77

BARD

FINAL REPORT

PROJECT No. I-264-81

Evaluation of Parasitoids for the Control of Whiteflies

D. Gerling, S.B. Vinson

1986

BARD Research Project No. I 26481

Title of Research Project:

Evaluation of Parasitoids for the Control of Whiteflies

Name & Address of Investigators:

Principal Investigator: Dan Gerling, Dept. Zoology, Tel Aviv University

Cooperating Investigator: S.B. Vinson, Dept. Entomology, Texas A. & M.
University

Project's Commencement Date: December 1, 1982

Type of Report: Final

Signature: *Don Gerling*
Principal Investigator

Institution's Authorized Official
(signature and official stamp)

B. Table of Contents	page
A. Cover page	1
B. Contents	2
C. Abstract	3
D. Objectives	4
E. Body of Report	5
Introduction	5
General Materials and Methods	5
Foreign exploration	6
Introduction of parasitoids	6
Taxonomic investigations	6
Studies with the host, <u>Bemisia tabaci</u>	9
I. Behavior of the host	9
Courtship and mating behavior	9
II. Relationships between <u>Bemisia tabaci</u> and its host plants	15
Biology and Behavior of the Parasitoids	22
I. Biology and behavior of local parasitoids	22
Laboratory studies - <u>Encarsia lutea</u>	22
Field studies	35
II. Biology and behavior of introduced parasitoids	42
<u>Encarsia deserti</u>	42
<u>Eretmocerus</u> n.sp. from Southwestern U.S.	55
Utilization of the host <u>Bemisia tabaci</u> by <u>Eretmocerus</u> n.sp.	55
Behavior associated with recognition of the host by the parasitoid	59
III. Release and recovery of the parasitoids	69
Acknowledgements	72
F. Description of cooperation	73
G. Achievements	73
H. List of publications	75

ABSTRACT

Our studies centered around Bemisia tabaci and its parasitoids.

Mating of B. tabaci was shown to involve a complex behavior with only 7% success. Plant acceptance was conditioned by the insect's previous food.

Six of the many existing exotic parasitoids were introduced., and 3 were released. Establishment of 2, Eretmocerus sp. and Encarsia formosa is still uncertain, whereas En. deserti has been recovered often. There are several more foreign parasitoids spp. that warrant introduction.

The biology of En. lutea which is indigenous to Israel and of the introduced En. deserti was studied. Mated females of both species were able to distinguish between hosts that have been parasitized by conspecifics. En. lutea were unable to discern previous parasitization by Eretmocerus mundus, whereas unmated En. deserti failed to differentiate between parasitized and unparasitized hosts. The latter species also had an 11 day developmental period at 25°C - which is the shortest known for parasitoids of B. tabaci.

The behavioral sequence associated with Eretmocerus sp. was worked out. Host feeding was found to constitute a major mortality factor in laboratory populations, causing about 50% of the mortality.

The knowledge that has been gained, greatly improves our understanding of the biology of B. tabaci and its enemies, and the introduction of parasitoids will, hopefully, also increase the environmental pressure on this pest. It is suggested that additional species of enemies should be introduced and that more knowledge about their mode of action should be obtained.

D. OBJECTIVES

The originally stated objectives were listed thus:

The ultimate objective of the proposed study is to achieve improved control of the tobacco and greenhouse whiteflies through the utilization of their parasitoid natural enemies.

We propose to reach this objective through the following intermediate goals.

1. Recognition of the parasitoid complex attacking B. tabaci, Trialeurodes vaporariorum and T. abutiloneus with emphasis on their full associations.

2. Introduction of the parasitoids that have the suitable host associations into Israel, rearing and releasing them for the control of B. tabaci and T. vaporariorum.

3. Evaluate in the laboratory the biological characteristics of few chosen species of parasitoids along the following lines: life history and reproductive capacity, host finding abilities, competitiveness, and host suitability.

4. Compare the laboratory host finding abilities with greenhouse studies and the field studies in Israel.

Due to a cut in funding, we were not able to work on T. abutiloneus. Intermediate goal No. 4. has also not been worked on. All other objectives have been worked on, with more emphasis on the biology of the host B. tabaci than originally contemplated.

I. BODY OF THE REPORT

Introduction

The studies that we undertook involved foreign exploration for the discovery and introduction of the parasitoids, taxonomic investigations to identify the species of parasitoids attacking Bemisia tabaci and Trialeurodes vaporariorum, life history and behavioral studies of the host B. tabaci and the parasitoids, and field releases of the parasitoids.

General materials and methods

Studies with parasitoids were conducted in the laboratory in wooden or plastic sleeve cages. B. tabaci cultures were usually kept on cotton, but Lantana camara was also used for both B. tabaci and T. vaporariorum. The latter was also reared on Nicotiana glauca, N. tabacum and Sonchus oleraceus.

Rearings were conducted in walk-in environmental chambers that were usually kept at a constant temperature of 25-27°C and some 60% R.H., except when experiments required otherwise. Greenhouses were used for plant and whitefly culture in Texas and for plant, whitefly and parasitoid culture in Israel.

Behavioral experiments and observations were conducted in the laboratory with a dissecting microscope, and in the field, by direct observations. Results of field parasitization were assessed by collecting whitefly-infested leaves, observing and dissecting them, or by rearing-out the parasitoids from the collected whitefly puparia.

Release sites were determined by their geographic location, the degree of whitefly infestation, and by the chances of parasitoids to become established, i.e. the continuity of host material, and the lack of insecticidal treatments.

FOREIGN EXPLORATION

An article describing the foreign exploration in Africa is included. D. Herling, 1985. Parasitoids attacking B. tabaci (Homoptera: Aleurodidae) in Eastern Africa. Entomophaga 30(2):169-165.

INTRODUCTION OF PARASITIDS

Encarsia deserti and Eretmocerus sp. were introduced from Western Arizona and the Imperial Valley in California. They were sent to Israel by Dr. George Butler (USDA Cotton Research Lab., Phoenix, Az,) in the fall of 1982 and were propagated in the laboratory and greenhouses until further use was made of them.

Encarsia formosa was introduced from Holland (Koppert laboratories) in the summer of 1983. Some were propagated in the laboratory and some released in the field.

Encarsia tricolor was introduced from France (INRA laboratories, Versailles; courtesy of Dr. J.C. Onillon), and reared in the laboratory.

Encarsia n.sp. "p", from Pakistan was received from the CIBC laboratories at Silwood Park, England (courtesy of Drs. D.J. Greathead and D. O'Donnell), reared in the laboratory and released in the field (Table 1).

TAXONOMIC INVESTIGATIONS

The parasitoids that were collected in Africa and sent to Israel for rearing and examination as to their suitability as controlling agents for B. tabaci, were keyed out to genus and, where possible; to species. Most of the material was not processed taxonomically due to the complexity of the subject and its lack of direct relationship with B. tabaci control. However, among the relevant material we found Encarsia sublutea (Det. Dr. G. Viggiani,

University of Naples), a parasitoid that attacks T. vaporariorum and B. tabaci. We were also able to determine that it was synonymous with Prospeltella transvena occurring in Hawaii, leading to a new name combination, Encarsia transvena, for both populations. This change has been mentioned in the publication reporting our findings in Africa, and will also be documented in a wider taxonomic paper by Dr. Viggiani.

Whiteflies were collected throughout Israel and their parasitoids were reared out in order to determine which species existed, and what their host ranges were. A total of 15 species of parasitoids were registered, including three that were new to science. Five species of Encarsia and of Eretmocerus were reared from B. tabaci including 3 recent introductions, one (E. partenopea) that is probably a migrant from Europe, and one (E. reticulata) a new species to science that is rare. Table 1 summarizes these findings as they pertain to B. tabaci. It also includes the above-mentioned species, Encarsia "p", that originated in Pakistan.

A manuscript is being prepared in which the full taxonomic details and host relationships in our findings will be enumerated, and the new species will be described: Rivnay, T. and D. Gerling. Whitefly (Aleurodidae) parasitoids in Israel. Submitted to Entomophaga.

Table 1. Parasitoids of B. tabaci in Israel**

Specific name	Immediate origin of our material	Known range	Additional hosts	Comments
<i>Encarsia deserti</i>	5	1,5	T. vap.	a
<i>Encarsia formosa</i>	6	7	T. vap.	b. commercially used in many countries
<i>Encarsia lutea</i>	1	1,2,3	?	-
<i>Encarsia partenopea</i>	1	4(in part)	T. vap. Siphoninus granati	probably a migrant from Europe
<i>Encarsia</i> n. sp. "reticulata"	1	1+5?	?	name unofficial, will soon be described
<i>Encarsia</i> sp. "p"	6	?	?	obtained from Pakista through CIBC in G.B.
<i>Eretmocerus mundus</i>	1	1,2,3,4,5	-	-
<i>Eretmocerus</i> sp.	5	1,5	-	a

1, Israel; 2, Mediterranean; 3, North & East Africa; 4, Asia Minor to India;

5, Southwestern U.S.; 6, Europe; 7, Extensive, world-wide distribution.

T. vap. - The greenhouse whitefly, Trialeurodes vaporariorum.

a - introduced during this project; b - recently introduced, before the project;

? - unknown.

** All the above mentioned species, except Encarsia "p" have been recovered from field collected hosts. *Encarsia* "p" was only received during the spring of 1986 and was reared in greenhouses.

STUDIES WITH THE HOST, BEMISIA TABACI

I. Behavior of the host

Understanding the behavior of the pest insect is of great importance in planning and executing pest management strategies. Natural enemies, which are the subject of this study, have been shown to respond to the distribution of their hosts (Waage, 1979) and to the sex pheromones which they emit. We decided, therefore, to embark on behavioral studies, one in the lab, where the courtship and mating behavior were studied, and the other in the field, where we examined the relationships between the cotton plant-hosts and B. tabaci.

1. Courtship and mating behavior

The main aims of this study were: a) To provide a general description of courtship and mating behavior of B. tabaci and, b) to determine the frequency spent at each step. With that knowledge on hand, we were able to discuss some aspects of possible pest control by mating disruption.

Materials and Methods

The whitefly B. tabaci and its cotton host plant, Gossypium hirsutum (Stoneville 213) were cultivated within large cages in a greenhouse. The humidity fluctuated between 50-80% and the temperature ranged from 22° to 32°C.

Whiteflies are generally located on the underside of leaves. To facilitate observing the sexual behavior of B. tabaci, leaves containing both sexes were placed under a binocular microscope and observations were aided with a mirror situated so that the underside of the leaf could be observed, or the leaf was gently turned over. Observations of each courting pair were conducted for one to two hours, or until copulation was completed. Once contact between the two sexes occurred, care was taken not to disturb the leaf. A stopwatch, video tape recorder and camera with a photomicro adapter

lens were used to record the various behaviors. The frequency of antennal tapping was too fast to record using a stopwatch, and certain courtship behavior underwent rapid changes that could only be described from slow-motion videotape.

A paired t test was utilized to compare the time consumed in certain phases of the courtship and copulatory behaviors and significance was expressed at a 95% confidence level.

Results

1. Behavioral sequences

A. Precopulatory sequence:

Phase 1:

Prior to sexual encounter, females were generally quiescent on the underside of the leaf and were involved in feeding or resting, while males appeared more active and moved randomly over the underside of the leaf. Males often passed within several millimeters of a female with no change detected in the males' behavior. The initial approach of a male to a female appeared to be visual and occurred only when males were within a short distance of a female. The male, upon encountering a female, would often move first in a circle around her, followed by placing his fore tarsi on the edge of her wings or touching her with his antennae. If the female did not move and no other males interfered, the male would move up parallel to the side of the female. If the female refused the male's attention, she would flap her wings, push the male with her feet, forcing him away, or she would fly away. In many cases the male approached the female several times (see section II) before arriving at a parallel orientation. For most males, once the female was contacted, the time it took to reach a parallel orientation next to a female was short.

Phase 2:

Once the male reached a parallel position beside a female, both sexes raised their antennae and held them forward at approximately a 45° angle with respect to the horizontal axis of the head. The antennae of both sexes were spread apart to an angle of approximately 100° , and the male would drum the distal segments of the female's flagellum with the more proximal portion of his own antennae. At the same time, the male's abdomen moved up and down, generally keeping time with the antennal drumming. This phase was characterized by the male gradually increasing the speed of the antennal and abdominal movements. Sometimes the male was located slightly behind the normal position with respect to the female, so that his antenna, which still vibrated, did not reach the female's. In such cases the male gradually adjusted his position.

Phase 3:

Phase 3 only occurred in 15% of the observed pairs and was characterized by the males hastening the tempo of their antennal drumming, followed by pushing the females with the side of their body. This resulted in the posterior portion of the pair performing a clockwise or counterclockwise circular movement. Phase 3 occurred from 3-20 minutes after the initiation of phase 2, and lasted 2-5 minutes.

Phase 4:

Phase 4 begins with the separation of the antenna between the sexes. The male then raises the pair of wings nearest the female and covers her. At the same time he swings his abdomen beneath hers at an angle of nearly 25° . The clasper is opened and the aedeagus is protruded as the male attempts to seize the female's terminalia. Phase 4 immediately preceded copulation and occupied less than 20 sec. During phase 4 many males were prevented from copulation by

the actions of the female. If the female did not accept the male, she flapped her wings or pushed the male's abdomen away with her mesothoracic legs. Just prior to this point an additional 70% failed to complete this phase. About 30% of the unsuccessful males would often court the same female (one male went through the courtship behavior with the same female 8 times), usually beginning with phase 2. The success rate of the male in achieving copulation when phase 4 was reached was about 23%.

Phase 5: Copulation

B. Copulatory behavior

The female appeared to accept the male by permitting him to pull down the terminal flap that covers her gonopore. During sperm transfer, the male's abdomen is bent upward at an angle of nearly 90° . The aedeagus also bends at a 90° angle so that it parallels the longitudinal axis of the female's body and is inserted into the gonopore. Final mating success between a particular initiating pair was 33%. Copulation lasted from 2.05 to 3.85 minutes (2.6 ± 0.27 min.).

C. Post copulatory behavior

The female actively terminated copulation by prying the male loose with her meso and metathoracic legs. Usually both sexes rested next to each other, the male usually remaining 1-2 minutes and the female longer (2-5 min); she sometimes also moved a short distance away. After resting, the female groomed, using her hind legs to wipe over the wings, insert her proboscis into the leaf, or defecate. Males generally began the search for additional females.

2. Unsuccessful encounters

Of the males that were observed to contact females, 52% did not complete phase 2 and another 63% failed to complete phase 4. The most frequently encountered behaviors that led to disengagement were:

a. Rejection by the male. This happened immediately after the first encounter, or after a more lengthy examination of the female by the male. At times, the male also started phase 1 or even completed phase 2, and left without apparent female rejection behavior.

b. Rejection by the female. During phases 1-3 the female walked away while the courtship attempts of the male were in progress. During phase 4, she flapped her wings, or pushed the male's abdomen away with her mesothoracic legs. Such female rejections accounted for over 70% of all rejections.

In either case, males frequently return to phases 1, 2 or 4, for repeated courting and thus increase the probability of mating success. The mating sequence and rejections at each phase are represented in Fig. 1.

Possible control by mating disruption.

It appears that, although visual stimuli are of paramount importance in B. tabaci courtship and mating, there is also chemical communication involved. This includes chemicals that are extruded by the male when he approaches the female, or once contact has been reached; and/or materials that the female produces to signal initial acceptance at phases 1 or 2, and materials that are associated with readiness to copulate in phase 4. Rejection, although usually associated with the lack of acceptance-signalling materials, may also be associated with the active emission of pheromones.

These studies show that at several points in the sexual interaction, chemical communication may be critical. This fact and the very high percentage of unsuccessful mating attempts that may be related to chemical communication, point to the probability that further investigations in this direction could be fruitful.

Fig. 1. Sequence and frequencies of courtship behavior in Bemisia tabaci

② NUMBERS IN CIRCLES SHOW COURTSHIP SEQUENCE

10, 90..... % EACH STEP = 100%

ARROWS WITHOUT NUMBERS = OCCASIONAL EXCEPTIONS

II. Relationships between Bemisia tabaci and its host plants.

Bemisia tabaci is polyphagous and has an extensive host range. The expression and intensity of damage on different host plants varies. Since cotton is a crop of paramount importance in Israel and in the U.S., and since it is a host for B. tabaci that damages it economically in both countries, we chose to investigate plant-insect relationships of this interaction.

Materials and Methods

Adults were monitored by averaging the catch of 5 yellow traps (Gerling and Horowitz, 1984), and immature populations were estimated by counting the numbers of late larvae and pupae on the "most infested leaf" (Gerling et al., 1980) taken from 10, randomly selected plants. Experiments were conducted in the Bet Shean valley, with Acala SJ2 cotton. Oviposition patterns were determined by counting all of the eggs upon 5 leaves taken from 4 randomly selected plants. Eggs were considered to be grouped if the distance between 2 eggs was less than the width of one egg. In calculating the grouping ratio, we considered a single egg as a group of 1.

Results

1. Observations of field populations

In order to define the parameters of our investigations, we first compared the population trends of B. tabaci on a Lantana camara L. hedge and on an untreated cotton field about 2 km away. The results (Fig. 2) show that the great differences in adult populations observed from May onwards, diminished gradually, disappearing altogether during August.

Concurrently, potted cotton plants were placed under the same L. camara hedge and the numbers of whitefly immatures upon both were compared. Although these were mainly qualitative observations, it was established that during June, when the L. camara leaves often bore over 100 nymphs per leaf, those of the cotton amounted to only a few individuals per leaf. From July on, the

numbers of nymphs on the cotton rose sharply, reaching levels equal to those on L. camara.

Observations of the distribution and abundance of whitefly immatures in the cotton field were conducted from late May. At that time, B. tabaci was a relatively rare insect in the field and its distribution was sporadic. One or 2 eggs and nymphs could be found on occasional leaves but in no case did we observe a large group of eggs on a leaf. Such groups, typical of B. tabaci, are often semicircular or circular and can be found readily later in the season.

In order to quantify the possible behavioral difference in oviposition throughout the season, we determined the oviposition pattern and calculated its correlation with the sampling dates. The results (Fig. 3) show a significant ($P < 0.01$) rise of clumping with the season ($r=0.758$).

2. Influence of host-plant age

The observed changes in oviposition behavior and in population development throughout the season occurred on cotton plants that were sown in March and were maturing up to the cotton harvest in October. Therefore, it was necessary to test the role of plant age upon them. This was done in a group of 8 x 12 m cotton plots that were arranged in a random block design and replicated 6 times. Each replicate consisted of several blocks, including "date 0" cotton that had been sown on 22 March; "date 1" sown on 10 July; "date 2" sown on 10 August and 2 plots called "def.1" and "def.2" that were sown on 22 March but defoliated manually on 20 July and 20 August, respectively.

Fig. 2. Weekly trap catches of Bemisia tabaci adults - Tirat Zvi, 1982

Fig. 3. Sizes of the average oviposition batch of Bemisia tabaci - Sde Eliyahu, 1983

Two sets of comparisons were conducted. In the first, on 25 August, we compared the numbers of immature populations on "date 0" with those on "date 1", and "def 1"; and in the second, on 22 September we compared numbers on "date 0" with "date 2" and "def 2". The date 1 plants were treated with 0.1% Fenprothrin some 6 weeks before each sample was taken. This insecticide was known to remove all whitefly populations from the plants, but its influence was determined by us to last, at most, 10 days. In this way, the effects of previous accumulation of whiteflies was eliminated and all 3 treatments - mature plants ("date 1"), young plants ("dates 1 and 2") and young leaves upon mature plants (def. 1 and 2) were exposed contemporaneously for 1 month before being sampled.

The results (Table 2) showed a clear trend of higher infestation on younger plants and leaves. This trend was not significant in the 25 August sample, due to extensive variability, but was highly significant in the 22 September sample, indicating that the lack of early population buildup in cotton fields is not due to unsuitability of young cotton plants.

Table 2: Infestation of cotton leaves of different ages in the field, by late nymphs and pupae of B. tabaci

date of observation	treatment				
	date 0 +SE	date 1 +SE	date 2 +SE	def 1 +SE	def 2 +SE
25.8.82	15.93+15.4	50.98+32.5		39.54+18.2	
22.9.82	17.22+9.75		149.17+76.8*		33.72+33.6

*difference significant at a 1% level (3-way ANOVA)

date 0 - cotton sown on 22 March; date 1 - sown on 10 July; date 2 - sown on 10 August

def 1 - sown on 22 March, defoliated manually on 20 July;

def 2 - sown on 22 March, defoliated manually on 20 August.

3. Influence of previous hosts.

Since the whiteflies on cotton arrived each season from other host plants, we examined the influence of a change in host plant upon longevity and oviposition of B. tabaci.

Stocks of B. tabaci were prepared, with one being kept for 3 generations on L. camara and the second on cotton. Each was then tested on cotton and on L. camara.

Two tests were conducted. In one, we determined the oviposition behavior of the females, and in the other, their longevity, fecundity and oviposition behavior. In the first test, 2 females from a host plant, with males, were confined for 3-4 days on a leaf. They were then removed and oviposition was examined as to the number of eggs and their grouping. In addition to the transfers of adult whiteflies, we also attempted to determine if feeding by the B. tabaci female on the plant species of emergence before her transfer to the second species, influenced her oviposition behavior. For this purpose, we removed whitefly puparia and let them emerge separately before using the females.

The results (Table 3) show that egg groups of 3 eggs or more, were more abundant in oviposition on the same plant species than after a transfer, and that the females that were reared from separated pupae showed the same preferences as those collected as adults from their host plants.

The second test was conducted during the winter in a greenhouse. Females were confined individually and transferred from one leaf to another twice each week until their death. The number of eggs and oviposition pattern were followed.

The results (Tables 4 and 5) show a definite trend in all cases to higher numbers of eggs and more eggs in groups when females were allowed to oviposit on the host plant species on which they had developed. These differences were

significant for the numbers of eggs per female in both tables and for the egg-group parameters for cotton-reared females.

Table 3: Oviposition patterns of females reared on one host and allowed to oviposit either on the same host species or on an alternate species.

	Treatment					
	L/L	C/C	C/L	L/C	Cp/L	Lp/C
% eggs in groups of 3 or more	50	75.8	29	32.8	32.7	36.7
n	14	27	22	29	30	18

L = Lantana camara; C = cotton; n = number of females used.

L/L, L/C.... = females reared on L. camara tested on L. camara etc.

Cp; Lp = females reared on cotton or L. camara, separated as pupae and used as adults to infest the other plant species.

Table 4: Results of oviposition tests with single females that developed for 3 generations on cotton plants, expressed as means of the number of females used.

Host plant	longevity (days)	oviposition per female	daily oviposition	No. of eggs in groups of 2 or more	size of egg groups
cotton	22.80	67.80	2.67	31.20	1.51
<u>L.camara</u>	14.71	25.71	2.00	3.29	1.09
F value	3.2022	3.7540	1.5672	7.000	7.878
Significance of difference (P<0.05)	-	+	-	+	+

*Using the Student Neuman-Keuls multiple range procedure.

Table 5: Results of oviposition tests with single females reared for 3 generations on plants of Lantana camara, expressed as means of the number of females used.

Host plant	longevity (days)	oviposition per female	daily oviposition	No. of eggs in groups of 2 or more	size of egg groups
<hr/>					
<u>L. camara</u>	22.00	35.89	1.97	22.66	1.56
cotton	14.22	19.78	1.19	17.22	1.32
F. value	4.3662	4.9645	2.5070	1.923	3.9060
Significance of difference (P<0.05)	-	+	-	-	-

*Using the Student Neuman-Keuls multiple range procedure.

Discussion

In our search for reasons for the shape of the population curve of B. tabaci in the cotton fields of Israel, we were able to demonstrate that whitefly behavior was a decisive factor. This behavior was triggered through transfer of the whiteflies from one host plant to another, an occurrence that takes place each year, as cotton is an annual crop that germinates during April and May.

Manifestation of the behavioral changes is in the form of a shift from early season sporadic oviposition of, mainly, single eggs in small numbers, to oviposition of egg groups in larger numbers later in the season. It is reasonable to suppose that such a change in behavior may be an important factor in the outbreaks of B. tabaci infestations during July.

Berlinger et al. (1983) have attributed the late whitefly infestations in cotton fields to changes in leaf pH. They showed adult attraction to higher pH, that is typical to older leaves, and concluded that adults would prefer such leaves in the field. Our tests, that were conducted under field conditions, showed the opposite, a definite preference to young plants and leaves and, at this time, we can offer no explanation for this discrepancy.

The role of stress upon plants was examined by Mor and Marani (1984), who employed different degrees of water stress on cotton plants and showed that stressed plants were more heavily attacked by whiteflies. This observation probably explains the heavy damage by whiteflies to unirrigated cotton as usually happens in Israel. It may also explain the particular situation of certain cotton fields with specific irrigation regimes late in the season, where the plants are under stress and severely attacked by whiteflies. However, as previously stated, whiteflies greatly prefer young, well-irrigated cotton plants to old, stressed ones, if the former are available.

BIOLOGY AND BEHAVIOR OF THE PARASITIDS

The studies were divided into 3 parts: Biology and behavior of parasitoids already existing in Israel; Biology and behavior of species that have been introduced into Israel, and host attraction and host location studies.

I. Biology and behavior of local parasitoids

a. Laboratory studies - *Encarsia lutea*

In Israel, there are several parasitoid species known to attack *B. tabaci* (see previous taxonomic section) but the most prominent are *Eretmocerus mundus* and *Encarsia lutea*. The life history and host discrimination capabilities of *Er. mundus* have recently been published (Foltyn and Gerling, 1985), but those of *E. lutea* have not. Moreover, for better understanding of the host-

parasitoid interactions, we also found it necessary to examine the relationships between the 2 parasitoid species, especially in relation to host discrimination capacities.

Materials and Methods

B. tabaci and the parasitoids were initially obtained in the field. In the laboratory they were kept and reared using the methodology described by Foltyn & Gerling (1985). Developmental studies were conducted with females that were kept, after emergence, with honey and yeast hydrolyzate. They were allowed to oviposit in a batch of hosts for 24 hours, after which they were removed. Each day, 15 hosts were dissected in a drop of saline to determine the stage of the parasitoid.

Males of E. lutea were obtained through the same procedure. However, instead of unparasitized B. tabaci nymphs we used ones that contained E. mundus or E. lutea.

As before, four nymphal instars of B. tabaci were recognized. The 4th was subdivided into three stages, the first in which no eyes were yet discernable, the second or prepupa, with red eyes and the third, the late or pupal stage.

Preferred oviposition stage was examined using two methods:

The host stages in which E. lutea will oviposit, and those preferred for oviposition were examined through direct observations, and through dissections of hosts after a 24-h confinement with one parasitoid female. The indirect dissection method was applied to progeny of both mated and unmated females. Each confinement included unparasitized hosts of all four instars and was repeated nine times with unmated, and 30 times with mated females. We performed ten direct observations. In each, the female's movements and behavior upon a mapped leaf with different host stages were

registered, and the hosts in which oviposition was assumed to have occurred, were dissected.

Intraspecific host discrimination was studied by using the data from the preferred oviposition - direct observation tests and also by observing the behavior of E. lutea upon previously parasitized, early 4th instar host nymphs. For this purpose we subjected each of 15 mapped leaves to a mated E. lutea female until we have observed oviposition posture on about 1/3 of the hosts. The female was then removed and a second female was introduced and observed until she showed no more interest in the leaf. All of the hosts that either female had probed with her ovipositor were dissected.

Interspecific host discrimination through direct observations was studied using 20 leaves. Ten were first kept for 24-h with a female of E. lutea and then with E. mundus and 10 vice versa. All leaves were mapped and parasitization behavior by all parasitoids was registered. The results were subjected to a G test to detect differences between behavior on "new" and already parasitized nymphs.

The indirect, or dissection method, was applied to field collected material and to three sets of experiments, and was designed to determine whether the gap in time between oviposition by the first and the second parasitoids influenced the capacity for host discrimination. In the first, 3rd instar hosts were kept for 24 hours with 1 species of parasitoid, and the following 24 hours, with the second. In the 2nd set, 1 species of parasitoid was confined for 24 hours with 2nd instar nymphs whereas the second parasitoid female was placed on it only when the hosts reached the 4th nymphal instar. Finally, in the 3rd set, both species were left together for 24 hours on 3rd instar nymphs. Dissection and examination of host material in the 2nd and 3rd sets began 4 days after removal of the parasitoids, and took place every 1-2

days until mature pupae were observed. Care was taken to dissect each time only a few nymphs from each leaf. In this way we tried to follow both the rates and the outcomes of multiparasitism.

Results

Development of *E. lutea* at 25°C

Mated *E. lutea* females oviposit within the body fluids of their whitefly hosts and larval development takes place therein. The first 2 larval instars have no visible tracheal system, but in the third, and last, instar it is well developed and has 10 spiracular pairs on segments 2-12. This change is accompanied by gradual drying-up of the dead host.

Total development of the female lasts 13-18 days (Table 6).

Table 6. Development of *E. lutea* female at 25±1°C

	Duration (days)			Size (mm)		Remarks and distinguishing characters
	From	To	Median	Long	Wide	
Egg	0	4	-	0.06(+0.001)	0.02(+0.001)	at day 3 egg larger, 0.26x0.15 mm and larva seen through chorion
LI	4	8	2	0.48(+0.03)	0.14(+0.02)	no trachea seen. Tail prominent
LII	6	10	2	0.49(+0.04)	0.16(+0.01)	no trachea seen. No tail
LIII	7	11	3	0.8(+0.01)	0.3(+0.01)	Trachae present, spiracles in segments 2-12. Development ends with meconial casting.
Prepupa	8	12	1	-	-	gut clear, prepupa's body straight with head at anterior of whitefly nymph.
Pupa	9	18	5	-	-	gradual development of legs, antennae, eyes and wings. Pharate adult turns with mouth parts upward.

Total developmental duration 13-18.

Number of parasitoids examined each day n = 15.

Males develop from unfertilized eggs that are laid inside the body fluids of late larvae or pupae of parasitoids within immature whiteflies. Their

first instar has a prominent tail and as in the female, no tracheae were visible in instars 1-2. The tracheated 3rd instar leaves the host and continues to feed upon it from the outside while within the whitefly "shell". Its developmental duration is 14-15 days (Table 7).

Table 7. Development of *E. lutea* males at 25±1°C.

	Duration (days)			Size (mm)		Remarks and distinguishing characteristics
	From	To	Median	Long	Wide	
Egg	0	4	4	0.06(+0.005)	0.02(+0.001)	egg deposited inside larvae III or pupae parasitoid inside the whitefly host
LI	4	5	2	0.22(+0.02)	0.08(+0.009)	has prominent tail, no trachea visible
LII	6	8	2	0.25(+0.23)	0.09(+0.01)	has no tail and no trachea. At end of development, leaves host body
LIII	7	11	3	0.96(+0.08)	0.42(+0.04)	feeds externally on remnants of host. Trachea and spiracles visible. At end of development casts meconia
Prepupa	10	12	1	-	-	as in female, remnants of devoured female visible.
Pupae	11	15	4	-	-	as in female, but final colors darker

Total developmental duration: 14-15 days

Number of parasitoids examined each day n = 15.

Oviposition behavior

The studies were conducted through direct observation. We used young mated females that have previously been kept for up to 24 hours with a few unparasitized hosts, for host feeding and for obtaining oviposition experience, as suggested by van Lenteren et al. (1980).

The behavioral components found included antennal drumming while standing, walking and examining the host, oviposition posture, preening and host feeding; and were similar to those described by van Lenteren et al. (1980) in their sequence, mode, and approximate durations.

Fig. 4. Results of the preferred oviposition stage test by *E. lutea*

A. dissection method
B. direct observation

Preferred oviposition stage.

In the indirect dissection method, unmated females failed to oviposit in all 10 tests, whereas mated ones, laid eggs in 17 out of the 30 tests. No oviposition occurred in instar 1, whereas 2nd instar larvae as well as late instar 4 (pupae) had occasional eggs in them. Instar 3 was parasitized to a substantial degree and the first 2 stages of instar 4 showed highest parasitization (Fig. 4A).

In the direct observations, the females chose to oviposit only in instar 3 and in the first 2 stages of instar 4 (Fig. 4B). No oviposition occurred within the pupae. An χ^2 test showed preference for the 2 first stages of instar 4 over instar 3 ($p < 0.01$). The first and second instar nymphs were often ignored or abandoned after short antennation. The females did not stop on top of these stages and did not attain a stinging pose except when it was followed by host feeding.

Intraspecific Host Discrimination

Observations were conducted to determine if E. lutea discriminated between hosts that were previously parasitized by conspecifics included those made during the study of preferred host instars. In these studies we observed that in eight (25%) out of 32 instances whence a female came upon a previously parasitized host, she deposited a second egg.

As said, we also followed the behavior of E. lutea on 15 leaves with previously parasitized hosts. On 6 leaves one of the 2 females failed to oviposit; of the remaining 9, the second female examined totals of 126 unparasitized nymphs, 66 nymphs that had been parasitized by the first female, and 37 nymphs that she had already parasitized herself. Of these, she laid eggs in 49 (39%), 13 (20%) and 7 (19%) nymphs respectively. Thus, she rejected

significantly more ($p < 0.05$) parasitized hosts than unparasitized ones (Table 8). Superparasitism occurred at any time during the searching sequence, even before the female had examined most or all of the available nymphs on the leaves (Table 9).

Table 8. Results of host discrimination tests using the direct observation method.

Species	No. of nymphs	No. of contacts				with				G test
		unparasitized		parasitized		unparasitized		parasitized		
		contacts	oviposition	contacts	oviposition	contacts	oviposition	contacts	oviposition	
		No.	%	No.	%	No.	%	No.	%	
<u>E. lutea</u> alone	229	126	49	38.9						+
<u>E. lutea</u> on <u>E. mundus</u>	253	186	56	30.1						NS
<u>E. mundus</u> on <u>E. lutea</u>	188	119	73	61.3						NS

+ difference between rejections of unparasitized and parasitized significant, $p < 0.05$

NS not significant

Table 9. Oviposition sequences leading to superparasitism by 8 females of E. lutea.

Female No.	Time (min.& sec.) of Contact with the same host and Outcomes				Total exposure time (min.)	Degree of* patch utilization
	1st Contact	2nd Contact	3rd Contact	4th Contact		
1.	13'14" = 0	25'13" = +	36'40" = +	92'15" = 0	120	$\frac{7}{40}$
2.	25'06" = +	76'56" = +	-	-	120	$\frac{7}{40}$
3.	01'00" = 0	25'00" = +	42'30" = +	-	100	$\frac{8}{17}$
4.	22'26" = +	49'36" = +	59'00" = +	-	100	$\frac{8}{20}$
5.	10'44" = +	24'47" = +	-	-	85	$\frac{11}{18}$
6.	04'04" = +	52'09" = +	-	-	120	$\frac{12}{15}$
7.	26'54" = +	51'00" = +	-	-	60	$\frac{10}{22}$
8.	48'00" = +	54'00" = +	-	-	60	ND

+ = egg laid; 0 = no egg laid; NO - no data.

* Ratio of parasitized hosts to total nymphs at instars 3 and 4. In addition, some 10-40 younger nymphs were present on each leaf patch.

In all of the tests there were still numerous unparasitized hosts available when superparasitism took place (Table 9). Yet, the more already parasitized hosts were present, the faster the female moved among the hosts, often examining them only with a brief antennal contact. Finally, she left the leaf. At times she returned to it later, but no oviposition took place.

Table 10. Interspecific host discrimination in the lab and in the field. In set No. 1 the parasitoids were introduced onto 3rd instar hosts one day after the other. In set No. 2 the first parasitoid species was placed on the 2nd instar and the second species, on the 4th instar; in set No. 3 both species were kept together on the host for 24 hours.

The Experiment		Hosts Dissected						No. of Survivors		
Name	Condition	Total paras. hosts	No. with <u>E. m.</u> only	No. with <u>E. l.</u> only	With Both No.	% of multi-parasitism (1)	% of <u>E. l.</u>	% of <u>E. m.</u>	Undet. ^b	<u>E. m.</u> <u>E. l.</u> ^c
	1st	2nd	(1)	(2)	(3)	(4)	100x4/3+4	100x4/2+4		
Set No. 1	<u>E. m.</u>	<u>E. l.</u>	140	80	30	30	21.4	50	-	-
	<u>E. l.</u>	<u>E. m.</u>	210	101	65	44	20.9	-	30.3	-
Set No. 2	<u>E. m.</u>	<u>E. l.</u>	272 (331) ^a	132 (191) ^a	69	71	21.4	50.7	-	13 1 57
	<u>E. l.</u>	<u>E. m.</u>	217 (313) ^a	74 (170) ^a	119	24	7.6	-	12.4	2 4 18
Set No. 3	Both Together		317 (ND) ^a	156	129	32	ND	19.8	12.0	2 0 30
Tel Aviv	Field		310	112	177	21	6.8	10.6	15.9	- - -
Nir David	Field		134	48	82	4	2.9	4.7	7.7	- - -

E. m. = E. mundus, E. l. = E. lutea; ND = No Data

a = Numbers in parentheses include E. mundus pupae that were not dissected.

b = Fate undetermined, both species alive.

c = Determined through the presence of a living E. lutea inside the host, and an egg chorion of E. mundus under it.

Interspecific host discrimination

In direct observations no difference was detected between the degree of parasitization of hosts already parasitized by another species vs. that of unparasitized nymphs (Table 8). Also, during the observations we could not detect differences in the behavioral sequences leading to oviposition or in the durations of each of these sequences when compared with the same data obtained with unparasitized hosts. The behavior in these cases was in sharp contrast to the clearly discriminatory behavior displayed when encountering a host already parasitized by conspecifics, especially in E. mundus.

Field collection of infested leaves was carried out during September and October 1981 in the untreated cotton field of Nir David and in the experimental plot of Tel Aviv University. The eight leaves from Nir David bore 223 nymphs (range 15-43) and in Tel Aviv we collected 81 leaves with 383 nymphs (range 1-33). Multiparasitism was found in both places, as could be expected (Table 10).

The indirect, or dissection method, was applied to 3 sets of experiments. The results of the first set resembled those of the direct observations (Tables 8 and 10), with somewhat higher numbers in the latter. Percentage multiparasitism of E. lutea on E. mundus was 35.8 and 30.3, and that of E. mundus on E. lutea was 59.4 and 50.7 in the direct observations and dissections, respectively. During the dissections of the whiteflies of the 2nd and 3rd sets of experiments, we were unable to find the remains of E. lutea when, following multiparasitism, E. mundus overcame it and had already developed to late larval and pupal stages. Consequently, the results (Table 10, sets 2 and 3) indicate minimal values of multiparasitism under their specified conditions.

From Table 10 it is evident that multiparasitism occurs in all instances, irrespectively of the gap between oviposition by the first and second

parasitoid. Multiparasitism by E. lutea reached 21.4% of total parasitism and 50% of her laid eggs. When it was allowed to oviposit upon 3rd instar hosts, 24 hours after E. mundus (1st set). Multiparasitism was about as high when the parasitoid was placed on the 4th instar, previously parasitized nymphs (2nd set). E. mundus also caused high multiple parasitism on the first set, but in the 2nd set when placed on a non-preferred 4th instar (Foltyn and Gerling, 1985), it apparently caused much lower multiparasitism (7.6% of total parasitism, and 12.4% of its laid eggs).

In the 3rd set of experiments, the total number of parasitized hosts was not recorded, therefore it can only serve as an indication that multiparasitism occurred also when both species were allowed to oviposit together.

Survival, following multiparasitism was followed in the 2nd and 3rd sets of experiments (Table 10). However, as said, when E. mundus was the victor, multiparasitism could only be detected up to the late larval stages of the parasitoid, and our record is, therefore, incomplete. The small proportions of surviving E. mundus found in our dissection (Table 10) indicate that this species is probably overcome by E. lutea in most cases of multiparasitism. This finding also indicates that our estimates of the rates of multiparasitism in the second set of experiments are close to the true values.

Discussion

In our laboratory tests, E. lutea and E. mundus were incapable of interspecific host discrimination. A similar condition was suggested for whitefly parasitoids in Hawaii (Gerling 1985), but that was based on dissection of field collected material, not on laboratory tests. These results are also in line with the observation of Bakker et al. (1985) that "interspecific host discrimination is rare".

The female of E. lutea discriminated between parasitized and unparasitized hosts. However, two questions remained open: the reason for the high degree of superparasitism, and the apparently premature departure from the infested leaf patch, when many unparasitized hosts have not yet been examined. With respect to superparasitism, a number of possibilities exist.

The marker, that indicates to the female that parasitization has already occurred, may take time to develop. Alternatively, the females may reach the leaf patch with numerous ripe eggs in their ovaries and, due to oviposition pressure, their efficiency in host discrimination may be reduced. If that is so, superparasitism should occur mainly at the onset of the observation period.

The fact that a similar degree of superparasitism occurred in our studies of preferred host instars as in the host discrimination studies (ca. 20-25%), (Table 9), and that superparasitism occurred both after 6 m.n. and after 51 m.n. 50 sec from the first oviposition, indicate that a time factor was probably not involved here. As to the oviposition pressure, we were able to analyze only 8 cases for their sequence of parasitization, but these did not support that postulate since superparasitism was distributed throughout the observation period (Table 9).

Bakker et al. (1985) summarized 4 points of selective advantage to host discrimination. Prevention of the wastage of eggs, of time, and of hosts; and contribution to the parasitoid's ability to assess the decrease in the profitability of the patch that it is searching. They also mentioned that host discrimination is clearly advantageous when the number of hosts and time available are not limiting factors, and when the survival chances of the second-laid parasitoid are too low in comparison with the first.

Our experiments were insufficient to assess the chances of survival of supernumerary progeny, but we may assume that they are less than those of

primary ones. The experiments also offer no answer to the questions of the high rate of superparasitism and of premature departure from the examined leaf patch. The answers to these questions may be related to the artificial condition of our experiments and can only be resolved by future studies.

b. Field studies

The natural fauna of B. tabaci in Israel includes two species of parasitoids, Eretmocerus mundus and Encarsia lutea. As part of our efforts to determine the biological characteristics of the enemies of B. tabaci, we conducted observations on their behavior in the field. The parameters that were followed included absolute numbers of adults of both species, and their locations upon the plant, as related to the daytime and to the season.

Methods

Observations and counts were made during the summers of 1982, 83 and 84 in an untreated cotton plot of 3 dunams that was part of a 50 dunam field treated from the ground, so that insecticide drift was avoided. Observations were conducted by examining 10 cotton plants thoroughly, observing each leaf and registering the parasitoids found upon them. The exact location of the parasitoid-bearing leaf was also registered and the whiteflies present upon it were sorted to their stage and condition (whether parasitized or not) and registered.

In order to characterize the behavior of the parasitoids, cotton plants were divided into 3 regions, which roughly corresponded to the age of their leaves. They were: Outer region of youngest leaves, middle region of middle-aged leaves and low central core of the plant, bearing old leaves.

Results

Bemisia tabaci populations were most abundant in the middle region of the plant throughout the season (Fig. 5). Absolute numbers of parasitoids were

low throughout all seasons. They ranged, for the 10 plants examined, from 0-16 for Er. mundus and from 0-24 for E. lutea. Until mid August, Er. mundus predominated, to be later replaced by E. lutea (Fig. 6). The same figure also shows that numbers of adults of both species fluctuated in cycles that lasted about 3 weeks. Two such cycles were observed during each summer's observation, and a third cycle began in 1982

The region bearing the middle-aged leaves was the one that bore most susceptible hosts and was most frequented by the parasitoids (Fig. 5). Eretmocerus mundus was also often found on the oldest leaves during 1982 and 1983. In 1984, when parasitoid populations were highest, the number found in the young region almost equalled that of the middle-aged region (Fig. 7). Encarsia lutea was found in about equal numbers in the younger and older regions (Fig. 8).

The hour of parasitoid activity was examined once, on 17th July, 1984 from 0600-1740, on 20 preselected cotton plants. Thereafter, during August, only 2 daily examinations, in the morning (0730) and afternoon (1200 and 1400) were carried out. At 0600 on July 17th, all the plant parts were wet and the parasitoids were standing motionless, possibly waiting for their habitat to dry out. At that time, about 60% of the Er. mundus were on leaves of the middle-aged part, and 4 out of the 5 E. lutea that we found were on the leaves of the younger region. At 0900 of that date, and from then on, E. mundus was most frequently found in the middle-aged region, whereas E. lutea moved to the younger region (Fig. 9). During August, both parasitoid species were found more on the middle region, with larger numbers occurring there at 1200 and 1400 than at 0730.

Fig. 5. B. tabaci populations by plant region

Fig. 6. Fluctuations of the populations of Er. mundus and E. lutea on cotton, 1982-1984

Fig. 7. Distribution of adult Er. mundus per 10 cotton plants, 1982-1984

Fig. 8. Distribution of adult E. lutea per 10 cotton plants, 1982-1984

Fig. 9. Distribution of parasitoid adults on cotton plants, 1984

II. Biology and behavior of introduced parasitoids

a. Encarsia deserti

Encarsia deserti Gerling and Rivnay was introduced into Israel during 1982 from the southwestern United States where it was a parasitoid of B. tabaci. It was grown in our laboratories, released in the field and its biology and life history were studied.

Materials and Methods

All of the experiments were conducted with B. tabaci reared on cotton plants (Acala SJ2). Parasitoids were kept in wooden sleeve cages for general rearing purposes. For specific experiments they were confined either in "plant cages" or in "leaf cages". The first consisted of a transparent plastic cylinder (20 x 5 cm) that was placed over the infested plant and covered with a fine mesh piece of cloth. The second was constructed from a small clip-on vial the top of which was replaced by a 100 mesh wire screen, or from a petri dish with a glass bottom and a plastic top, part of which was also replaced by a 100 mesh wire screen. Direct behavioral observations were conducted with similar petri dishes, but with a glass top. Virgin parasitoids were obtained by confining females in small vials in which a piece of honey-soaked paper had been placed. The vials were watched daily and the females removed according to the requirements of the experiments. Mated females were obtained in similar vials, to which a newly-emerged male had been added shortly before the females started to emerge. Behavioral observations and dissections were conducted as described in Foltyn and Gerling (1985).

Methodology and Results

Developmental duration

Eight mated females were placed on each of 3 cotton plants that were infested with about 150 2nd and 3rd instar whitefly nymphs within a plant

cage. The female E. deserti were removed after 24 hours and each day following several, randomly selected, whiteflies were dissected until 6 parasitized individuals were found. The experiments were conducted at a constant temperature of 25°C.

Male development was followed in a similar fashion by releasing 2 unmated females in 3 replicates on plants at 25°C. Each whitefly containing leaf bore 50-60 late larvae, prepupae, or young pupae of E. deserti females (a parasitoid of the whitefly). Daily dissections were conducted until 8 parasitized individuals were found.

The results (Tables 11, 12) show that both males and females begin to emerge after 11 days (at 25°C), there being no protandry. Male emergence ends after about 3 days, whereas females continue to emerge up to 18 days.

Table 11. Developmental duration of E. deserti females at 25°C. Numbers represent no. of immatures found in 18 parasitized hosts that were dissected each day.

Day	1	2	3	4	5	6	7	8	9	10	11	12	Remarks
Egg	18	18	12										In host blood
Larva I			6	13	2								Elongate and caudate
Larva II				5	13	1							closed respiratory system seen
Larva III					3	12	4	3					host mycetomes dislodged
Prepupa						5	6	5					open spiracles seen
Pupa							8	10	all				meconia cast
Adults emerged											13	11	
Total	18	18	18	18	18	18	18	18			13	11(18 ^{**})	+ 1 dead pupa

^{**} - 18 additional adult females emerged from day 13 to 28

Total progeny, n = 186.

Table 12. Developmental duration of E. deserti males at 25°C
Numbers represent no. of immatures found in 24 parasitized hosts
that were dissected each day.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	Remarks
Egg	24	24	12											Deposited in <u>E.deserti</u> body fluids
Larva I			12	9										feeds internally
Larva II				15	20	7								feeds internally upon molt
Larva III					4	17	8							leaves host and feeds externally
Prepupa							4							spiracles open
Pupa							12	all						meconia cast
Adults emerged										15	18	3		1 dead pupa remained
Totals	24	24	24	24	24	24	24				15	18	3	
Total progeny n = 205														

Longevity

Parasitoids were kept in small vials each with a piece of honey-soaked paper, at the desired temperature and a photoperiod of 14:10 L/D. Those held at 15°C were removed to room temperature for 1 hour every day in order to feed and digest their food. Ovipositing females were kept with a whitefly-bearing leaf for the first 12 days of the experiment since those were the days during which the females deposited most of their eggs. A total of 8 experiments, involving mated and unmated females, as well as males, at 15 and 25°C constant temperatures and at 22-30°C (14:10 hrs) fluctuating temperatures were conducted.

The results (Table 13) showed that females lived longer than males at 15 and 25°C. Unmated females lived less than mated ones at 15°C and non-ovipositing mated females at 25°C lived longer than those at fluctuating temperatures. Non ovipositing females lived somewhat longer than ovipositing ones.

Table 13. Results of the longevity studies conducted with Encarsia deserti

conditions	females						males		
	unmated			mated					
	n	med	max	n	med	max	n	med	max
15°C NO.	59	57	79	36	84	90	30	40	57
25°C NO.		-		25	25	40	28	16	28
25°C OV.		-		15	17	33			
22-30°C OV.		-		15	14	21			
22-30°C NO.		-		18	20	26			

n = no. of individuals tested

med = no. of days at which median survival was observed

max = no. of days after which all individuals died

NO. = non ovipositing; OV. = ovipositing

Mating and Oviposition

The preferential mating age was determined by observing females that were confined with males from emergence until mating. We also confined virgin females of different ages with males for 2 hours and determined whether they mated or not by letting them oviposit individually on unparasitized whitefly nymphs. The ages examined were: 0-6, 6-11, 24-36 and 48 hours old. We also tested females that had previously been kept at 15°C for 10 days. Each case was replicated 4 times, with groups of several females that were confined in small glass vials with approximately the same number of males. All of the females that were 11 hours old or less oviposited. Of the older females, about 70% of the 24-36 hour old age group laid eggs, whereas those 48 hours or

older only laid occasional eggs. Only 2 progeny were obtained from the chilled females.

Direct observation indicated no male-female attraction and no mating, even when the sexes were brought together in a confined space during the first 2 post-emergence hours. Thereafter mating readily occurred. Attraction of the males to virgin females lasted about 48 hours.

The attracted male attempted to climb on the female's back, and then attempted to establish antennal contact which lasted for 3-5 minutes, after which the male moved backwards where genital contact was often established. No additional pre- or post copulatory behavior has been observed. Fertilized females laid only female producing eggs on unparasitized hosts. When given hosts that contained mature parasite larvae or parasite pupae, they refrained from laying eggs. Daily oviposition of fertilized females was examined individually, by confining each of 15 females for 24 hours after emergence with a male and then in a plant cage with a cotton plant that had 100-150 second to fourth instar hosts. Confinement was for 24 hours either at 25°C constant temperature or at 22-30°C (10/14 hr) fluctuating temperatures. Each day the female was transferred to a new plant. This lasted 12 days, after which the experiment was discontinued. This was done since preliminary experiments showed that a female laid most of her eggs during the first 10-11 days of life. The hosts were kept for 7-9 days and then examined for parasitism.

The results (Fig. 10) showed an oviposition peak between the 2nd and the 7th day. The oviposition pattern was similar in both, fluctuating and constant temperatures, whereas the number of eggs laid was somewhat higher in the former (945, 63 ± 4.16 vs. 868, 57.8 ± 4.74 totals and averages $\pm$ SE per

Fig.10. Daily oviposition of 15 E. deserti females during the first 12 days of their lives under two temperature regimes, Photoperiod = 14/10 L/D

female for fluctuating and constant temperatures respectively). However, the differences were not statistically significant. The peak number of eggs per female under constant temperatures were obtained in most cases on day 4 and 5. Under fluctuating temperatures 7 of the peak ovipositions occurred from days 1-3, and 6 peak oviposition occurred on day 4, indicating a shift to earlier peak oviposition. The daily oviposition rates were 5-16 eggs/female under constant and 9-16 under fluctuating temperatures.

The behavior of the female while on a host-infested leaf was observed and found to contain similar elements to those described by van Lenteren et al. (1980) for Er. formosa. The 4 leading elements were antennal drumming, drilling, host feeding and preening. The first is practiced after examination of the host, while encountering hosts and while examining them. After examining the host nymph, an act that may include walking on it and occasionally turning 180°, the female may start drilling with the ovipositor. Her wings and antennae adhere to her body and the ovipositor is extruded. At times the female may retract the ovipositor while moving about on the host. Once drilling has commenced, she may perform short drilling bouts of up to about 60 sec, or longer ones from 90-200 sec each. At times, after a short drilling bout, the female resumes drumming for a short time and then commences to host feed on the oviposition wound. Drilling is always terminated with preening. Preening may also take place between 2 sessions of antennal drumming.

In some cases we saw the female reexamine, redrill and even reoviposit in the same host several times, i.e., the female that has finished drilling left the host, then took a walk on the leaf during which she might examine other hosts, and came back to the original host for another bout. On one occasion, this behavior was seen with a mated female that repeated it 6 consecutive times and laid 3 eggs. Four unmated females, out of the 6 that were observed,

showed similar behavior, returning to the same host 2-4 times each. Oviposition preference was tested by observing the behavior of 7 mated and 6 unmated females each in a multiple choice situation. For experiments with mated females we isolated a female upon emergence with a male and a cotton leaf bearing a few hosts for 24-36 hours. This permitted her to mate and host feed and to gain some oviposition experience. The females were then confined in a leaf cage on a cotton leaf bearing some 50 whitefly nymphs in all larval instars and observed until she left the leaf or became disinterested. All activities of the parasitoid were registered, the hosts that were touched by her were dissected and the presence of parasitoid eggs was registered.

The females mainly oviposited in the 3rd and early 4th instars, whereas host feeding occurred on the 1st, 2nd and pupal stages (Table 4). Unmated females were placed on a leaf with whitefly nymphs that had previously been exposed to mated En. deserti females, and contained parasitoid larvae of all developmental stages. In order to better categorize the stages of host acceptance in this case, we classified the late stages of immature parasitoid development as: feeding 3rd instar, prepupa, young pupa (non pigmented), mature (fully pigmented) pupa. The results were that the 3rd instar larvae, the prepupae and the young pupae were the stages whose oviposition most often occurred. It was interesting to note that host feeding occurred only on non-hosts, i.e. on unparasitized nymphs (Table 15).

Table 14. Results of host-instar oviposition preference tests with 6 unmated

females of Encarsia deserti

Instar of Host *	No. of encounters		Drilling		Oviposition**		Host feeding	
	x $\pm$ SE,	Range	x $\pm$ SE,	Range	x $\pm$ SE,	Range	x $\pm$ SE,	Range
1st	3.0 $\pm$ 0.82,	0-5	0.3 $\pm$ 0.21,	0-1	0 0 0		0.3 $\pm$ 0.21,	0-1
2nd	2.7 $\pm$ 0.67,	1-5	1.5 $\pm$ 0.43,	0-3	0.17 $\pm$ 0.17,	0-1	0 0 0	
3rd	3.5 $\pm$ 0.76,	1-6	2.0 $\pm$ 0.63,	0-4	1.3 $\pm$ 0.42,	0-2	0 0 0	
prepupa	4.0 $\pm$ 1.10,	2-9	3.8 $\pm$ 0.96,	2-8	3.7 $\pm$ 0.61,	2-6	0 0 0	
young pupa	6.3 $\pm$ 1.48,	2-11	6.0 $\pm$ 1.13,	0-3	5.7 $\pm$ 1.09,	2-9	0 0 0	
mature pupa	2.1 $\pm$ 0.48,	1-4	1.3 $\pm$ 0.49,	0-3	0.3 $\pm$ 0.21,	0-1	0 0 0	
unparasitized host	2.6 $\pm$ 0.42,	1-4	1.3 $\pm$ 0.17,	1-2	0 0 0		1.3 $\pm$ 0.3,	0-2

* Host was an immature Encarsia deserti within a 4th instar or a pupa of B. tabaci, except for the "unparasitized nymph" which was a 3rd instar B. tabaci.

** As indicated by the presence of an egg upon dissection.

Table 15. Results of host-instar oviposition preference tests, with 7 mated

females of Encarsia deserti.

Instar of <u>B. tabaci</u>	No. of encounters		Drilling		Oviposition*		Host feeding	
	x $\pm$ SE,	Range	x $\pm$ SE,	Range	x $\pm$ SE,	Range	x $\pm$ SE,	Range
1st	5.9 $\pm$ 0.51,	4-8	0.7 $\pm$ 0.16,	0-1	0 0 0		0.7 $\pm$ 0.16,	0-1
2nd	4.9 $\pm$ 0.96,	3-10	2.1 $\pm$ 0.40,	0-4	0.4 $\pm$ 0.30,	0-2	1.57 $\pm$ 0.53	0-4
3rd	6.7 $\pm$ 0.64,	5-10	4.6 $\pm$ 0.53,	2-6	3.7 $\pm$ 0.47,	2-6	0.3 $\pm$ 0.18,	0-1
4th early	4.9 $\pm$ 0.74,	3-9	3.7 $\pm$ 0.52,	2-6	3.3 $\pm$ 0.47,	1-5	0 0 0	
4th prepupa	4.4 $\pm$ 0.69,	3-7	1.3 $\pm$ 0.29,	0-2	1.1 $\pm$ 0.26,	0-2	0 0 0	
4th pupa	5.0 $\pm$ 0.52,	3-7	0.1 $\pm$ 0.14,	0-1	0 0 0		0.14 $\pm$ 0.14,	0-1

* as indicated by the presence of an egg upon dissection.

Host discrimination

The ability to discriminate between already parasitized and still unparasitized hosts was tested by examining the dissection data obtained during the study of developmental duration and by direct observation. From dissections of hosts exposed to mated females, eleven cases of superparasitism with no more than 2 parasitoid progeny per nymph were found. However, superparasitism was not found after the first 6 postoviposition days. By that time we had discovered a total of 108 parasitized hosts superparasitism amounted to 10.2%. Superparasitism by unmated females could be detected throughout the immatures development during which we found 144 parasitized hosts of which 50 (35%) were superparasitized, each containing between 2 and 14 progeny amounting to 308 supernumeraries (Fig. 11).

Direct observations of the activity on a leaf were conducted with 4 mated and 6 unmated females. In each case the female was placed on a leaf with a suitable host population (24-43 3rd and early 4th instars with the mated female and 29-51 prepupae of E. deserti with unmated females). Each female was followed until she showed no interest in hosts or left the leaf patch. Observations were followed by dissection of all hosts with which the females had come into contact.

The 4 mated females were given a total of 130 hosts with which they had 106 encounters that resulted in 46 rejections and 60 acceptances. Some rejections occurred after antennal contact (19), after short ovipositor probes (13), or long ovipositor probes (14). Of the 60 accepted hosts, 53 were first encounter ovipositions and 7 were cases of superparasitism, that comprised 28% of all (25) encounters with already parasitized hosts. Fifty eight ovipositions, including all those resulting in superparasitism, were performed during long ovipositor insertions.

Fig. 11. Frequency distribution of the supernumerary eggs deposited by unmated E. deserti females during 24 hour confinements

The unmated females were given 224 hosts, of which they encountered 184, accepted 102 and rejected 82. The rejections included 37 after antennal contact only, 32 after short probes, and 13 after long probes. Of the 102 accepted hosts, 82 were first encounter ovipositions and 20 were cases of superparasitism, which were 40% of all (50) encounters with parasitized host. Ninety ovipositions, including 18 of those resulting in superparasitism, were performed during long ovipositor insertions. The ratio of rejections to encounters of unparasitized hosts was 28/81 for mated and 52/134 for unmated females. The ratio for rejections of already parasitized hosts was 18/25 and 20/25 for mated and unmated females respectively. Statistical evaluation (G test for independence) showed that mated females discriminated between parasitized and unparasitized hosts ($P < 0.05$) whereas unmated females did not.

Discussion

Encarsia deserti differs from other parasitoids of B. tabaci that have been studied previously (Encarsia lutea (Masi), (Foltyn, 1984); Eretmocerus mundus Mercet, (Foltyn and Gerling, 1985); Eretmocerus sp. from California, (Ostrowska, Vinson, Rose and Gerling, in prep.)) in developmental duration. Male pupae are found on the 7th post-ovipositional day and female pupae on the 9th. Adult emergence began for both sexes, on the 11th day with practically no protandry. However, whereas male emergence is concluded within 2-3 days, that of the females is prolonged, with a few emerging as late as 18 days after pupation.

The lack of protandry correlates well with the receptivity of the female which can occur a few hours after emergence, but not at emergence as is the case in numerous parasitoid species. This may provide the female with a chance to oviposit a few male producing eggs, since mated females fail to produce

male progeny.

The female En. deserti host relationship resembles those of En. formosa (van Lenteren et al., 1976), En. lutea (Foltyn, 1984), and Er. mundus (Foltyn and Gerling, 1985), in that she rejects some hosts after antennal contact and others after ovipositor probes. However, host rejection following host probing by the ovipositor was greater in En. deserti (55-60% of the rejections) than in Er. mundus (2-5% of the rejections) (Foltyn and Gerling, 1985). While the numbers of females tested in regard to host discrimination were small, mated females showed similar percentages of superparasitism in the dissection data as by direct observation (10.2 and 11.6%, respectively). Only one of these hosts had 3 eggs, the rest had 2 each. Observations showed that mated females discriminated between parasitized and unparasitized hosts, since their rate of rejection for the first was significantly higher than the second. However, either their ability to discriminate was incomplete, or there are additional parameters associated with the decisions to oviposit that are unknown since the female was occasionally seen to repeatedly return to an already parasitized host. Similar observations on the behavior of E. formosa by van Lenteren et al., (1976), indicated that a host that was rejected several times may be accepted for oviposition at a later encounter". However, they also were left without an adequate explanation.

Progeny of unmated females were distributed in a different fashion. The dissections that followed 24 hours of activity by 2 females, each upon 50-60 hosts, resulted in 20% superparasitism, with up to 14 eggs per host. Direct observations of a female En. deserti upon a whitefly infested leaf patch until she left, resulted in 35% superparasitism, but only 2 eggs per host. In addition, no discrimination between parasitized and unparasitized hosts could be shown, since the number of rejections of hosts from both categories did not

differ significantly. These data correlate well with additional field and laboratory observations obtained, but are still insufficient for a complete analysis of the behavior of En. deserti, for which more detailed studies are necessary.

b. Eretmocerus n.sp. from Southwestern U.S.

Utilization of the host Bemisia tabaci by Eretmocerus n. sp.

Eretmocerus sp. utilizes its host for procreation (endoparasitic larval development) as well as a source of protein for the adult females (host feeding). In this study we tried to follow the fate of whitefly nymphs that were fed upon or otherwise handled by the parasitoid female, and relate their results to the rate of normal parasitization.

The study was done through observations that consisted of two parts: Firstly, B. tabaci larvae were exposed to contact with a previously mated female of Eretmocerus sp. whose behavior towards individual hosts was carefully observed. Attacked host larvae were then marked and their development was followed. These observations were conducted daily until the death of the host individual or adult emergence of either host or parasitoid progeny. Individual nymphs of B. tabaci that were found on the same leaf, but were not contacted by the parasitoid, were used as controls.

Results are presented in Tables 16-19. Table 16 refers to the total mortality of B. tabaci larvae caused by Eretmocerus sp. which reached a total mortality of 80.4% for all larvae encountered by the parasitoid, including those rejected as possible candidates for oviposition. In the control individuals, not subjected to parasitoid attack, mortality was only 9.8% (Table 16). Corrected total mortality (CTM) due solely to Eretmocerus sp. attack should, therefore, be: $80.4 - 9.8 \% = 70.6 \%$. This figure is much higher than the parasitization rate of 37.3% of attacked host individuals

(Table 17).

Results concerning B. tabaci development following host feeding by the parasitoid are presented in Table 18. From 26 observed cases of host feeding, 17 (65.3%) host individuals were observed dead within 3 days. However, 9 (34.6%) of the larvae that were fed upon, continued to develop further, and one case resulted in whitefly emergence. During a previous study on the behavior of Eretmocerus sp. we also found a parasitoid egg under the whitefly nymph which was fed on.

Day to day observation on developing parasitoids in different whitefly instars provided the possibility of observing the difference in duration of development of Eretmocerus sp. Table 19 shows the results; total time from oviposition to emergence of parasitoid adult was similar in nymphs of instars 1-3 and somewhat shorter in instar 4.

The results of this study indicate that host handling by the parasitoid, i.e. feeding, examining the host and unsuccessfully attempting to oviposit, was a major mortality factor of B. tabaci populations under our experimental conditions.

Table 16. Mortality and survivorship of B. tabaci larvae subjected to Eretmocer sp. attack

Instar of <u>B. tabaci</u> nymph	No. of encounters observed	Mortality No. %	
1st	47	41	87.2
2nd	67	57	85.1
3rd	67	48	71.6
4th	39	31	79.5
total	220	177	80.4
Control	No. of host nymphs		
	152	15	9.8

Table 17. Eretmocer sp. attack on Bemisia tabaci nymphs and its consequence

Host instar (nymphs)	No. encounters observed	Mortality (dead <u>B. tabaci</u>)		Survivorship emergence <u>B. tabaci</u>		Parasitization emergence <u>Eretmocer</u>	
		No.	%	No.	%	No.	%
1	47	21	44.7	6	12.7	20	42.5
2	67	35	52.2	8	11.9	24	35.8
3	67	28	41.8	19	28.3	20	29.8
4	39	14	35.9	7	17.9	18	46.1
total	220	98	44.5	40	18.2	82	37.3

An 'encounter' was any contact of an Eretmocer sp. female with the host larva, engaging both antennae and ovipositor for a period of time lasting at least 10 sec. It may manifest attempts to accept the host or to reject it.

Table 18. The consequence of Eretmocerus sp. host feeding on Bemisia tabaci development.

<u>B. tabaci</u> instar	No. host feedings observed	No. dead nymphs	as instar
1	8	6 1 1	1 2 4
2	10	4 3 3	2 3 4
3	3	3	3
4	5	4	1 emerged 4
Total	26	17 (63.3%) did not continue to develop after being fed)	
		9 (34.6% continued development.	

Table 19. Duration of Eretmocerus sp. development in different nymphal stages of Bemisia tabaci at 25±1°C.

Instar of <u>B. tabaci</u>	No. of <u>eretmocerus</u> sp. developed		Average duration of development (days)	
	♀♀	♂♂	♀♀	♂♂
1	11	3	25.5	25.7
2	7	10	23.6	24.3
3	7	11	25.0	24.2
4	11	-	21.3	-

Behavior associated with recognition of the host by the parasitoid.

Introduction

Bemisia tabaci has a complex of parasitoids attacking its larval stages but very little is known about the host selection of these various parasitoids. The host selection process is one of several critical factors that determines the effectiveness of biological control agents. It has been divided into several possible behavioral events and the amount of time spent in each of these activities, and the effectiveness of each activity in ultimately resulting in oviposition in a suitable host, are considered to be major factors in determining the effectiveness of one species over another. Once the host is located, Eretmocerus sp. displays 4 different behavioral activities which are: host examination, ovipositor probing, oviposition, and host feeding; each of which contributes significantly to the efficiency of the parasitoid.

Our study describes the behavior of Eretmocerus sp. once contact for host acceptance has been made. In addition to the behavioral sequences, their duration and frequency have been recorded. Observations regarding the host selection behavior of Eretmocerus sp. will enable us to develop a comparative study of the same species group and to begin to evaluate their potential as biocontrol agents. The significance of developing a detailed analysis of parasitoid behavior prior to field release has been pointed out by several authors (Viggiani 1984, van Lenteren et al. 1980, van Lenteren 1981).

Materials and Methods

Eretmocerus sp. were reared on B. tabaci which were maintained on cotton (Delta Pine 264) grown under controlled climatic conditions in a greenhouse at $28^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and a relative humidity held between 60 and 70%. Both host and parasitoid were collected at the University of Arizona Experimental Farm at

East Pheonix and were provided by Dr. G. Butler of the USDA ARS Western Cotton Research Laboratory in Pheonix AZ. Eretmocerus sp. females used in all tests were collected from the continuous culture, and were exposed to hosts prior to experimentation, to ensure that they were experienced in the behavioral events leading to oviposition. Single females were presented with a cotton leaf infested with all B. tabaci immature instars. Direct observations were conducted for about 1 hour with the aid of a stereomicroscope and a fiber optic light. Over 20 hours of observations were conducted on 22 females with over 8 hours of additional observations conducted in connection with other studies.

A preliminary study helped establish the behavioral sequence and aided in the description of the general behavioral activities performed by Eretmocerus. Each of the various activities was given a symbol, then using an event recorder and a stop watch, the behavioral sequence and time of each behavioral event was noted. The events were also recorded on videotape and replayed for additional detail. Following the behavioral observations, parasitized B. tabaci were gently lifted from the substrate and the presence of Eretmocerus eggs was noted, so the behavioral events leading to oviposition or host rejection could be examined.

For scanning electron microscopy specimens were killed, mounted on aluminum holders and coated (20nm) with gold-palladium. They were examined with a JEOL JSM-2 Scanning Electron Microscope.

Results and Discussion

When released on a whitefly-injected leaf, female Eretmocerus display the following behavioral activities:

Walking-antennating-cleaning: The female randomly walks and makes short stops to closely examine various objects such as host eggs, leaf hairs, caste

East Phoenix and were provided by Dr. G. Butler of the USDA ARS Western Cotton Research Laboratory in Phoenix AZ. Erismoneura sp. females used in all tests were collected from the continuous culture, and were experienced in mating to ensure that they were experienced in mating to males.

Single females were presented to all Erismoneura sp. males. Males were presented to females about 1 hour with the aid of a glass slide. Over 10 hours of observation were made of the interactions between the sexes.

Observations were made of the interactions between the sexes. Males were presented to females about 1 hour with the aid of a glass slide. Over 10 hours of observation were made of the interactions between the sexes.

Observations were made of the interactions between the sexes. Males were presented to females about 1 hour with the aid of a glass slide. Over 10 hours of observation were made of the interactions between the sexes.

Observations were made of the interactions between the sexes. Males were presented to females about 1 hour with the aid of a glass slide. Over 10 hours of observation were made of the interactions between the sexes.

whitefly cuticle, with her antennae. While she walks, she keeps her antennae widely spread and moves them horizontally and vertically (Fig. 12). When she encounters an object she brings her antennae together and drums the object. These stops usually last no longer than 3 seconds. Similar short stops are made to feed on moisture and honeydew that occur on the leaf. The female's movement is often interrupted by preening which generally involves the antennae.

Antennating: The first contact with a host is always made with the antennae which the female brings together and she begins to drum the host very thoroughly, in particular the margin. Then the female often mounts the host, turns and drums the margin of the whitefly and the cuticle near the edge, and on rarer occasions, the middle of the host. Females usually spend 13 to 27 seconds in antennation (Table 20) but as little as 3 and up to 85 seconds have been recorded.

Ovipositor thrusting: Female Eretmocerus lay eggs underneath the immature whitefly and in order to accomplish this, the female unsheaths her ovipositor while mounted on the host and bends her abdomen down, so that the tip of ovipositor touches the host's surface. By moving forward she slides the tip of the ovipositor over the host's integument until the ovipositor tip reaches the edge of the host. The ovipositor is dropped down over the edge of the host and by pushing the gaster down and backwards, the female thrusts her ovipositor under and between the host and leaf. The female may withdraw her ovipositor completely and thrust it under the whitefly from a different angle.

Oviposition: Once the ovipositor reaches the proper location, the female becomes motionless for 70 - 80 seconds except for some abdominal movements. Following oviposition, the female withdraws her ovipositor and begins to preen, or leaves the host and preens. The egg is most commonly placed near the

mouthparts of the host, and less commonly posteriorly under the abdomen (Fig. 13a).

Fig. 12. Antennal movements of a searching Eretmocerus female - a. side view, b. top view

Fig. 13. Directions of the body of Eretmocerus sp. female a. when ovipositing, darker arrow - most frequently encountered stance; b. when piercing the vasiform orifice. * - locations of eggs under the host.

Postoviposition dance: Immediately after oviposition and before preening, the female alternately rubs her hind legs over the abdomen and tap the host surface. This activity, lasting from 3 to over 90 seconds, is sometimes alternated with some preening. However, there is no consistency observed with regard to its occurrence on various host stages, occurring only 75% of the time.

Preening: After oviposition, some females leave the host and preen, this activity lasting from a few seconds to minutes.

Pre-host feeding: Females often lick the vasiform orifice area of the host prior to host feeding. Before they host feed, females usually assume a position and behavior that is identical to pre-oviposition activity, with the female assuming her oviposition-like posture at the rear of the immature whitefly. The ovipositor is thrust along the midline (Fig. 13b) of the cuticle until the vasiform orifice is reached. The female then thrusts her ovipositor into the vasiform orifice in a similar way as described by Vet 1982 for another Eretmocerus species. Penetration of the orifice seems difficult, but the female repeats her attempts with final penetration involving the entire length of ovipositor which is being moved back and forth into the orifice. This activity also precedes host feeding.

Host-feeding: The female feeds by licking the area surrounding the vasiform orifice. Following ovipositor penetration of the vasiform orifice, the female turns around, lowers her head and stretches her antennae forward and close together and licks the area around the orifice from which oozes a liquid. Feeding was observed to last up to 47 minutes.

Standing-still: Females were observed to stand motionless for periods of time on the leaf surface or on the host usually with the antennae bent down and held together. This inactivity was frequent particularly after females had been active for an hour or so.

Fig. 14. Sequence and frequency of behavioral activities involved in Eretmocerus sp. attack of Bemisia tabaci.

Behavioral Sequence

Fig. 14 provides information regarding the sequence in which one behavior is likely to follow another. Once a host is contacted, most females (98%) antennated the host. Of the 98% responding to hosts, 30% rejected them and kept on walking. While the remainder mounted the host (63%), a few (5%) went on to host feed rather than oviposit. However, once females antennated the host (63%) most initiated ovipositor probing and oviposited (59%). These data are based on an average of the first 3 nymphal host instars. As presented in Table 20, the actual number of eggs deposited under 4th instar hosts was just over 7%.

Of the 5% that initiated licking of the vasiform orifice, 98% went on to pierce it. It was observed that the vasiform orifice probing usually increased the flow of material which the parasitoid consumed. A small amount of honeydew and material from the probed vasiform orifice was collected and compared to honeydew using gas chromatography, while the results indicated the presence of body fluid contaminants, it was not possible to prove by this method whether the body was penetrated. However, the fact that 98% of hosts in which the vasiform orifice was penetrated died, indicated that the host was injured by the parasitoid. Females always approached the host from the posterior end during host feeding, with the ovipositor sliding anteriorly over the cuticle until reaching the orifice, where it was thrust down. The vasiform orifice appeared to be the only accessible region where Eretmocer was able to penetrate it.

Viggiani (1984) considered that the reduced funicle segments and shape of the antennal club of Eretmocer to be an adaptation to "extensive" antennal examination of the large host surface conducted by the female. Indeed, the antennae begin each host encounter which is followed by a thorough antennal

examination of the host. Host contact with legs (tarsi) did not elicit antennation of the host though the host seemed to be perfectly acceptable (Viggiani 1984). We observed that while a female may accept a host on the first try, many female parasitoids withdrew their ovipositor and started again, usually by antennating the host (which is never as long as the initial antennation). After withdrawing their ovipositor, females thrust the ovipositor beneath the host often from a different angle.

Parasitoids ovipositing externally develop various adaptations for the attachment of the egg, often at a certain position on the host's integument (Flanders 1973). Eretmocer sp. oviposits externally although into a protected area between the immature whitefly and the leaf to which it is attached. This seems to be a good strategy in which the egg is provided with adequate protection against certain environmental conditions and, at the same time, escapes possible predation, and immune reactions of the host. This strategy may require the precise oviposition at certain sites underneath the whitefly which may be the function of the numerous sensillae found on the tip of Eretmocer ovipositor. The integument of the 4th instar whitefly larvae is undoubtedly thicker and, therefore, more difficult to penetrate by the young Eretmocer larva than that of previous instars. Thus, the location of a "weak spot" on host's undersurface may require more time in older B. tabaci larvae than younger. That may be the reason why we observed that "oviposition" under older host instars took longer than the same process under younger host larvae (Table 20).

Adult aphelinids derive their food mainly from nectar, sap and honeydew. However, females may obtain needed proteinaceous nutrition by host feeding (Viggiani 1984). The occurrence of host feeding in Eretmocer was first described by Vet and van Lenteren 1981. Our observations, as well as interpretations, of this phenomena are the same. The only difference concerns

the duration - we observed parasitoids feeding much longer (up to 40 minutes) than Vet and van Lenteren (1981).

The attempts to observe host feeding occurrence in starved females (kept in a vial 24 h with no water or honey), thirsty females (kept with honey but no water), and females which were allowed to drink water before being exposed to B. tabaci larvae did not give an answer with regard to the nature of Eretmocer sp. host feeding. All of the tested females were observed to host feed at some point, although starved females tended to start to feed on hosts and on honeydew, rather than initiate an extensive search for hosts and oviposition.

Parasitoids sometimes attempted to oviposit prior to host feeding and on two separate occasions (one out of about 30 observed host feeding) an egg was found underneath the host that was fed on by a parasitoid.

Rejection of parasitized hosts is done after antenna contact. Only Eretmocer sp. do not use the ovipositor to discriminate whether the host is parasitized. This type of behavior suggests detection of external marking pheromone and was also noticed for E. mundus by Foltyn and Gerling (1985). The majority of non-moving or slow-moving hosts are marked externally (van Lenteren 1981) which supports the case of a scale insect as a host. The marking substance may be spread over the host's surface during post-oviposition dance. However, this dance does not occur after all Eretmocer sp. ovipositions.

Table 20. The duration (in seconds) of behavioral activities involved in host acceptance and oviposition compared to percent of eggs laid by Eretmocerus sp. on different larval instars of Bemisia tabaci.

host instar	<u>antennation</u>				<u>ovipositor-probing</u>				%eggs deposited
	mean	min	max	n	mean	min	max	n	
1	19.3	3	45	39	88.6	20	140	39	39.7
2	13.5	5	25	29	121.5	65	210	29	29.7
3	25.6	5	70	23	168.1	85	380	23	23.4
4	27.4	5	85	7	193.6	140	485	7	7.1

III. Release and recovery of the parasitoids

Encarsia formosa, Encarsia lutea and Encarsia transvena were reared for 2-4 generations in the lab and then released in the fields when B. tabaci or T. vaporariorum (for E. transvena) populations were available.

Eretmocerus n.sp. and Encarsia deserti were reared in greenhouses that were located in Tel Aviv University, in Akko, and in the Eden Experimental Farm in the Bet Shean Valley. During 1984, we had considerable problems in rearing the parasitoids in large numbers, and were able to make only few releases throughout the whole summer. The reason for this difficulty was not discovered, but in 1985 we had better successes with the cultures.

Parasitoids were released in untreated cotton plots that were set aside for this purpose at Akko, Eden and Sde Eliyahu; and also on various untreated hosts of B. tabaci, most frequently Lantana camara. Hedges of Ipomoea and plants of Euphorbia also served as release sites when populations of B. tabaci were found infesting them.

Efforts were made to release the parasitoids as pupae, but when we had adults available in our cultures, we released them also.

Recovery was checked by collecting whitefly-infested leaves and rearing out the parasitoids from the whiteflies. They were then placed on microscope slides and classified.

Already in the spring of 1985, we found, both in the Tel Aviv University greenhouse and at the Eden Farm, sporadic infestations of Encarsia deserti in places adjacent to the release sites. In Eden, we also found Eretmocerus n.sp. Further releases that were made during 1985, were directed to gain a better foothold in the previous areas and to spread the parasitoids into other regions - like the Arava (Ein Yahav) or along the coast (Avichayil). Finally, we made a series of releases during the fall, on populations in the greenhouses of the Botanical Gardens of Tel Aviv University, hoping that the

all-year-round favorable temperatures that prevail there, will enable continuous survival of the hosts and their parasitoids.

This did not prove to be the case, since the B. tabaci populations dropped to a very low level during the spring of 1986, but recoveries of both species of parasitoids have been made.

Table 21 lists the releases of parasitoids. Records of first recoveries were as follows: Sde Eliyahu (1 recovery only in Sept. 1984)

Tel Aviv experimental greenhouse, 27.3.85 (En. deserti)

and 10.6.85 (Eretmocer n.sp.)

Eden Farm greenhouse, both species, 11.4.85

Sde Eliyahu, 6.8.85

Akko, 16.9.85

TABLE 21 Release records of parasitoids of B. tabaci and I. vaporariorum in Israel. E = Eretmocer; D = Encarsia deserti; T = Encarsia transvena; a = adult; p = pupae.

Date	Place	Parasites	Plant
30. 1. 84	Ein Yahav	150Ep, 50Dp	Lantana
13. 5. 84	Akko	45Ep	Cotton
27. 5. 84	Akko	?Ep	"
27. 5. 84	Sde-Eliyahu	?Ep	"
4. 6. 84	Eden	20Da	"
4. 6. 84	Akko	70Ea+p, 20Dp, 30Ta	"
11. 6. 84	Eden	560Ep, 15Ea	"
11. 6. 84	Akko	30Ea, 300Ep	"
18. 6. 84	Akko	60Ea	"
9. 7. 84	Sde-Eliyahu	25E, 10Da	"
9. 7. 84	Akko	10Ea, 5D + 20Ta	"
9. 7. 84	Eden	300p	"
27. 8. 84	Sde-Eliyahu	600Ea, 2500Ep, 20Da, 140Dp	"
17. 9. 84	Jericho	100Ea, 100Da	Euphorbia
19. 9. 84	Ramat Hasharon	50Da	"
1.10. 84	Sde-Eliyahu	300Ep, 100Dp	Malvaviscus
1.10. 84	Eden	100Ea, 50Da	Cotton
2.10. 84	Ramat Hasharon	150Ea	Euphorbia

7.10. 84	West Galilee	300Ep	Cotton
7.10. 84	Ein-Gedi	700Ep	Lantana
8.10. 84	Jericho	300?	Lantana, Euphorbia
8.10. 84	Ein-Gedi	?	Lantana
8.10. 84	Mevo-Hamma	500?	Cotton
9.10. 84	Mevo-Hamma	400Ep, 90Dp	Lantana
4.12. 84	Gan Shomron	30Ea, 10Da	"
5.12. 84	Sde-Eliyahu	250Ep	Cotton
5.12. 84	Jericho	250Ep	Euphorbia
18.12. 84	Gan Shomron	40Ea, 30Da	Lantana
26.12. 84	Gilat	420Ep, 200Dp	"

8. 1. 85	Akko	270Ep	Cotton
22. 2. 85	Jericho	280Ep, 520Dp	Euphorbia
19. 3. 85	Tirat-Zvi	400Ep, 500Dp	Lantana
29. 5. 85	Akko	400Ep	Cotton
9. 6. 85	Akko	350Ep	"
25. 6. 85	Akko	450Ep	"
4. 7. 85	Sde-Eliyahu	400E	"
16. 7. 85	Sde-Eliyahu	200Da, 500(E+D)p	Lantana
30. 7. 85	Sde-Eliyahu	2186Dp	Cotton
5. 8. 85	Akko	600E	"
11. 8. 85	Sde-Eliyahu	1360Ep, 360Da, 960Dp	"
18. 8. 85	Sde-Eliyahu	570Ep, 210Dp, 2500(E+D)p	"

25. 8. 85	Ramat Hasharon	200aE+D	Euphorbia
25. 8. 85	Ramat Hasharon	200aE+D	Lantana
3. 9. 85	Ein-Yahav	1000Ep, 300Dp	Lantana
11. 9. 85	Avichayil	50Da	"
17. 9. 85	Avichayil	50D	"
19. 9. 85	Ein-Yahav	1000E, 100D	"
24. 9. 85	Ramat Hasharon	270E, 60D	Lantana, Ipomoea
24. 9. 85	Ramat Hasharon	60E, 60D	"
21.10. 85	Baptist's Village	400E	Lantana
25.10. 85	Botanical Garden (TA)	300E	Various plants
28.10. 85	Botanical Garden (TA)	1000E	" "
7.11. 85	Botanical Garden (TA)	765E, 270D	" "
11.11. 85	Botanical Garden (TA)	536E, 20D	" "
14.11. 85	Botanical Garden (TA)	80E, 30D	" "
24.11. 85	Botanical Garden (TA)	140E, 199D	" "

Releases on the greenhouse whitefly:

25. 7. 84	Kfar Hanagid	50Ta	Verbena
28. 7. 84	Kfar Hanagid	150Ta	"
1. 9. 84	Kfar Hanagid	50Ta	"

Acknowledgements

We believe that one of the aims of this BARD grant was the training of young scientists in the process of scientific thinking, as well as in methodology and practice of entomology. Consequently, several graduate and post graduate students participated in the research leading to this report. Several subjects with which the report is dealing have served, and are still being pursued, as topics for M.Sc. and Ph.D. dissertations. They are as follows: Mating behavior of B. tabaci, Mr. L. Tzu-Yin (Ph.D.); plant-insect relationships of B. tabaci and cotton - Mr. R.Or (M.Sc.); behavior of Er. mundus and E. lutea in the laboratory - Ms. S. Foltyn (M.Sc.); behavior in the field - Mr. G. Forer (M.Sc.); biology of E. deserti - Ms. Y. Spivak (M.Sc.); host searching behavior of E. deserti - Ms. O. Shimron (Ph.D., ongoing project); biology and behavior of Er. n.sp. - Dr. Z. Ostrowska; taxonomy of the parasitoids, including determination of the imported material and description of new species - Dr. T. Rivnay; Dr. G. Viggiani from the University of Naples identified some of the parasitoids.. The work of all the above-mentioned is gratefully acknowledged.

Technical assistance has been rendered throughout the study, by staff and students of both institutions. In addition, Ms. Rebecca Burghardt helped with scanning electron microscopy and the following technicians participated, at one time or another, in the project: Mr. K. Barkai, Ms. S. Tamam, Ms. N. Liran Ms. S. Gilboa, Ms. S. Foltyn, Mr. S. Zozovski and Ms. T. Stern. We wish to thank all for their help. The help of the typists, Ms. N. Paz and Mrs. C. Shapiro and that of the photographers Ms. L. Maman and Mr. A. Shoob is also acknowledged herewith. Special thanks are also due to the Commonwealth Institute of Biological Control and at Silwood Park, Great Britain and to its head, Dr.D.J. Greathead. Dr. G. Butler, Jr., from the USDA laboratory at Phoenix, AZ, USA, the Koppert Company of the Netherlands and Dr. J. Ouillon from INRA, France.

F. DESCRIPTION OF COOPERATION

Two levels of cooperation were employed. Exchange of ideas and work plan enabled both partners to keep abreast of the latest scientific developments and to employ the techniques and achievements of one lab, in the second.

Fields of Research: As planned in the research proposal Israel and America worked on identical host and parasitoid species B. tabaci and Eretmocer sp. (in addition to work with other parasitoids). Therefore, the results of the basic studies in the U.S., where the behavioral components in the lab were studied, could be employed in the insect cultures that preceded field releases in Israel.

G. MAIN ACHIEVEMENTS

1. Bemisia tabaci

In the lab - this insect was shown to employ chemical attraction in mating, opening the way to possible mating disruption studies.

In the field - dependence of the oviposition rate upon the previous host plant has been shown.

2. Taxonomy. Three new species of whitefly parasitoid were found AND described from Israel.

3. Foreign exploration and introduction. Eretmocer sp. Encarsia formosa, Encarsia tricolor, Encarsia deserti, Encarsia transvena and Encarsia sp. from Pakistan, were all identified as parasitoids of B. tabaci and introduced into Israel. En. deserti has been recovered in several places while the status of En. formosa and Eretmocer is still doubtful.

4. Biology and behavior of the parasitoids. En. lutea and En. deserti females recognize parasitization by conspecifics, but not by Eretmocer. Unmated En. deserti readily cause superparasitism. This species has a very short developmental duration (11 days at 25°C) but some of the females exhibit delayed pupal emergence for as much as 15 days after pupation.

Eretmocer n. sp. spend much time host feeding during which about

as many hosts are killed as by direct parasitization.

5. Rearing, release, and recovery of material. The parasitoids that were introduced into Israel were reared on B. tabaci with young cotton plants as hosts.

Recovery of Eretmocerus n. sp. was, at best, occasional in spite of releasing thousands of individuals on untreated hosts that were infested with B. tabaci. En. deserti was recovered in low numbers during the fall of 1984. In the spring of 1985, it appeared spontaneously in greenhouses near the release sites at Eden Experimental Farm, and later also in various locations near Tel-Aviv University.

H. List of Publications

Gerling, D. 1985. Parasitoids attacking Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae) in Eastern Africa. *Entomophaga* 30(2):163-165.

Accepted

Gerling, D. (1986) Natural enemies of Bemisia tabaci, biological characteristics and potential as biological control agents. A review. *Agric. Ecosys. Env.*

Gerling, D., A.R. Horowitz and J. Baumgaentner. (1986). Autecology of Bemisia tabaci. *Agric. Ecosys. Env.*

Submitted

Gerling, D. and S. Foltyn. Development and host preference of Encarsia lutea (Masi) and interspecific host discrimination with Eretmoceris mundus (Mercet), parasitoids of Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae). *Z. Ang. Entomol.*

Gerling, D., Dita Spivak and S.B. Vinson. Life history and host discrimination of Encarsia deserti, a parasitoid of Bemisia tabaci (Hymenoptera, Aphelinidae: Homoptera, *Ann. Entomol. Soc. Amer.*

Gerling, D. and Reuben Or. Insect plant relationships between Bemisia tabaci and cotton in Israel. *Environ. Entomol.*

Rivnay, T. and D. Gerling. Whitefly (Aleyrodidae) parasitoids in Israel. *Entomophaga*.

In preparation

Ostrowska, E.Z., S.B. Vinson and D. Gerling. Eretmoceris sp. behavior associated with recognition of its host Bemisia tabaci.

Tzu-Yin, Li, S.B. Vinson and D. Gerling. Counting and mating behavior of the sweetpotato whitefly, Bemisia tabaci (Gennadius).

References

- Bakker, K., van Alphen, J.J.M., van Batenburg, F.H.D., van der Hoeven, N., Nell, H.W., van Strien-van Liempt, W.T.F.H. and Turlings, T.C.J. (1985). The function of host discrimination and superparasitization. Oecologia 67:572-576.
- Berlinger, M.J., Magal, Z. and Benzioni, A. (1983). The importance of pH in food selection by the tobacco whitefly, Bemisia tabaci. Phytoparasitica 11:151-160
- Flanders, S.E. (1973). Particularities of diverse egg deposition phenomenon characterizing carnivorid Hymenoptera (with morphological and physiological correlations). Can. Ent. 105:1175-1187.
- Foltyn, S. (1984). Relationship between Bemisia tabaci (Gennadius) (Homoptera:Aleyrodidae) and its parasitoids Encarsia lutea (Masi) and Eretmocerus mundus Mercet (Hymenoptera:Aphelinidae). M.Sc. Thesis, Tel Aviv Univ. 89 pp.
- Foltyn, S. and Gerling, D. (1985). The parasitoids of the aleyrodid Bemisia tabaci in Israel: Development host preference and discrimination of the aphelinid Eretmocerus mundus. Ent. Exp. Appl. 38:225-260.
- Gerling, D. (1985). Observation of the biologies and interrelationships of parasites attacking the greenhouse whitefly Trialeurodes vaporariorum (West.) in Hawaii. Proc. Hawaii Ent. Soc. 24:217-226.
- Gerling, D., Motro, U. and Horowitz, A.R. (1980). Dynamics of Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae) attacking cotton in the coastal plain of Israel. Bull. Ent. Res. 70:213-219
- Gerling, D. and Horowitz, A.R. (1984). Yellow traps for evaluating the population levels and dispersal patterns of Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Amer. 77:753-759
- Lenteren, J.C. van. (1981). Host discrimination by parasitoids. In: Semiochemicals, ed. by D.A. Nordlund, R.L. Jones and W.J. Lewis, John Wiley & Sons, New York.

- Lenteren, J.C. van, Nell, H.W., Sevenster van der Lelie, L.A. and Woets, J. (1976). The parasite-host relationship between Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae). III. Discrimination between parasitized and unparasitized hosts by the parasite. Z. Angew. Entomol. 81:377-380.
- Lenteren, J.C. van, Nell, H.W. and Sevenster van der Lelie, L.A. (1980). The parasite host relationship between Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae) IV. Oviposition behavior of the parasite, with aspects of host selection, host discrimination and host feeding. Z. Ang. Ent. 89:442-454.
- Mor, U. and Marani, A. (1984). Relationships between physiology of the cotton plant and development of the tobacco whitefly Bemisia tabaci. Abstract of a paper presented at the 3rd meeting of whiteflies in field crops and vegetables. Phytoparasitica 12:141.
- Vet, L.E.M. and van Lenteren. 1981. The parasite-host relationship between Encarsia formosa Gah (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Westw.) (Homoptera: Aleyrodidae), X. A comparison of three Encarsia spp. and one Eretmocerus sp. to estimate their potentialities in controlling whitefly on tomatoes in greenhouses with a low temperature regime. A. Ang. Ent. 91:327-348.
- Viggiani, G. (1984). Bionomics of the Aphelinidae. Ann. Re. Entomol. 29:257-276.
- Waage, J.K. (1979). Foraging for a patchily-distributed host by the parasitoid Nemeritis caenescens. J. Anim. Ecol. 353-371.

BARD
P. O. Box 6
Bet Dagan, 50250 ISRAEL

BARD Research Project No. I-264-81

Title of Research Project:

"Evaluation of Parasitoids for the Control of Whiteflies."

Name and Address of Investigators

Principal Investigator: Dr. Dan Gerling
Cooperating Investigator(s): Dr. S. Bradleigh Vinson

Name and Address of Affiliated Institutions

Principal Institutions: Dept. of Zoology, Televiv University
Tel Aviv, ISRAEL
Cooperating Institution(s): Dept. of Entomology, Texas A&M University
College Station, Texas

Projects Commencement Date: December 1982

Type of Report: Final cooperators report.

Signature
Cooperating Investigator

S. Bradleigh Vinson

Institution's Authorized Official
(Signature and Official Stamp)

Charlene Miller
Charlene Miller, Administrator
Texas A&M Research Foundation

Report BARD Project I-264-81
Prepared by Dr. S. B. Vinson, Cooperator

A species of whitefly parasitoid, Eretmocers spp., was discovered attacking Bemesia tabaci in cotton in Arizona. Because of its tolerance to hot dry conditions and because it differed from Encarsia, Eretmocers spp. was chosen for this study. This parasitoid was found to not only attack and develop in Bemesia but was found to extensively host feed.

Our initial interest was to determine if Eretmocers would attack the various instars of Bemesia and determine which were preferred. Studies of host utilization revealed a total parasitism rate of 37.3%, however, if total mortality of exposed whitefly larvae was considered then over 80% of the whiteflies exposed to Eretmocers failed to reach the adult stage. The discrepancy was due to extensive host feeding by Eretmocers. However, host feeding, while extensive, did not always result in death of the Bemesia. Over 34% of the Bemesia which had been fed upon continued to develop.

During this investigation we found that the development time increased as younger instars of Bemesia were attacked. We determined that Eretmocers larval penetration into its Bemesia host only occurred when the host reached the 4th instar. We also found that 2nd instar hosts are preferred as oviposition sites and that the egg is laid beneath the host where it lies dormant, hatching and penetrating the 4th instar host to begin development. Due to the delay in egg hatch the eggs of Eretmocers are subjected to some mortality. This information is being written up as a publication.

Orientation of Eretmocers to the plant and host:

We observed that Eretmocers approached the plant down wind and would hover above leaves when a very gentle air stream was used. We also observed that the parasitoids preferred orientating to leaves from plants which had a Bemesia infestation. However, we were not able to complete the research and suggest that some effort be expended at a future date on this research aspect as we believe orientation to the plant is important.

We also observed that Eretmocers would settle on a leaf, move around briefly and then fly again unless encountering honey dew. When honey dew was contacted females would antennate the leaf surface more vigorously and would remain on the leaf and in the area longer. Attempts to fractionate the honey dew to determine what components were responsible for the behavior were also not completed.

Host-examination behavior:

We developed a flow diagram of the behavioral elements of host examination leading to oviposition or host feeding. We also incorporated the frequency of each type of behavior into this diagram and the time allocated to each behavior. This is written up as one manuscript to be submitted for publication. We hope it will serve as a model for comparison of other species attacking Bemesia. Of interest was the finding that handling time of older host larvae increased as percent oviposition decreased. Thus, the presence of older instar hosts has a double impact on the population increased of Eretmocers by increasing handling time as well as reducing reproductive success.

Host feeding was a major mortality factor for Bemesia and exceeds mortality due to oviposition. We also found that while the Eretmocerus discriminates between already parasitized hosts as oviposition sites, they are less effective in discrimination when host feeding.

In addition to research on Eretmocerus we had to obtain some information on the host Bemesia. We have completed some life tables and examined the sexual behavior of Bemesia. The sexual behavior is similar to Trioleurodes vaporariorum. We also suggest that a pheromone is involved that might have potential in influencing mating success of Bemesia if isolated and identified. Two publications address this research.

Publications:

Ostrowska, E. Z., S. B. Vinson and D. Gerling (in prep.). Eretmocerus sp. (Hymenoptera: Aphelinidae) behavior associated with recognition of its host Bemesia tabaci Genn. (Homoptera: Aleyrodidae). Environ. Entomol.

Ostrowska, E. Z., M. Rose, S. B. Vinson and D. Gerling (in prep.). Utilization of Bemesia tabaci Genn. (Homoptera: Aleyrodidae) by the parasitoid Eretmocerus sp. (Hymenoptera: Aphelinidae). Entomophaga.

Li, Tzu-Yin, S. B. Vinson and D. Gerling (in prep.). Courtship and mating behavior of the sweetpotato whitefly, Bemesia tabaci (Gennadius). Ann. Entomol. Soc. Amer.

Li, Tzu-Yin, S. B. Vinson and D. Gerling (in prep.). Life tables for experimental populations of the sweetpotato whitefly Bemesia tabaci (Gennadius) under five different controlled temperatures. Ann. Entomol. Soc. Amer.