg Parasitoids*. Wallingford. CAB International.
- Bournier JP. 1982. Behaviour of various strains of *Trichogramma* towards eggs of *Heliothis armigera* (Lep. Noctuidae) and *Chilo* sp. (Lep. Pyralidae). *Les Trichogrammaes, le Symposium International*, pp. 85-96. Antibes 20–23 April, Paris, France
- Brower JH. 1983. Eggs of stored products Lepidoptera as hosts for *Trichogramma evanescens* (Hym. Trichogrammatidae). *Entomophaga* 28: 355-362.
- Carey JR. 1993. *Applied Demography for Biologists with Special Emphasis on Insects*. Oxford University Press.
- Dadpour Moghanlou H. 2002. An investigation on the Host-Parasitoid system between *Trichogramma pinto* (Voegelé) and the Mediterranean Flour and Angoumois Grain Moth, in laboratory conditions. *M.Sc. thesis of Entomology*. College of Agriculture, Tarbiat Modares University.
- Dimitrius L. 1978. Adaptive value, entropy, and survivorship curves. *Nature* 257: 213-214.
- Dent DR, Walton MP. 1997. *Methods in Ecological and Agricultural Entomology*. CAB International.
- Dutton A, Cerruti F, Bigler F. 1996. Quality and environmental factors affecting *Trichogramma brassicae* efficiency under field conditions. *Entomologia experimentalis et applicata* 81: 71-79.
- Ebrahimi E. 2004. Investigation and Identification of species of *Trichogramma* Westwood in Iran. In: Azema M, Mirabzadeh A, editors. *Issues on Different Aspects of Applying Natural Enemies for Biological Control of Insect Pests*, pp. 1-71. Nashre Markaz, Tehran, Iran.
- Ebrahimi E, Pintureau B, Shojai M. 1998. Morphological and enzymatic study of the genus *Trichogramma* in Iran (Hym. Trichogrammatidae). *Applied Entomology and Phytopathology* 66: 122-141.
- El-Wakeil NE. 2007. Evaluation of efficiency of *Trichogramma evanescens* reared on different factitious hosts to control *Helicoverpa armigera*. *Journal of Pesticide sciences* 80: 29-34.
- Farazmand A, Iranipour Sh. 2006. Functional response of *Trichogramma brassicae* Bez. (Hym.: Trichogrammatidae) to different densities of *Anagasta kuehniella* Zell. and *Plodia interpunctella* Hub. eggs in laboratory condition. *Proceedings of the 17th Iranian Plant Protection Congress*, Vol. 1: *Pests*, p. 173. 2-5 Sept. 2006, Campus of Agriculture and Natural resources, University of Tehran, Karaj, Iran.
- Greenberg SM, Nordlund DA, Zhizin Wu. 1998. Influence of rearing host on adult size and ovipositional behavior of mass produced female *Trichogramma minutum* Riley and *Trichogramma pretiosum* Riley (Hym.: Trichogrammatidae). *Biological Control* 11: 43-48.

- Haghani M, Fathipour Y. 2004. Effective kind of laboratory host on Population growth parameters of *Trichogramma embryophagum*. *Journal of Agricultural Sciences and Natural Resources* 10: 117-124.
- Haile AT, Hassan SA. 1999. *Life table parameters of two Kenyan locally occurring Trichogramma species*. Available online at <http://www.bba.de/abstracts/hum>
- Hichata K, Hirose Y, Kimoto H. 1976. The effect of host age on the parasitism by three species of *Trichogramma* (Hym. Trichogrammatidae), egg parasitoid *Papilio xuthus* L. (Lep. Papilionidae). *Japanese Journal of Applied Entomology Zoology* 20: 31-36.
- Hintz JL, Andow DA. 1990. Host age and host selection by *Trichogramma nubilale*. *Entomophaga* 35: 14-150.
- Hosseini Bai Sh, Yazdani Khorasgani A, Mashhadi Jafarloo M. 2006. The determination of body size of *Trichogramma brassicae* on *Sitotroga cerealella* and *Plodia interpunctella* and it's relation with wasp's fecundity and longevity. *Proceedings of the 17th Iranian Plant Protection Congress*, Vol. 1: *Pests*, p. 17. 2-5 Sept. 2006. Campus of Agriculture and Natural resources, University of Tehran, Karaj, Iran.
- Houseweart MW, Southard G, Jennings DT. 1982. Availability and acceptability of spruce budworm eggs to parasitism by the egg parasitoid, *Trichogramma minutum* (Hym. Trichogrammatidae). *Entomophaga* 25: 95-103.
- Jeffry YH, Robert FL. 2000. Age and suitability of *Amorbia cuneana* (Lep. Tortricidae) and *Sabulodes aegrotanta* (Lep. Geometridae) eggs for *Trichogramma platneri* (Hym. Trichogrammatidae). *Biological Control* 18: 79-85.
- Karimian Z. 1999. Biology and ecology of parasitoid wasp *Trichogramma brassicae* in Guilan's Rice fields. *MSc thesis of Entomology College of Agriculture*. Guilan University, Gilan, Iran.
- Karimi Malati A, Hatami B, Seyedoleslami H, Salchi L. 2004. Effect of sugar and protein diets on fecundity of *Trichogramma brassicae* Bezdenko (Hym.: Trichogrammatidae). *Proceedings of the 16th Iranian Plant Protection Congress*, Vol. 1: *Pests*, p. 65 28 Aug.-1 Sept. 2004. University of Tabriz, Tabriz, Iran.
- Laing JE, Eden GM. 1990. Mass production of *Trichogramma minutum* Riley on factitious host eggs. *Memoirs of the Entomological Society of Canada* 153: 10-24.
- Lewis WJ, Redlinger LM. 1989. Suitability of eggs of the almond moth, *Cadra cautella*, of various ages for parasitism by *Trichogramma evanescens*. *Annales of the Entomological society of America* 65: 1482-1484.
- Li LL. 1994. *Worldwide Use of Trichogramma for Biological Control on Different Crops*. CAB International.
- Mansfield S, Mills NJ. 2002. Direct estimation of the survival time of commercially produced adult *Trichogramma platneri* Nagarkatti (Hym. Trichogrammatidae) under field conditions. *Biological Control* 25: 41-48.
- Messenger PS. 1964. Use of life tables in a bioclimatic study of an experimental aphid-braconid wasp host-parasite system. *Ecology* 45: 119-131.
- Meyer JS, Ingersoll CG, Mc Donald LL, Boyce MS. 1986. Estimating uncertainty in population growth rates: Jackknife vs. Bootstrap techniques. *Ecology* 67: 1150-1166.
- Monje JC, Zebit CPW, Ohnesorje B. 1999. Host and host age preference of *Trichogramma galloi* and *T. pretiosum* (Hym. Trichogrammatidae) reared on different hosts. *Journal of Economic Entomology* 92: 97-103.
- Noldus LPJJ, Lewis WJ, Tumnilson JH. 1990. Beneficial arthropod behavior mediated by airborne semiochemicals. IX. Differential response of *Trichogramma pretiosum*, an egg parasitoid of *Heliothis zea*, to various olfactory cues. *Journal of Chemical Ecology* 16: 3531-3544.
- Pak GA. 1986. Behavioural variations among strains of *Trichogramma* spp. A review of the literature on host-age selection. *Journal of Applied Entomology* 101: 55-64.
- Parra JRP, Zucchi RA, Silveiraneto S. 1987. Biological control of pests through egg parasitoids of the genera *Trichogramma* and *Trichogramatoidea*. *Memorias do Instituto Oswaldo Cruz* 82: 153-160.
- Praissoli D, Parra JRP. 2000. Fertility life table of *Trichogramma pretiosum* (Hym. Trichogrammatidae) in eggs of *Tuta absoluta* and *Phthorimaea operculella* (Gelechiidae) at different temperatures. *Journal of Applied Entomology* 124: 339-342.
- Reznik SYa, Umarova TYa. 1990. The influence of hosts' age on the selectivity of parasitism and fecundity of *Trichogramma*. *Entomophaga* 35: 31-37.
- Roriz V, Oliveira L, Garcia P. 2006. Host suitability and preference studies *Trichogramma cordubensis* (Hymenoptera: Trichogrammatidae). *Biological Control* 36: 331-336.
- Ruberson JR, Timothy JK. 1992. Parasitism of developing eggs by *Trichogramma pretiosum* (Hym. Trichogrammatidae): host age preference and suitability. *Biological Control* 3: 39-46.
- SAS Institute Inc 1999. *SAS/STAT user's Guide, Ver. 7*. SAS Institute Inc.
- Sepasgozarian H. 1966. *Storage Pests of Iran and Their Control*. University of Tehran Pub., Tehran, Iran.
- Shirazi J. 2004. Effects of factitious host *Corcyra cephalonica* (St.) and natural host *Helicoverpa armigera* (Hub.) eggs on some important biological characters of *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae). *Proceedings of the 16th Iranian Plant Protection Congress*, Vol. 1: *Pests*, p. 14. 28 Aug.-1 Sept. 2004. University of Tabriz, Tabriz, Iran.
- Shojai M, Ostovan H, Khodaman AR, Hosseini M, Daniali M, Seddighfar M, Nasrollahi AA, Labbafi Y, Ghavam F, Honarbakhsh S. 1998. An investigation on beneficial species of *Trichogramma* spp. (Hym., Trichogrammatidae), active in apple orchards, and providing optimum conditions for mass production in laboratory cultures. *Journal of Agricultural Sciences, Islamic Azad University* 16: 5-39.
- Slobodkin LB. 1980. *Growth and Regulation of Animal Populations*, 2nd edition. Dover Press.
- Smith SM. 1996. Biological control with *Trichogramma*: advances, successes, and potential of their use. *Annual Review of Entomology* 41: 375-406.
- Sorokina AP. 1999. Trophic links of species of the genus *Trichogramma* West. (Hym. Trichogrammatidae) of the world fauna. *Entomological Review* 79: 125-132.

- Van Bergeijk KE, Bigler F, Kaashoek NK, Pak GA. 1989. Changes in host acceptance and host suitability as an effect of rearing *Trichogramma maidis* on a factitious host. *Entomologia experimentalis et applicata* 52: 229-238.
- Van Driesche RG, Bellows TS. 1996. *Biological Control*. Chapman and Hall.
- Van Lenteren JC, Woets J. 1988. Biological and integrated pest control in greenhouses. *Annual review of Entomology* 33: 239-269.
- Van Lenteren JC, Roskam MM, Timmer R. 1997. Commercial mass production and pricing of organisms for biological control of pests in Europe. *Biological Control* 10: 143-149.