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Comparative study of two sex life table parameters of *Encarsia formosa* Gahan (Hym.: Aphelinidae) vs. *Bemisia tabaci* (Hem.: Alyrodidae)

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Abstract
To provide reliable information concerning reproductive potential of *Encarsia formosa* and its Host (*Bemisia tabaci*), their related life tables were studied under controlled laboratory conditions. The unprocessed data of life tables were analyzed taking the Euler-Lotka as the basic model. Standard error of population growth parameters was calculated using the Boot strap re-sampling method. The intrinsic rate of increase (r_m) of parasitoid was 0.09±0.0031day^{-1}. Other table parameters, including net reproductive rate (R_0), mean generation time (T), the finite rate of increase (λ) were estimated as 19.62±1.62 offsprings, 32.79±0.34 d, 1.08±0.0034 d^{-1}, respectively. These parameters were estimated for *B. tabaci* as: r_m= 0.12.±0.01 d^{-1}, R_0= 20.68±2.25 offspring, T = 27.22±0.28 d, λ = 1.11±0.0048 d^{-1}. A comparison of the two life table parameters showed that there are significant differences between life table parameters of *E. formosa* and those of *B. tabaci*. In all cases, *B. tabaci* exhibited a more prominent reproductive trait.

Keywords: Biological control, Euler-Lotka, Intrinsic rate of increase, Life table

Introduction
Bemisia tabaci is secondary pest of cotton plays an important role in the ecosystem and food chain. In fact, its honeydew is a food source for many arthropods. In addition to *B. tabaci* is used as a host or prey for many parasitoids and predators [8]. However this insect pest transfers more than 100 plant viruses [6]. One of the parasitoids that have been considered for use in the IPM program is *Encarsia formosa* (Gahan) [9] (Hymenoptera). Several studies on the use of *E. formosa* for *B. tabaci* on different plants in greenhouse suggest this parasitoid is effective [13]. There was a need to evaluate the ability of *E. formosa* to control *B. tabaci* on cotton crops. Therefore, it became important to increase the use of effective biological control agents that can efficiently control the pest, are safe for the environment and are acceptable to farmers and greenhouse growers [14, 5]. *E. formosa*, a uniparental, thelytokous hymenopteran parasitoid [1, 11], was first discovered and utilized to control the greenhouse whitefly, *Trialeurodes vaporariorum*, in greenhouses in England [19]. Although able to successfully parasitize *B. tabaci*, *E. formosa* is not as effective in controlling this pest species of whitefly as in controlling *T. vaporariorum* [1, 7, 12, 19]. Here we describe the biological parameters of *Bemisia tabaci* with duration of *E. formosa* development and parasitoid longevity [10]. We also provide evidence that why *B. tabaci* is not a more suitable host for *E. formosa* than is *T. vaporarum*. We compare of the two life table parameters of *E. formosa* and *B. tabaci* According to Southwood (1966) [17, 22]. One of the most complete parameters is intrinsic rate of increase. Intrinsic rate of increase (r_m) depends on fecundity, development duration and growth rate. This parameter is used to determining fitness of natural enemies such as *E. formosa*. So far, there are not studies about comparing *E. formosa* life table with *B. tabaci*. This information will be useful for using the *E. formosa* to control *B. tabaci* on cotton.

Materials and methods
Insect
Bemisia tabaci
Cotton crops (Sahel variety) were planted in the pots were placed in the net covered cages (75cm×75cm×75cm) in a controlled greenhouse conditions at temperature of 27±1 °C, 60%

relative humidity, 16 h light: 8 h dark photoperiod. Plants with 6 leaves were used for experiment. The whiteflies, *B. tabaci* (Hemiptera: Alyrodidae) originally were collected from cotton fields of Golestan Provence, Gorgan city, Iran, and were reared on cotton plants.

Life table study of *Bemisia tabaci* on cotton

100 eggs of *B. tabaci* were collected randomly cotton and numbered for the next assessment. First instar nymphs of *B. tabaci* slowly move and then fixed. Pupa did not have nutrition thus we kept them separately in micro-capsules till adults emergence. Larval mortality and development were checked every 12-h until the adult stage. The life cycle was studied during May to July 2014. After the emergence of adults, males and females were paired and checked daily to record survival and number of eggs laid until females dead.

Encarsia formosa

Third instar nympha (120 individuals) of *B. tabaci* that had developed on the cotton were individually exposed to a single attack (0-24 hold) by *E. formosa* that were held in an individual cage with 10% sugar water. After 5 days (expected delay for egg eclosion at minimum temperature 19ºC), 10 presumably parasitized whitefly were randomly selected for dissection to determine egg eclosion incidence. When whiteflies blacked indicating parasitoid survival to the pupal stage started, checking frequency was increased to 3 per day, and newly blacked pupa were placed in individual gelatin capsules. This allowed determination of emergence success, development time from egg to pupation, and from pupation to emergence.

Developmental time of all individuals (egg + larva), pupa and Adults including males (is rarely observed in the parasitoid), females and those dying before the adult stage, and female daily fecundity were analyzed according to the age-stage, two-sex life table theory [2]. The following population parameters of each cohort were estimated:

Reproductive Rate (*R*$_0$)

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

And intrinsic rate of increase (*r*)

$$\sum_{x=0}^{\infty} e^{-1(x+1)} l_x m_x = 1$$

Mean Generation Time (*T*)

$$T = \text{In}\frac{R_0}{r}$$

And Finite Rate of Increase

$$\lambda = e^r$$

Data analysis and population parameters (r, R_0, T, GRR and λ) were calculated using the TWOSEX-MSChart program [4]. The TWOSEX-MSChart is available in http://140.120.197.173/Ecology/prod02.htm (Chung Hsing University). The means and standard errors of the life table parameters were estimated using the bootstrap techniques embedded in the TWOSEX-MSChart [4, 15]. Survival, fecundity and reproductive values curves were constructed using Sigma Plot 11.0. We used student t-test to determine differences between results of the population parameters of two treatments [21, 16].

Results and discussion

The life table parameters were calculated based on data of the entire cohort, i.e., both sexes and the variable developmental rates among individuals. Calculated parameters and standard errors of the intrinsic rate of increase (*r*), net reproductive rate (R_0), mean generation time (*T*), and the finite rate of increase (*λ*) obtained using age-stage specific two sex model are shown in Table 1. Statistical analysis indicated that there were significant differences in *r*, R_0 and *T* between the both *E. formosa* and *B. tabaci* calculating by the t-test (P<0.05). The lower developmental time and earlier oviposition of *B. tabaci* was due to the larger intrinsic rate of increase (*r*). Also the mean generation time (*T*) in *E. formosa* was longer than that in *B. tabaci*.

Pre-adult developmental time (egg+larva+pupa) of *E. formosa* on cotton was 23.05 days,. Thus developmental time of *B. tabaci* (17.44) was significantly lower than that *E. formosa* (Table 2). *B. tabaci* on cotton reached the adult stage faster and started to lay egg sooner than that *E. formosa*. Also amount of eggs per female *B. tabaci* was more than *E. formosa*, significantly (Table 2).

The life table parameters are shown in Table 1. Statistical analysis demonstrated that there were significant differences in all the parameters (P<0.05). The intrinsic rate of increase (*r*), the finite rate of increase (*λ*), the net reproductive rate (R_0) of *E. formosa* were less than *B. tabaci*. However the mean generation time (*T*) of *E. formosa* was longer than that *B. tabaci*. The higher

A number of plant factors such as plant species and morphological features can affect the efficiency of *E. formosa* [14, 18, 20]. Intrinsic rate of increase (*r*) in the *E. formosa* rearing on *B. tabaci* was smaller than *B. tabaci*. This indicated that *E. formosa* grows slower on the *B. tabaci*. The relatively poor host attribute of the *B. tabaci* for *E. formosa*, causing delay in the development. The *B. tabaci* has different characteristics that effect on the life table parameters (*T*, *r*, λ).

The age-specific survival rate calculated according to Chi and Liu (1985) [2] is defined as: $l_x=\sum_{j=1}^{\beta} Sxj$ where β is the number of stages. In fact l_x is a simplified form of s_{xj} and shows how survivorship decreased with age. As shown in the Figure 1, age specific survival rate (*lx*) had not similar trend in both (*B. tabaci* and *E. formosa*). age-specific fecundity of the total population (m_x) of *B. tabaci* is calculated higher than that on *E. formosa*.

The intrinsic rate of increase of parasitoid is dependent on dependent on whitefly size, high trachoma densities, excessive honeydew, encounters with nymphs suitable for host feeding and parasitism, decreasing temperature, low barometric pressure, and smaller egg loads [13]. In this present study, there was significant difference in pre-adult (*B. tabaci* and *E. formosa*) development times. The mean total fecundity of *E. formosa* was relatively lower than the fecundity of *B. tabaci*. Peak of m_x on *B. tabaci* is higher than *E. formosa* but occurred same day. The mean generation time of *E. formosa* was significantly lower than *B. tabaci*.

In this study the comparing life table parameters *Bemisia tabaci* with *E. formosa* was investigated *B. tabaci* was not suitable host for *E. formosa*. Smaller r (intrinsic rate of increase) in *E. formosa* indicated that parasitoid grows slower than *B. tabaci*. Intrinsic rate of increase of *B. tabaci* is more than intrinsic rate of increase *of E. formosa.* Ultimatly, the decision on the fiteness of *E. formosa* depends on future studies. Unfortunately, articles is not available that simultaneously compare life table parameters of *B. tabaci* and *E. formosa*.

Table 1: Life table parameters (mean ± SE) of *Bemisia tabaci* and *Encarsia formosa* cotton at 27ºC.

Parametrs	*Bemisia tabaci*	*Encarsia formosa*	*t*-student	*P*
r (day^{-1})	0.12±0.01	0.09±0.0031	2.020	0.032*
λ (day^{-1})	1.11±0.0048	1.08±0.0034	1.202	0.04*
R_0 (offspring/individual)	20.68±2.23	19.62±1.62	2.028	0.04*
T (day)	27.22±0.28	32.27±0.34	9.971	0.0001*

*(P<0.05) significance level

Table 2: Life history statics (Mean ± SE) of *Bemisia tabaci and Encarsia formosa* at 27ºC.

	Pupa (days)	Total preadult (days)	Fecundity (eggs/females)
Bemisia tabaci	4.6±0.03	17.44±0.83	0.75±45.12
Encarsia formosa	10.09±0.01	23.05±0.5	0.80±24.14
t-student	5.09	11.98	14.23
p	<0.0001	<0.0001	<0.0001
df	173	167	165

Means in a column followed by different letters are significantly different (P < 0.05) (t-test).

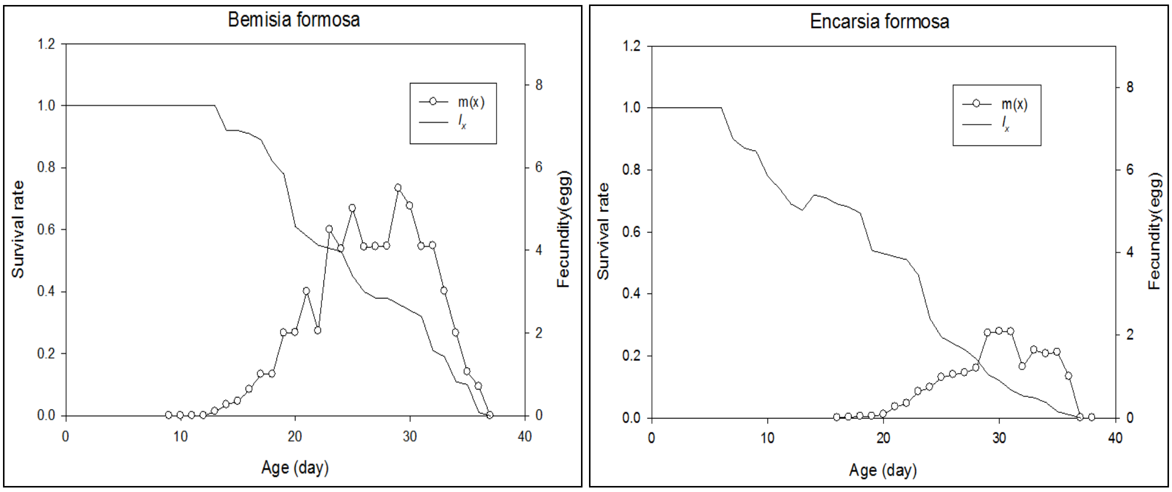

Fig 1: Age-specific survival rate (l_x) and age-specific fecundity (m_x) of *B.tabaci* and *E. formosa*.

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