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STUDIES ON THE LIFE HISTORY OF METAPHYCUS FLAVUS (HOW.)

(ENC YRTIDAE)*

by

Z. Avidov and H. Podoler

The Hebrew University of Jerusalem, Faculty of Agriculture

Rehovot, Israel

Hebrew University of Jerusalem

Faculty of Agriculture, Rehovot

A B S T R A C T

Metaphycus flavus (How.) is the most abundant parasite of the brown soft scale (Coccus hesperidum L.) in Israel. Its life history and its ecological requirements were studied in order to develop methods for its mass production for biological control purpose. It was found that at 28°C and 70 - 80% R.H. it is possible to obtain large parasite populations of uniform age in short time. Higher temperatures and lower humidities are detrimental to the parasite's development or shorten the life span of its adults. On the average, there are 35 progeny per female, the maximum being 49. Development of the parasite takes from 12 - 27 days at temperatures of 28 - 18.5°C respectively. In young scale insects the parasite lays only one male egg, while from mature adult scales two and more parasites of both sexes emerge.

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Metaphycus flavus is the most abundant parasite of the brown soft scale (Coccus hesperidum L.) in Israel. It is found all the year round throughout the coastal plain as well as in the interior valleys. A survey carried out recently in the citrus groves of Israel (Rosen, 1967) has shown, that this parasite was common even in extremely sparse populations of the scale, a fact attesting to its excellent host-searching capacity. All stages of the brown soft scale are freely attacked by M. flavus, the parasite developing solitarily in younger larvae and gregariously in mature females of the host. Both sexes of the parasite may develop in a single host, whence up to 13 adult parasites have been obtained. In nature the sex-ratio varied with the season: Females greatly predominated in the spring and early summer, when the parasite and the host were most abundant; during other seasons, when the parasite as well as its host were relatively rare, a higher percentage of males emerged (Rosen, 1967).

M. flavus is an insignificant parasite of the black olive scale (Saissetia oleae (Bern.)) Israel.

In order to develop methods for the mass production of M. flavus for a biological control project, laboratory rearings were carried out to study the parasite's life history and especially its ecological requirements.

1. Rearing methods of the brown soft scale

As host material for the mass production of the brown soft scale various plant species and their parts, such as potato tubers, butternut squash (Cucurbita moschata) and citron melon (Citrullus vulgaris var. citroides) were tried. The only plant which was found suitable as a host for the brown soft scale was the citron melon. Rearing methods of this scale were obtained from Dr. T.W. Fisher, Riverside (personal communication) and were adapted, after preliminary trials, to the conditions of the laboratory.

It was found that for successful rearing of the scale it is necessary to pay close attention to the following factors:

- 1) Age of the melon: It was found that the closer infestation follows the picking of the fruit, the lower the mortality of the scale's larvae. The covering of all scales is more uniform and their development more rapid and homogeneous. About 3 weeks after harvesting, the effectiveness of the infestation decreases rapidly and many-fold more crawlers are necessary for sufficient covering of the fruit. Furthermore the normal development of the scales is disturbed.
- 2) Color of the melon: Fruits of dark green color are preferable. The effectiveness of the melons the color of which changed to yellow decreased as a food medium for the scales, sometimes independent of the fruit's age.
- 3) State of the melon: Great care must be given to the health of the melon.

Injuries such as scratches and squeezings extremely decrease the period of the melon's conservation.

The scales in our laboratory were reared at 25°C. At this temperature the total development (from birth to giving first birth) lasts about 50 days. In its first instar the larva is very motile and is positively phototropic, habits which are used for the gathering of the crawlers. In the second larval instar there is little movement. The oviposition period lasts about two weeks. Afterwards the scales die and every light touch causes them to drop from the melon.

The melons intended for infestation were thoroughly washed with lukewarm water and gently wiped. Prior to infestation they were transferred, for temperature adaptation, from storage to the rearing room, for about 24 hours.

To gather the crawlers light attraction was used (DeBach and White, 1960). The crawlers were transferred to the upper half of the melon, for the following reasons:

- a) Convenience of handling in later stages (in parasitization tests it is difficult to examine the whole surface of the melon).
- b) It is easier to check on the cleanliness of the melon which may be stained by the honeydew excreted by the scales.
- c) Easier handling and holding when transferring or washing
- d) Increase in melon conservation time, due to the reduced number of scales on them.

Immediately after the dispersion of the crawlers, the melons were transferred to a dark room, so as to encourage the crawlers to settle down and to cease their wanderings. Young melons, up to 5 weeks after harvesting, were kept in the dark room for 48 hours, older melons for 72 hours. They were then transferred to the rearing room in which a constant temperature of 25°C was maintained.

The brown soft scale excretes such honeydew which covers the melon in a short time. This honeydew interferes with the free migration of the larvae and causes death of scales. In order to diminish the amount of honeydew, the melon was covered by filter paper which sponges most of the squirted honeydew. The paper was renewed every 2-3 weeks, according to need. Once in 6 to 7 weeks the melons and the wooden frames on which they were placed, were rinsed and dried by air current.

2. Life History and ecology of *Metaphycus flavus* (Howard)

a. Developmental Biology of the Parasite

Rearing methods. Transparent plastic capsules, 7 sq. cm. at their basis and 3.5 cm. high were glued onto citron melons, artificially infested with the brown soft scale. Males and females of the parasite were confined in these capsules. At the start of the parasites' confinement, the scale insects were 35-45 days old. Small honey drops were smeared on the inner walls of the capsules as food for the adult parasites. The capsules were covered with fine muslin gauze. The melons were kept at 25°C in constant illumination.

For stock rearings of the parasite, scale-infested melons were maintained in plastic cages having 60 cubic cm of volume.

Development at various temperatures

Adult parasites were confined in plastic capsules according to the standard method, and kept there at 27°C for 24 hours. The melons were subsequently transferred to incubators of 5 various temperatures. The results of these trials (see Table 1) show that:

- a) Temperature of 32°C is detrimental to the development of this parasite;
- b) The threshold of development is 11.6°C and for the completion of one generation 193 days-degrees are required. Thus, the parasite is able to produce about 15 generations annually under natural conditions in the coastal area of Israel, provided that hosts for oviposition are available throughout the entire year;
- c) The differences between minimum and maximum duration of development as given in Table 1 show a decrease of time of emergence, from 7 days, at 18.5°C to 3 days at 28°C. These facts should be brought into account for the purpose of the mass breeding of this parasite, as with the shortening of developmental duration larger population of uniform age may be obtained.

Table 1: Duration of development of *Metaphycus flavus*

Temp. °C	Duration of development in days		Number of emerging wasps
	Average	Range	
18.5	27.5	25 - 31	40
20.0	22.6	20 - 24	25
24.0	15.0	13 - 16	27
28.0	12.0	11 - 13	77
32.0	-	-	no development

The duration of the various developmental stages was examined at 28°C. Ten parasitized scale insects were removed daily from the melons and dissected under a stereoscopic microscope. The results (see Table 2) show that the pupal stage is the longest one and takes about half of the total development time of the parasite

Table 2: Duration of the developmental stages of Metaphycus flavus at 28°C

S t a g e	Duration in days	
	Range	Average
egg	1 - 2	1.5
larva	3 - 5	4.0
prepupa	1	1.0
pupa	5 - 6	5.5
Total development		12.0

b. Life History of the Adult Parasite

Oviposition and fecundity

Plastic capsules were placed on melon sections with about 25 - 30 brown soft scales and covered with fine muslin. One male and one female were confined to each of the capsules. Every two days during the first 3 weeks these adults were transferred into new capsules. After this period the transfer was done at 5-days intervals only. The number of emerging progeny was recorded for every capsule. In this experiment the progeny of every female were determined, because it was impossible to examine the scales to count the parasite's eggs.

The number of progeny, however, was not identical with the number of the laid eggs. It was observed that a part of the parasite's eggs did not develop, as the host scales inhibited the eggs' development by encapsulating them. The number of the encapsulated eggs was quite variable in the hosts; a maximum of 8 encapsulated eggs were found in one scale insect. About 24 hours after oviposition the color of these eggs changed to dark brown. They lost their flexibility, hardened and were conspicuous by their dark color on the bright background of the young scale's body. In dark adult scales it was difficult to differentiate the encapsulated eggs without dissecting the scale insect. It was found that the encapsulation of some of the eggs in the parasitized scale did not disturb the normal development of the other eggs laid in the same host's body. Sometimes most of the eggs were found to be encapsulated in the rearings on the same melon, but the reason for this was not known,

On the average, there were 35.0 progeny per female (from 16 females) in these rearings kept at constant temperature of 27°C and 70 - 80% R. H. and the maximum was 49. These females survived about 37 days on

the average (60 at the maximum) and the average of oviposition-days was 32.3 (50 at the maximum). The preoviposition period lasted not more than half a day in all these rearings, and the pre-oviposition period was on the average 4.0 (maximum 20) days. Thus the females laid on the average 1.08eggs per oviposition-day.

Details of the distribution of egg laying according to the age of the females, in percentages from the total oviposition are recorded in Table 3, showing the results of the rearings of the above-mentioned 16 females. These figures show that oviposition started with a high peak and decreased gradually. The females laid on the average about 69% of their eggs (79% at the maximum) during the first half of their lives.

Table 3: Average oviposition and age of females of Metaphycus flavus

Age of females in days	Percentage of total oviposition
1 - 5	20.5
6 - 10	18.3
11 - 15	14.0
16 - 20	13.7
21 - 25	11.7
26 - 30	8.9
31 - 35	6.8
36 - 40	4.3
41 - 45	1.2
46 - 50	0.6

Ovipositional behaviour

The female parasite examines the host's dorsum with rhythmical and quick drummings by means of its antennae. This examination is usually short and lasts about 5 - 10 seconds; sometimes it is prolonged up to 20 seconds and more. After finishing the examination the wasp inserts its ovipositor into the scale's body whilst being on the host's back or at its side, the tip of the parasite's abdomen turning to the scale. When inserting the ovipositor the whole wasp's body moves rhythmically and its effort during this action is recognizable. Sometimes the parasite draws out its ovipositor from the host's body without ovipositing and turns to another scale. In this case the inserting process and the pulling out last about 25 - 30 seconds. If the insertion is accompanied by oviposition, this process last 4 - 5 minutes on the average. In isolated cases it lasted 6 - 7 minutes and once even 13 minutes were recorded. At every insertion only one egg is laid and upon finishing the

oviposition the parasite turns to another oviposition into the same host.

It was observed that M. flavus oviposits even in hosts already parasitized by the same species.

The number of eggs laid in the host reaches 5 - 6 on the average; the maximum number which emerged from one parasitized adult host was 14 wasps but by means of dissection a total of 22 parasite pupae were found in one host.

It seems that the adult parasites are not phototropic; when melons infested with scale insects were kept in plastic cages, the wasps concentrated on the lower side of the melons.

Survival of adults at various temperatures

Small numbers of males and females were confined together in glass vials of 15 ml volume, and small honey drops were smeared on the walls as food. The vials were kept in incubators until the death of the parasites, the air humidity being 70 - 80%. Each test group contained about 50 adults.

As shown in figures 1 and 2, the length of life was much longer for females than for males. In both sexes the life-span was very short at a high temperature (32°C), but there were no differences at middle ones (24 to 28°C).

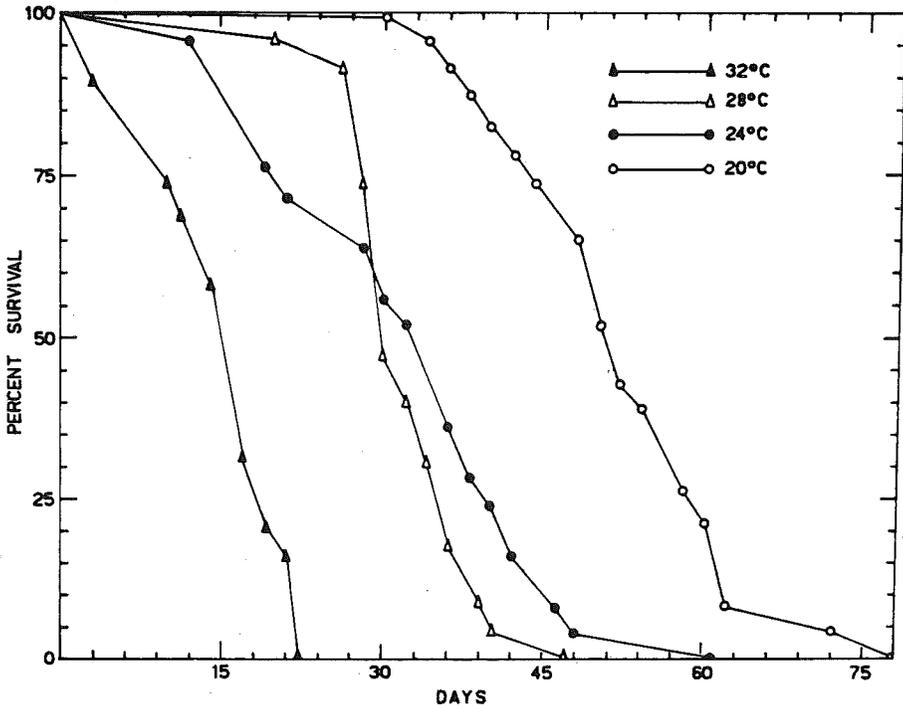


Fig. 1: Survival of Metaphycus flavus females under conditions of various temperatures.

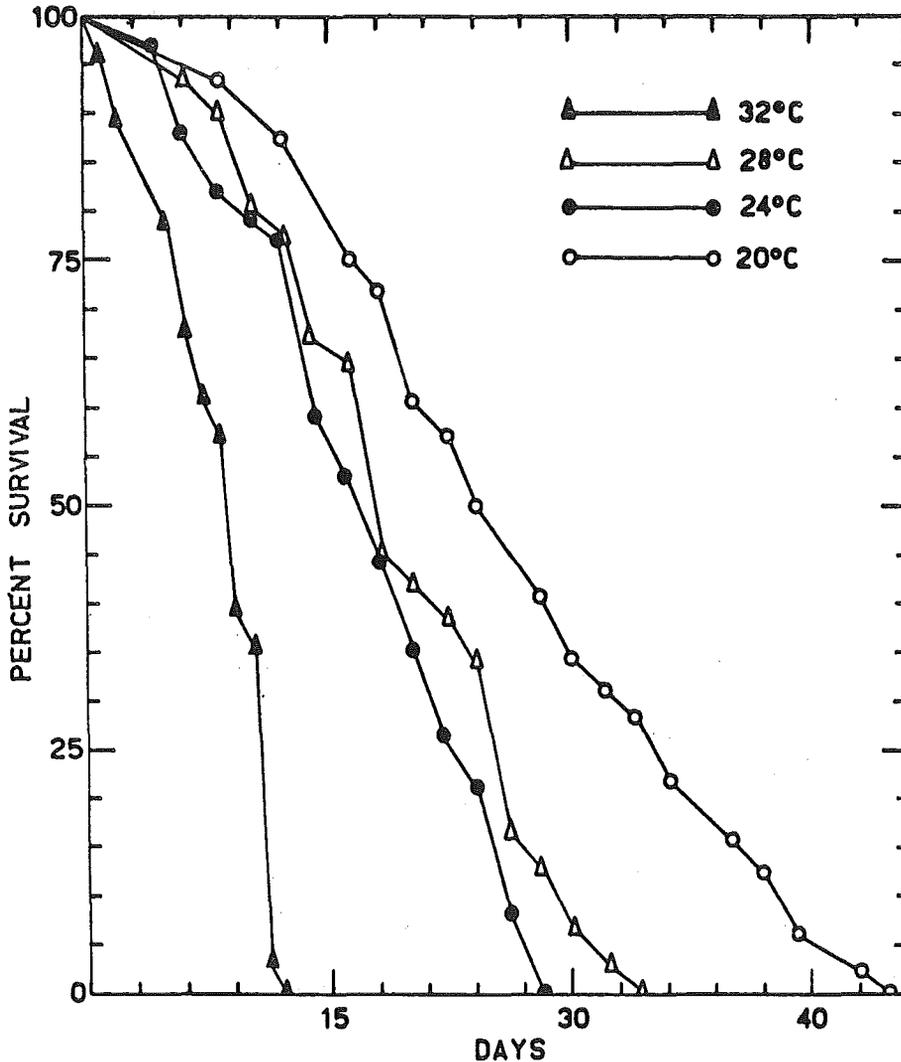


Fig. 2: Survival of Metaphycus flavus males under conditions of various temperatures.

Sixteen fertilized females were kept at 28°C in plastic capsules on scale-infested melons for oviposition. The maximum length of their life reached 57 days and a 75% mortality occurred after 45 days.

The results of these experiments showed that at the same temperature (28°C) ovipositing females lived longer than non-ovipositing ones.

Survival of adults at various humidities

Humidity solutions (on basis of KOH) were given in vials of 15 ml volume. The edge of the vials was closed with fine gauze, to prevent the parasites from falling into the solution. Upon the vial's edge a similar vial containing the adult parasites was attached with adhesive tape. On the walls of the upper vials, very small drops of a 50% sucrose solution were smeared as

food for the wasps. The empty vials were kept in the desiccators 48 hours before confining the parasites therein for the tests. The desiccators were kept at constant temperature of 28°C. For each humidity test at least 30 adults were used. The dead parasites were counted daily. Humidity of 0% was achieved by using crystals of P_2O_5 .

The results given in the two graphs (3 and 4) show that the influence of humidity on the parasite's females and males is similar. At 0% R.H. 75% of the males and females died after 7 and 8 days, respectively, and at the maximum after 10 days. At humidities up to 50% R.H. 75% mortality of the males and females occurred after 10 - 15 days and 17 - 19 days, respectively, and after a maximum of 18 or 20 days. Only at a higher humidity (69%) did 75% of the males and the females die after 23 and 26 days, respectively, and after a maximum of 30 and 32 days.

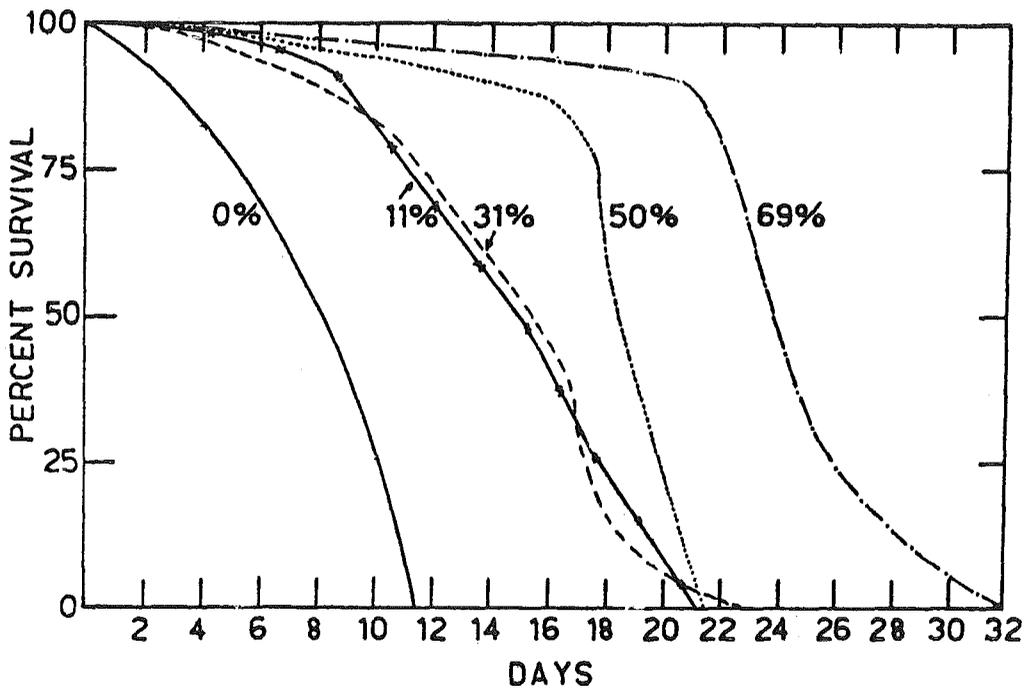


Fig. 3: Survival of Metaphycus flavus females under conditions of various humidities at 28°C.

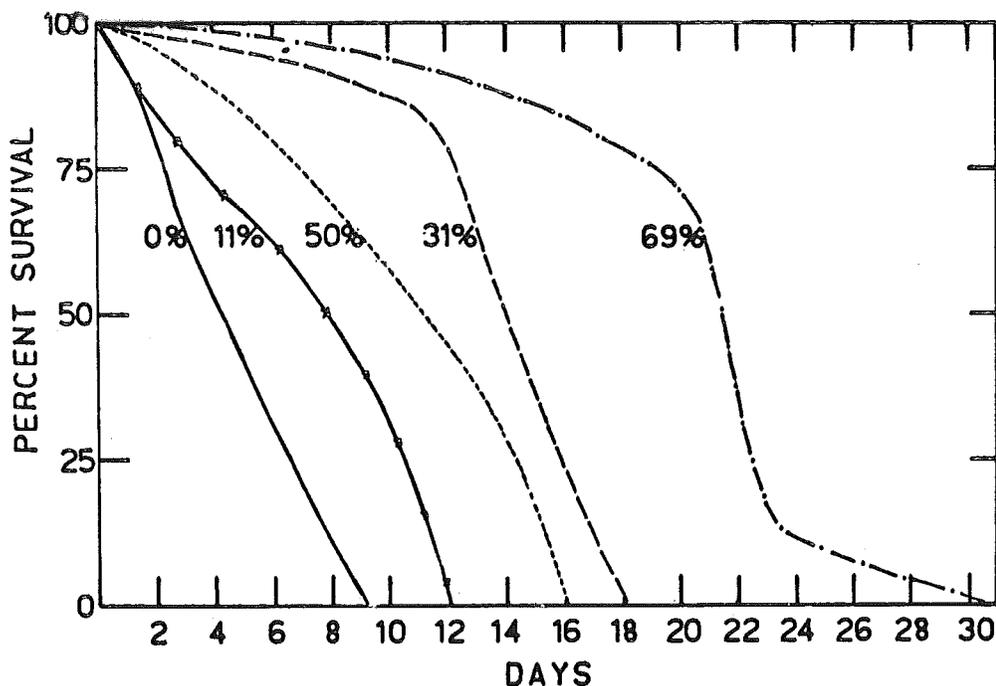


Fig. 4: Survival of *Metaphycus flavus* males under conditions of various humidities at 28°C.

Thus, it is apparent that for mass rearing the parasite the combination of 28°C and 70% R.H. is preferable to the other combinations tested.

Sex Ratio

During a country-wide year-round survey it was found that the females comprise 62.5% of the total field populations of *M. flavus*. Thus the ratio male: female in nature was about 1:2 (Rosen, 1967).

In laboratory rearings (at 28°C and 70 - 80% R.H.) from a total of 582 emergent parasites 329 were males and 253 females, i.e. 56.5% males and 43.5% females. It should be emphasized that these rearings started with a homogeneous young scale population. As will be shown later, mostly male parasites emerged from young scale insects, suggesting an explanation for the different ratio of the sexes in nature, where the host occurs always in all its stages, young and mature adults together.

Host's density and sex-ratio of the parasite

For these tests adult parasites, 24 hours after their emergence were used, i.e. a certain number of their eggs were already laid. The scale insects which served as hosts for oviposition were of equal age. Four parasite females and two males were confined in every plastic capsule for 4 days, and honey was used as food. In these tests densities of 2.8, 4.3 and 7.1

scales per sq cm were tried. The tests were carried out in 5 replications. The data summarized in Table 4 do not show an influence of host density on the ratio of the two sexes.

Table 4: Host's density and sex-ratio of Metaphycus flavus.

Number of scales per sq. cm.	Average progeny per female	Percentage of emerging		Ratio male:female
		males	females	
2.8	5.8	45.7	54.3	0.84
4.3	4.8	60.4	39.6	1.53
7.1	6.7	51.2	48.8	0.96

Host's age and sex-ratio of the parasite

Two series of tests were carried out:

- a) Mixed populations; i. e. scale insects of different ages. The aim of this series was to examine the sex-ratio, when the parasite could choose the host, according to its age, for oviposition.
- b) Populations of equal age. The purpose here was to examine the sex-ratio, when the parasite could not prefer a certain host age for oviposition.

In every plastic capsule two newly emerged parasite females and one male were confined for 48 hours and kept at 28°C and 70 - 80% R. H.

Two days before the assumed date of the parasite's emergence the parasitized scale insects in the first series were removed from the melon and classified into two groups:

- 1) Scale insects up to 4 weeks old (measurement 2 x 1 mm); in every host of this size only one parasite pupa was found.
- 2) Large scale adults (4 x 3 mm) which contained two parasite pupae or more.

The scales of the first group were transferred to small glass vials, 5 scale insects in every vial, covered with cotton plugs. In the second series (equal age populations) the scales remained in the capsules on the melon until emergence of the adult parasites, whose sex was then examined.

From the data summarized in Tables 5 and 6 it may be concluded that in young scales, whose size is not above 2 x 1 mm and whose body's volume cannot contain more than one parasite, the wasp laid only male eggs.

From 54 young scales (20 in the first and 34 in the second series) 54 adult parasites emerged and all of them were males. From mature adults scales, whose size reached 4 x 3 mm and which contained two or more parasite pupae wasps of both sexes emerged.

Table 5: Sex-ratio of Metaphycus flavus in mixed host populations (first series)

Classification of the hosts	No. of parasitized scale insects	No. of parasite progeny		Average number of progeny per scale
		total	♀♀ in %	
small young scales	20	20	0.0	1.0
big adult scales	20	62	27.4	3.1

Table 6: Sex-ratio of Metaphycus flavus in host populations of equal age (second series)

Age of the scales	No. of parasitized scale insects	No. of parasite progeny		Average number of progeny per scale
		total	♀♀ in %	
4 weeks	34	34	0.0	1.0
6 weeks	11	30	53.3	2.6
8 - 9 weeks	9	24	50.0	2.7

In the first series (mixed host populations) about 27% females emerged from mature adult scales, while in the second series their percentage was about twice as much. We are unable to explain this variability.

Effect of host and parasite-density on parasitization rate

Parasite females were confined in capsules for oviposition, their number per capsule differing according to the test series, and the number of host scales per area unit also differed. The parasites were kept in contact with their hosts for 4 days and subsequently removed. The melons were transferred to a 28°C incubator for parasite emergence. The trials were carried out in 3 - 5 replications.

Table 7: Changes in the parasitization rate of Metaphycus flavus with changes of host number per capsule.

No. of host scales per capsule	Average number of progeny per capsule	Average number of progeny per female
Series a		
	1 ♀ + 1 ♂ +	per capsule
10	2.0	2.0
20	2.0	2.0
30	2.3	2.3
50	2.0	2.0
Series b		
	2 ♀♀ + 1 ♂ ++	per capsule
10	3.5	1.8
20	4.0	2.0
30	4.0	2.0
50	4.3	2.2
Series c		
	4 ♀♀ + 2 ♂♂ ++	per capsule
20	23.2	5.8
30	21.3	5.3
50	24.0	6.0

From the data summarized in Table 7 the following conclusions may be drawn:

- 1) In series (a) and (b) the number of emerging parasites per mother-female was more or less equal in the various host populations.
- 2) In series (c), in which the number of parasite females was higher, the rate of progeny per mother-female was about 3 times higher than in the other series, but this was unrelated to the density of the host scales.

Based on these data concerning the number of scales per unit of area, Table 8 shows that the increasing number of host scales had no influence on the emergence-rate of the parasites in each one of the series, but this rate was about twice and eleven times higher in series (b) and (c), respectively, than in series (a).

Table 8: Relation between various combinations of inoculum (female parasites per sq. cm.) densities and scale density and resulting Metaphycus flavus progeny.

No. of host scales per capsule	No. of host scales per sq. cm.	No. of ovipositing parasites per sq. cm.	No. of emerging parasites per sq. cm.
Series a			
1 ♀ + 1 ♂ per capsule			
10	1.43	0.14	0.29
20	2.85	0.14	0.29
30	4.25	0.14	0.33
50	7.14	0.14	0.29
at the average			0.30
Series b			
2 ♀♀ + 1 ♂ per capsule			
10	1.43	0.28	0.50
20	2.85	0.28	0.57
30	4.25	0.28	0.57
50	7.14	0.28	0.62
at the average			0.56
Series c			
4 ♀♀ + 2 ♂♂ per capsule			
20	2.85	0.57	3.32
30	4.25	0.57	3.04
50	7.14	0.57	3.45
at the average			3.27

For the purpose of mass production of Metaphycus flavus we can summarize:

- a) Mass rearing of the host, the brown soft scale, can be done successfully on citron melon fruits.
- b) At 28°C and 70 - 80% R.H. it is possible to obtain within a short time large parasite populations of uniform age.

Higher temperatures and lower humidities are detrimental to the parasite's development or shorten the life span of its adults.

- c) In young scale insects the parasite lays only one male egg while from mature adult scales two and more parasites of both sexes emerge.

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References

- DeBach, P. and White, E. B., 1960. Commercial mass culture of the California red scale parasite Aphytis lingnanensis. Cal. Agric. Exp. Sta. Bull. 770, 58 pp.
- Rosen D, 1967. The hymenopterous parasites of soft scales on citrus in Israel. Beitr. Entomol. 17:225-283.