

HOST AGE PREFERENCE AND TEMPERATURE-DEPENDENT SEARCHING EFFICIENCY OF *Encarsia citrina*, A PARASITOID OF *Unaspis euonymi* IN AUSTRIA.

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ABSTRACT

Encarsia citrina (Craw.) is considered as a promising parasitoid to be used as a bio-agent against the cosmopolitan diaspidid insect, *Unaspis euonymi* (Comstock). Laboratory studies were carried out to determine 1) the ovipositional preference of *E. citrina* for host's age by exposing it to 5-20 day- old scales 2) effect of temperature (17.5, 20, 25, and 28°C) and parasitoid's density (1, 2, 3, 4, and 5 females/30 hosts) on host searching efficiency of *E. citrina*. *E. citrina* significantly preferred 10 day-old scales with the highest emergence rate. Temperature had significant effect on the searching efficiency of *E. citrina* over the range of 17.5–28°C. The highest rate of search was obtained at 20°C. Although increasing parasitoid density at 20°C reduced progeny production in *E. citrina* due to the increase of mutual interference, it was able to distribute its eggs among the hosts more regularly. The highest values of killing (k-value) were also obtained at 20°C and the ratio of 4 parasitoid females/30 hosts. The shortest and longest handling time (T_h) was measured at 20 and 17.5°C, respectively. Accordingly, 20°C is suitable condition to *Encarsia* reproductive and activity. *E. citrina* seems to be a good candidate to control *U. euonymi* from late spring to early summer as well as during autumn in regions like Austria, where the temperature is frequently around 20°C. Therefore, parasitoid releases within these seasons on the early 2nd instar (10 days old) with a ratio of 1 parasitoid: 7.5 hosts have to be considered in the future biocontrol program of *U. euonymi*.

Keywords: Search rate, Killing power, Mutual interference, Handling time.

INTRODUCTION

The cosmopolitan polyphageous aphelinid wasp, *Encarsia citrina* (Craw.) has a worldwide distribution (Viggiana 1990; Malipatil et al. 2000). It is a primary solitary endoparasitoid, proovigenic, and thelytokous (Cooper and Oetting 1987; Malipatil et al. 2000). It is capable of parasitizing both male and female of *Euonymus* scale (Matadha et al. 2005). There are very few studies that record the influence of *E. citrina* on the control of some diaspidid scales in the field. For example, McClure (1978) reported $\approx 88\%$ parasitism of *Fiorinia externa* Ferris and *Nuculaspis tsugae* (Marlatt) populations on eastern hemlock by *E. citrina* in Connecticut.

The *Euonymus* scale, *Unaspis euonymi* (Comstock) (Hemiptera: Diaspididae), is a serious pest of several ornamental shrubs (Gill et al. 1982; Özyurt and Ülgentürk 2007). It is an economically important pest of ornamental plants in urban landscapes (Kosztarab 1996; van Driesche et al.

1998) and attacks a wide range of plants (Kozár 1998). Van Driesche et al. (1998) estimated the annual economic losses caused by *U. euonymi* at approximately \$355,568 in Massachusetts and at approximately \$711,135 for the entire southern region of New England. Heavy infestations can result in senescence and abscission of premature leaf, followed by branch dieback and death of plants (Gill et al. 1982; Cockfield and Potter 1987, 1990; Sadof and Neal 1993). Generally, this insect develops large populations that are very difficult to control by using insecticides because of limitations of timing and coverage of plants (Sadof and Sclar 2000). From previous literature, it had not been studied before in Austria and the time of its entry is unknown.

A host's developmental stage is known to affect parasitoid fitness and encounter rates (van Driesche and Bellows 1996; Murdoch et al. 1997). The choices of female for oviposition can greatly affect the survival and development of its offspring (Thompson and Pellymyr 1991; Awmack and Leather 2002; Réale and Roff 2002). Moreover, various studies have shown the importance of temperature as an influential factor affecting the range of a parasitoid's efficiency (Logen et al. 1976; Schoolfield et al. 1981; Briere et al. 1999; Matadha et al. 2004). Such studies are important in understanding the dynamics of parasitoid-host interactions (Hassell 1982; Kfir and Podoler 1983). More importantly, they may contribute toward enhancing the quality of mass rearing and provide a quantitative basis for predicting development and activity in pest management programs (Huffaker and Messenger 1976).

Although *E. citrina* is well known to attack *Euonymus* scale by several authors (Gill et al. 1982; Rebek and Sadof 2003; Özyurt and Ülgentürk 2007), there are no documented studies on the influence of *Euonymus* scale age and temperature on its searching efficiency. Only Matadha et al. (2005) studied the effect of temperature on some biological aspects of *E. citrina* using the alternate diaspidid host, *Quadraspidotus perniciosus* (Comstock). Therefore, the main objectives were to determine 1) the preferred host age of *Euonymus* scale for *E. citrina* oviposition, 2) the optimal temperature range required by the parasitoid that maximizes its efficiency in both mass rearing and augmentative biological control programs for *Euonymus* scale.

MATERIALS AND METHODS

1. Host and parasitoid culture

The *Euonymus* scale, *U. euonymi* was cultured in the laboratory of Forest Entomology, Forest Pathology, and Forest Protection Institute (IFFF), University of Natural Resources and Applied Life Sciences, Vienna, Austria. Crawlers were collected from ligustrum trees, *L. japonicum* which have not been treated with insecticides and located in some houses' gardens of Vienna during early of May, 2007.

Euonymus scale, *U. euonymi* is biparental and was reared on ligustrum leaves. To have available host stock, groups of *U. euonymi* crawlers were transferred to ligustrum leaves during the peak of their occurrence for 24 h feeding period in Petri-dishes containing water saturated

cotton. Cotton was renewed every 5 days. Each dish contained 3 leaves. The dishes were incubated at $25\pm 1^{\circ}\text{C}$ and 16 L: 8 D photoperiod and controlled daily until scales' crawlers reached their 2nd instar. To rear the parasitoid, *E. citrina* wasps were collected in the pupal stage from heavily infested ligustrum trees with *Euonymus* scales in Vienna at mid- May, 2007. Adult females were introduced on ligustrum leaves artificially infested with *Euonymus* scales in Petri-dishes for 24 h ovipositing period, and then the dishes were incubated under the same previous conditions for rearing *Euonymus* scale until parasitoids' eggs reached their pupal stage. The host body containing parasitoid pupa was separated from its host cover by a pin and small camel's- hair brush and placed in small plastic tubes (0.5 cm in diameter and 3 cm in height). The tubes were marked and stored at room temperature until adult emergence.

2. Influence of host age on ovipositional preference

To study the influence of *Euonymus* scale ages on the oviposition preference for *E. citrina* and its emergence, ligustrum leaf was divided into four equal parts using sticky material (Tangle foot). The neck of each leaf was placed in Petri-dish containing water saturated cotton. Each part was infested by 15 crawlers (1st instar) five days interval. Prior to the parasitoid release, each infested leaf transferred to empty Petri-dish. At the time of release, the crawlers in the first part were 5 days old, in the second part were 10 days, in the third were 15 days, and in the fourth were 20 days old. The setup of infested leaves changed in rotation to avoid parasitoid aggregation in any part. Four *E. citrina* females (48 h old) were introduced into each Petri-dish for 24 h ovipositing period. Water saturated cotton pieces and honey streaked on small self adhesive paper strips were used to serve as a food source for the parasitoids. The experiment was replicated ten times. After the removal of parasitoids, each leaf was placed into new Petri-dish containing water saturated cotton (renewed every 5 days) to preserve the leaves. The dishes were incubated at 25°C and 16:8 L:D photoperiod until parasitoid emergences. After 3 weeks of endoparasitic development, the dishes were checked daily for newly emerged parasitoids. After most of wasps had emerged, the hosts' bodies without parasitoid emergence holes were dissected to check their state of parasitization. The numbers of both parasitized scales and emerging parasitoids of each host age class were recorded and proportions were analyzed.

3. Searching efficiency of *E. citrina*

To examine the effect of temperature on searching rates, k-value (Hassell 1978), mutual interference values (Hassell and Varley 1969), instantaneous of attack rate, and handling time (Royama 1971; Rogers 1972) of *E. citrina*; 1, 2, 3, 4 and 5 female wasps were introduced with 30 hosts of *U. euonymi* at various temperature regimes (17.5, 20, 25, and 28°C). Based on results of the ovipositional preference study, *E. citrina* females were provided with 10 day-old *Euonymus* scales on ligustrum leaves in clear plastic boxes (5 x 3 x 4 cm) for 24 h ovipositing period. The parasitoids (48 h old) used in this study were collected in their pupal stage from parasitoid colony. Each parasitoid density was replicated five times. Water was provided

in 2 ml plastic cups with cotton wicks and honey streaked on small self adhesive paper strips to serve as a food source for the parasitoids. After 21 days, the host larvae were investigated, the numbers of living and parasitized scales were recorded.

The area of discovery, which is a measure of searching rate (searching efficiency) of the parasitoid (a_t) was estimated using the formula of Hassell (1978) as follows:-

$$a_t = 1/P \log_e N / N - N_a \quad (1)$$

where P is the number of parasitoids, N the initial number of hosts (i.e. 30), N_a the number of parasitized hosts, and t constant time available for search (1 day).

The relationship between a_t and the density of parasitoids searching for hosts are described by the formula of Hassell and Varley (1969) as follow:

$$a_t = Q P^{-m} \quad (2)$$

where Q is the quest constant or the level of efficiency of one parasitoid (=the area of discovery when the parasitoid density, P, is 1 per unit area) and m the interference constant between searching parasitoids expressed in logarithms, the equation becomes linear as follow:

$$\log a_t = \log Q - m \log P \quad (3)$$

The searching rate (a_t) calculated using Hassell's equation at different parasitoid densities was compared with that calculated on the assumption that the parasitoid female searched randomly and laid a single egg per encounter a^- . The ratio a/a^- was used to assess the degree of aggregation of eggs on the hosts. If this ratio <1.0 implies that a species aggregates its eggs, if =1.0 implies that a species distributes its eggs at random, and if >1.0 implies that a species tends to distribute its eggs more regularly (Kafir and Podoler 1983).

To calculate the assumed search rate, we must first calculate the number of survivors we expect, given the assumptions of random search and a single egg lay per encounter. We used the binomial formula as follow:

$$N_x = N {}^yC_x (1/N)^x (1-1/N)^{y-x} \quad (4)$$

where N_x is the number of hosts containing x eggs, y is the number of encounters with a host or, since we assume a single egg is laid at each encounter, $y=n$ where n is the total number of eggs laid by the parasitoid, and N is the total number of available hosts. yC_x is the number of combinations in which x eggs per host can be obtained given y encounters.

$$N_x = N_0 = N (1-1/N)^n \quad (5)$$

N_0 was calculated by use of equation (5) and estimates N- N_a in equation (1).

To estimate the time required for handling hosts, we used a random parasitoid equation which developed concurrently by Royama (1971) and Rogers (1972) as follow:

$$N_a = N_0 [1 - \exp(-a T P / 1 + a T_h N_0)] \quad (6)$$

Where N_a is the number of host attacked, T the time of exposure, P the parasitoid density, a the rate of successful attack, and T_h the handling time.

The effectiveness of parasitoid at different parasitoid densities and temperatures was estimated as killing power (k-value) using formula of Hassell (1978) as follow:

$$K = \log N / N - N_a \quad (7)$$

4. Statistical analysis

Proportion of scale parasitized and emerged wasps of *E. citrina* was analyzed between the different host ages using one-way ANOVA and means compared by LSD at $\alpha=0.05$ using Student-Newman Keul's Test. Proportion of progeny per female and day, searching rate (a_t), k - values, and the searching rate (a/a^*) of *E. citrina* across different temperatures and parasitoid densities were analyzed using two- way ANOVA. When significant difference was detected, mean were compared using Student-Newman Keul's Test ($\alpha=0.05$). To measure mutual interference values (m), and to study rate of reduction in parasitoid production (b), linear regression analysis at $\alpha=0.05$ probability level was performed between searching rate ($\log a_t$), as well as proportion of progeny per female per day (dependent variable) and parasitoid density ($\log p$) (independent variable) at different temperatures. All statistics were performed using CoStat 6.3 software for Windows (CoStat 2005).

RESULTS

1. Influence of host scale age on ovipositional preference

E. citrina showed a significant preference ($F_{3,36}=38.53$; $P<0.001$) for 10 day-old *Euonymus* scales. However, adult emergence rate exhibited significant value ($F_{3,36}=5.13$; $P<0.001$) for 10 day-old scales. The proportion of emerging adults from 5 day old scales significantly differed from those emerging from 10, 15, and 20 day-old scales (Fig. 1).

2. Temperature-dependent searching rate of *E. citrina*

2.1. Searching efficiency

At the four tested temperatures, by increasing parasitoid density, the searching rates (*i.e.*, oviposition rates) of *E. citrina* significantly decreased resulting from increased mutual interference ($P<0.05$; Figs. 2 and 3). The highest rate search was at 20°C; however the searching rate significantly decreased at this condition (Figs. 2 and 4a). The slopes of the relationship between searching rate and parasitoid density were homogeneous at different temperatures ($P>0.05$). At 20°C, by increasing parasitoid density, the rates of search of *E. citrina* were significantly decreased apparently due to the highest value of mutual interference ($P<0.001$) (Figs. 2 and 4b and Table 1). Temperature, parasitoid density, and the interaction between temperature and parasitoid density had a high significant effect on searching rates by *E. citrina* (respectively, $P<0.001$, $P<0.001$, and $P<0.05$) (Fig. 4a).

Using Holling's model to estimate the parameters related to searching efficiency {instantaneous attack rate (a), handling time (T_h), and the estimated maximum number of parasitized hosts (T/T_h)}, *E. citrina* showed maximum performance at 20 and 25°C (Table 2). This implies that this range is most favorable for *Encarsia* activity and reproduction

Table 1: Mutual interference among foraging *Encarsia citrina* wasps at different temperatures resulting from Hassell and Varley equation ($\log a_t = \log Q - m \log P$).

Temperature (°C)	Mutual interference (m)	Quest constant (log Q)	Coefficient of determination (r ²)
17.5	-0.83	-0.72	0.93
20	-1.01	-0.48	0.87
25	-0.79	-0.71	0.86
28	-0.94	-0.94	0.74

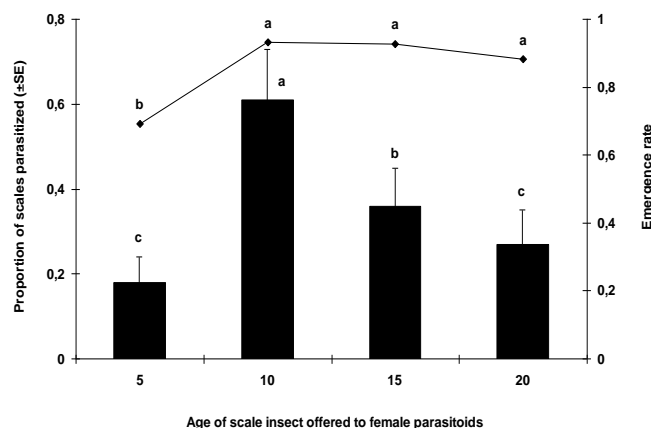


Fig. 1. Proportion of euonymus scales (5-20 day-olds) attacked by *E. citrina* in separate choice designs. Sixty scales were exposed to five parasitoid females (48 h old) for 24 h ovipositing period, at $25 \pm 1^\circ\text{C}$ and 16L: 8D photoperiod. Values labeled with the diverse letters are significantly different.

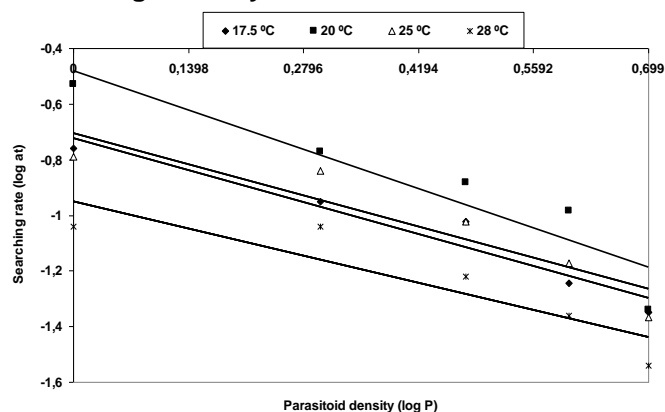


Fig. 2. Searching rates among foraging *Encarsia citrina* o at different temperatures. The parameters P, is the parasitoid density and a, is the searching rate of individual parasitoid.

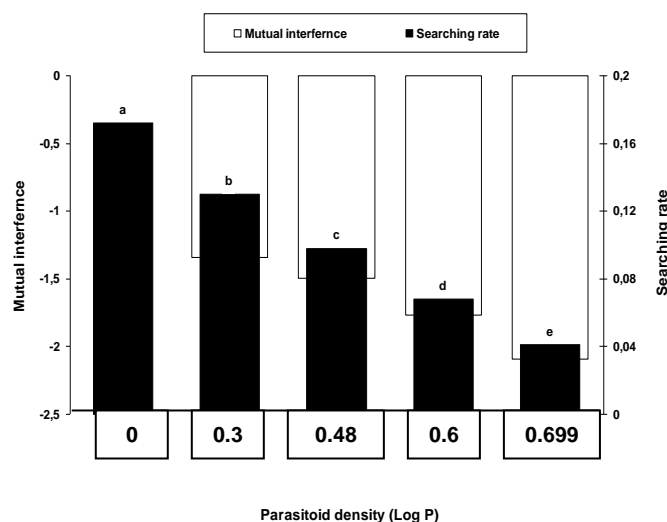


Fig. 3. Searching rate and mutual interference values at different parasitoid densities at 20°C. Values labeled with the diverse letters in black column are significantly different ($P < 0.05$).

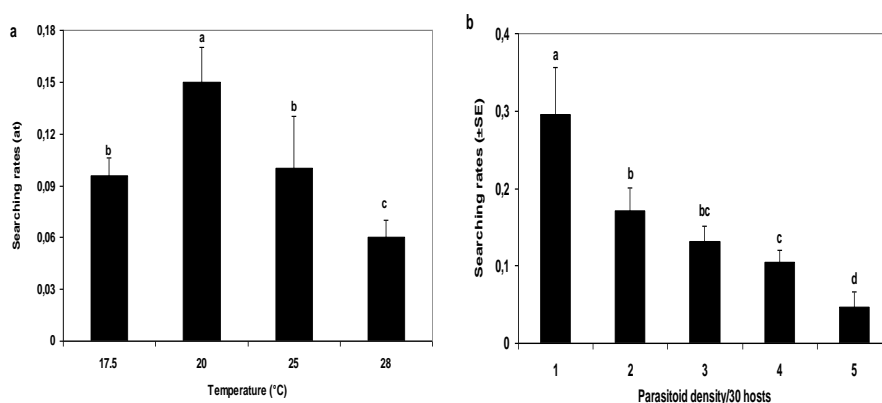


Fig. 4. Effect of temperature (a) and parasitoid density at 20°C (b) on searching rate of *Encarsia citrina* on *Unaspis euonymi*. Values labeled with the diverse letters are significantly different.

2.2. K-values

Temperature and parasitoid density had a high significant effect on k-values by *E. citrina*, whereas no significant effect of temperature by parasitoid density interaction on the killing power values by *E. citrina* was recorded (respectively, $P < 0.001$, $P < 0.001$, and $P > 0.05$). The highest value of k was recorded at 20°C (Fig. 5a). At 20°C, by increasing parasitoid density, the values of k significantly increased to a plateau which then levels off under the influence of handling time ($P < 0.05$) (Fig. 5b). This suggests that the ratio of 1: 7.5 parasitoid: hosts in conditions like 20°C might be used in the future bio-control programs.

Table 2: Estimated instantaneous attack rate (a), handling time (T_h), and maximum number of parasitized hosts (T/T_h) of *Encarsia citrina* at different temperatures derived from Holling equation ($T=1$ d).

Temperature (°C)	Instantaneous attack rate (a)	Handling time (T_h , h)	T/T_h	F	P	r^2
17.5	0.044	5.02	5.00	64.9	0.004	0.98
20	0.053	1.86	12.9	55.6	0.005	0.95
25	0.050	3.70	6.43	2134.4	0.001	0.99
28	0.037	6.97	3.44	236.1	0.001	0.99

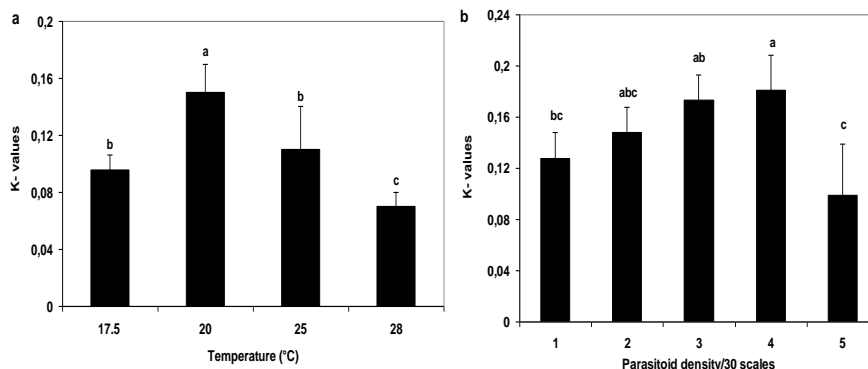


Fig. 5. K- values of *Encarsia citrina* on *Unaspis euonymi* at different temperatures (a) and different parasitoid densities at 20°C (b). Values labeled with the diverse letters are significantly different.

2.3. Egg distribution and oviposition rate

To study the effect of parasitoid density on egg distribution by *E. citrina* in hosts at different temperature, the ratio between observed searching rate and assumed searching rate (a/a') was assessed. Since this ratio (a/a') was greater than 1.0 for all tested conditions, the parasitoid tended to distribute its eggs regularly at different parasitoid densities and temperatures (Fig. 6). Temperature had a high significant effect on oviposition rate (a/a') by *E. citrina* ($P<0.05$). No significant effect of parasitoid density alone and parasitoid density by temperature interaction on oviposition rate (a/a') of *E. citrina* was detected ($P>0.05$ and $P>0.05$). The distribution of parasitoid's eggs was more regular at 20°C than on other temperatures (Fig 7a). At 20°C, the parasitoid distributed its eggs more regularly; however at this condition, no effect of parasitoid density on its egg distribution was performed (Fig. 7b)

Increases in parasitoid's density significantly reduced the oviposition rate per female and day at tested temperatures. The highest rate of this reduction was noted at 20°C (Fig. 8). High significant effect of temperature, parasitoid density, and parasitoid density by temperature interaction on ovipositional rate per female and day of *E. citrina* was observed (respectively, $P<0.001$, $P<0.05$, and $P<0.05$).

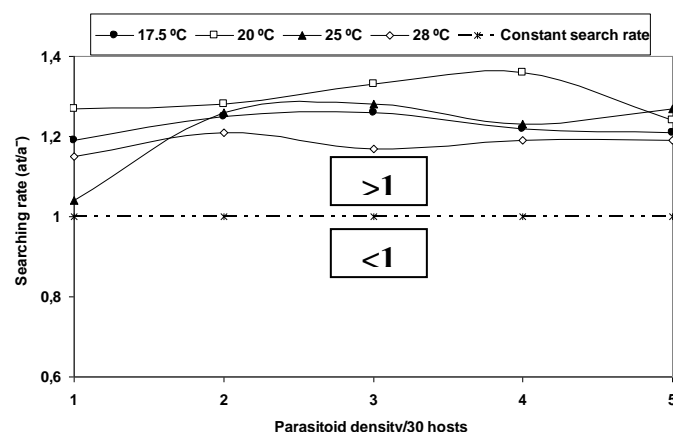


Fig. 6. The relation between *Encarsia citrina* density and the searching rate (a_t/a^-) at different temperatures. Dashed line represents the ratio of 1.0 implying a random distribution and the values for the ratio over 1.0 implying the distribution becomes more regular.

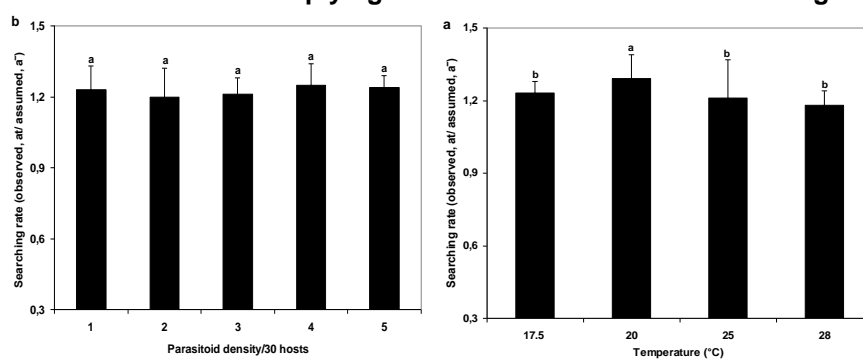


Fig. 7. Effect of temperature (a) and parasitoid density at 20 °C (b) on searching rate (a_t/a^-) of *Encarsia citrina*. Values labeled with the diverse letters are significantly different.

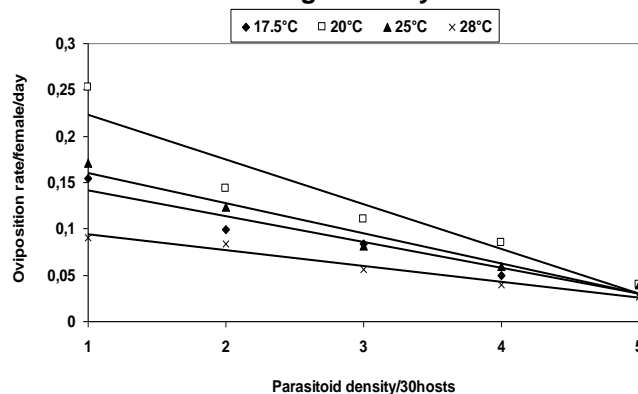


Fig. 8. The relation between parasitoid density and oviposition rate per female and day of *Encarsia citrina* at different temperatures.

DISCUSSION

From the previous literatures (*i.e.* Zhang and Gu 1995; Rebek and Sadof 2003), *E. citrina* preferred 1st and 2nd instar of diaspidid scales. The development of both instars for *Euonymus* scale lasted about 3 weeks (Unpublished data). Accordingly, the host age until 20 day-old was used. In the present study, we found that *E. citrina* generally parasitized all age classes (1st -2nd instars) but significantly preferred early 2nd instar (10 days-old). Similar results were reported in related studies on the ovipositional preference of *E. citrina* and *E. sp. nr. diaspidicola* (Alvarez et al. 1999; Matadha et al. 2005). The seasonal abundance of ovipositing adults of *E. citrina* was closely synchronized with that of first instar scales of *Tsugaspidotus tsugae* (Marlatt) (McClure 1978) and of *Euonymus* scale (Rebek and Sadof 2003). The parasitoid emergence rate was significantly reduced in smaller parasitized host larvae (5 d old). This suggests that scale ages ≤ 5 days may physiologically suitable to develop parasitoid's progeny successfully.

By studying the searching efficiency of *E. citrina* at different temperatures, an attempt to determine the most suitable temperature required by the parasitoid to increase its effectiveness was measured. Matadha et al. (2004) evidenced that 15 and 30°C appear to be lower and upper temperature thresholds for *E. citrina* oviposition and larval development on San Jose scale, *Q. perniciosus*. Contrarily, Logan and Thompson (2002) observed extended development times of ≈ 75 and 125 d, with 95 % emergence of *E. citrina* at 15°C on both greedy and oleander scales, respectively. Accordingly, the effect of these extreme temperatures on the estimated biological parameters did not examine.

The present work studied mutual interference among foraging *E. citrina* and the negative effects of mutual interference on the search rates and progeny production of the parasitoid. Although, *E. citrina* exhibited the highest rates of search at 20°C, it also has the highest value of mutual interference. Moreover, mutual interference values increased as parasitoid density increased. The lowest and highest values of interference were obtained at 1 and 5 parasitoid density/30 hosts. Mutual interference between searching parasitoids is a form of parasitoid density dependence and contributes to the stabilization of a parasitoid-host population dynamics (see Hassell 1978; May and Hassell 1988). The interference between parasitoids must increase with increasing parasitoid density (Hassell 1971). Mutual interference essentially reduces the time available for host searching, and this explains why the searching rate (are of discovery) dropped as parasitoid density increased. In addition, regression analysis showed that by increasing parasitoid densities the rates of search was reduced. As the density of conspecific increases, each parasitoid spends shorter time in searching for hosts and longer time in interacting with the conspecifics it encountered (Royama 1971; Rogers 1972; Hassell 1978). Arditi and Akçakaya (1990) suggested that because the equation used to estimate the search area (Eq. 1) does not take into account the influence of handling time or egg limitation on the parasitism rate of

parasitoids, it often underestimates the mutual interference constant. Based on Arditi and Akçakaya's (1990) suggestion, the estimated mutual interference constant among *E. citrina* females at different densities might be higher than those estimated in the present work. Without complementary behavioral observations, it was unclear if the reduction in parasitism efficiency was caused by mutual interference among foraging parasitoids or from increasing proportion of the total time available for searching and handling hosts. Direct observations showed that a female usually took about 45 s to oviposit in a host; this value is much lower than the values obtained from the experimental data at different temperatures. This is because the estimated time (T_h) also included the period of non-searching activity (e.g., searching, feeding, grooming, and resting) induced by egg depletion and mutual interference. This finding stresses suggestion of Arditi and Akçakaya's (1990), that mutual interference might be higher than those estimated in the present work.

In the current study, *E. citrina* females showed higher progeny production and killing power at 20°C than those at other temperatures. According to Matadha et al. (2004), the optimal temperature range for *E. citrina* development and reproduction was observed between 20 and 25°C. The fecundity of females, the intrinsic rate of increase, r_m , and net reproductive rate, R_0 were higher at 20 than at 25°C. A reduced progeny production per female and day with increasing parasitoid density is a well-known result and is thought to stem from the interference that comes with increasing parasitoid density or comes with increasing proportion of the total time available for searching as host density increased. Such a reduction is also expected to evince itself in reduced search rate (Royama 1971; Rogers 1972; Kafir and Podoler 1983). At 20°C, the parasitoid exhibited a steep slope in the graph of log a against log p, with high search values. In this case, rather high values for the mutual interference were obtained ($m = 1.01$). In addition, the highest rate of progeny production per female and day was observed at 20°C; however the highest rate of reduction in progeny production was also observed at 20°C. The apparent contradiction between a reduced progeny production per female and day and a high search rate at 20°C can be explained by the manner in which the progeny are distributed among hosts at these temperatures. Although the progeny per female and day decreased with increasing parasitoid density, this reduced number was distributed more regularly amongst the hosts at different temperatures ($a/a^* > 1$). Such behavior compensated for the effects of a reduced progeny production on the search rate. Similar responses were observed for *Aphytis holoxanthus* DeBach, *A. lingnanensis* Compere, and *A. melinus* DeBach (Podoler et al. 1978; Kafir and Podoler 1983). The progeny production for *E. citrina* was lower at 17.5 and 28°C than at 20°C. The decrease in temperature causes reduction in the parasitoid population and in the levels of parasitism (Soares et al. 1997). This suggests that *E. citrina* is better adapted to moderate temperatures which of course contradict with its field distribution. Accordingly, *E. citrina* seems to be a good candidate to control *U. euonymi* from late spring to early summer as well as during autumn in regions like Austria, where the temperature is frequently around 20°C. Additionally, the

parasitoid exhibited the highest value of killing at ratio of 4 parasitoids / 30 hosts. This suggests that the ratio of 1:7.5 parasitoid: hosts is an effective ratio for using it in the future bio-control programs.

The ability of *E. citrina* to search and parasitize hosts under field conditions is an important factor influencing the rate of increase in its population, and hence regulating the population of its hosts. This ability is influenced by the age of host and parasitoid-host ratio. Even where wasps offered the suitable age of host, if the capacity to parasitize host is compromised due to the negative effect of unappreciated numbers of the searched wasps (mutual interference), biological control may be not effective. As well, releasing parasitoids in unsuitable environmental temperature could diminish host encounters, and hence its effectiveness. When selecting natural enemies in a biological control program, several searching characteristics should be optimized (Hassell and May 1973; Kafir and Podoler 1983); for example, (a) a high intrinsic searching efficiency, which will reduce the average host population, and (b) a high tendency to distribute its progeny regularly where parasitoid density is highest, so that mutual interference among the parasitoid searches can modify their behavior, leading to the stability of host and parasitoid population.

In conclusion, parasitoid releases on early 2nd instar (10 days old) with a ratio of 1 parasitoid: 7.5 hosts into spring, early summer, and autumn might lead to an effective control of *U. euonymi* in the future. As consequence, the results obtained from this study are an essential step towards building a comprehensive understanding of the parasitoid–host interaction. Similarly, these results at constant temperatures will provide a trend for future research on evaluating the influence of *E. citrina* in urban landscapes under variable environmental conditions. The information obtained here will also contribute to optimizing laboratory-rearing procedures for the parasitoid species and improve augmentation programs using this parasitoid by refining release decisions to achieve higher levels of parasitism.

ACKNOWLEDGMENT

The authors thank Egyptian Cultural Office in Vienna for support this work through a join cooperation scholarship between Mansoura University in Egypt and Universität für Bodenkultur (BOKU) in Vienna, Austria. Thanks are extended to Dr. G. Hoch (IFFF, BOKU) for reviewing the draft of the manuscript and offering helpful comments.

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تفضيل عمر العائل والفاعلية البحثية المعتمدة على الحرارة لطفيل *Encarsia citrina* كطفيل للحشرة القشرية الصلبة *Unaspis euonymi* في النمسا

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يعتبر طفيل *Encarsia citrina* من الطفيليات المتوقعة كعامل مكافحة بيولوجية ضد الحشرة القشرية الصلبة *Unaspis euonymi*. أجريت دراسات معملية لتحديد (١) عمر العائل المفضل للطفيل لوضع البيض وذلك عن طريق تعريض الطفيل لحشرات عمرها يتراوح بين ٥-٢٠ يوم (٢) تأثير درجات الحرارة (١٧,٥ و ٢٠ و ٢٥ و ٢٨ °م) وكثافة الطفيل (١ و ٢ و ٣ و ٤ و ٥ انثى/حشرة) على الفاعلية البحثية للطفيل. أبدى الطفيل تفضيل معنوي للحشرات التي عمرها ١٠ أيام (بداية العمر الثاني) مع معدل خروج كان الأعلى من هذا العمر. كان للحرارة تأثير معنوي على الفاعلية البحثية للطفيل خلال المدى الحراري المختبر. حيث تم تسجيل أعلى معدل للبحث للطفيل على درجة حرارة ٢٠°م. وبالرغم من أن زيادة كثافة الطفيل على جميع درجات الحرارة المختبرة أدى إلى انخفاض إنتاج الذرية للطفيل نتيجة زيادة التداخل التبادلي، إلا أن الطفيل كان قادر على توزيع ذريته بانتظام بين العوائل المتاحة خاصة على درجة حرارة ٢٠°م. وبالنسبة لأعلى قيم لقوة القتل (K-values) فقد تم الحصول عليها على درجة حرارة ٢٠°م ومن خلال النسبة ٤ طفيل/٣٠ عائل. تم تقدير وقت الأداء الأقل والأعلى على درجة حرارة ٢٠ و ١٧,٥°م على التوالي. بناء على ذلك فإن ٢٠°م تكون أكثر ملائمة لنشاط وإنتاج الطفيل. ولذلك فإن الطفيل يبدو أنه عامل مكافحة جيد للحشرة من نهاية الربيع حتى بداية الصيف وكذلك خلال الخريف في المناطق ذات الظروف الحرارية الشبيهة بالنمسا عندما تدور درجة الحرارة حول هذه الدرجة. لذلك فإن إطلاق الطفيل خلال هذه المواسم على بداية العمر الثاني (١٠ أيام) بنسبة ١ طفيل / ٧,٥ عائل يجب أن تأخذ في الاعتبار في برامج مكافحة المستقبلية للحشرة.