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THE FEEDING BEHAVIOUR OF *PHAROSCYMNUS NUMIDICUS* (COCCINELLIDAE), PREDATOR OF THE DATE PALM SCALE *PARLATORIA BLANCHARDI**

BY

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The searching capacity of *Pharoscymnus numidicus*, determined by criteria of mobility and survival rates, increases with age of larvae. The searching pattern is of a random nature; the predator does not orientate toward its prey, and the direction of its movement is influenced by physical factors such as light. The ability to feed on alternative foods increases the predator's chance to survive under natural food scarcity conditions. In this respect, its cannibalistic behavior is of particular importance for survival. The feeding capacity is dependent on instar, sex, history of larvae in relation to amounts of food previously consumed, atmospheric temperature, and population density of the host insect.

Pharoscymnus numidicus Pic. is one of the most important predators of the date palm scale (*Parlatoria blanchardi* Targ.) in Israel. Its distribution, fecundity, fertility, resistance to unfavorable conditions, and synchronization with prey have been investigated (KEHAT, 1966; 1967a, b). Other important factors which should be taken into consideration when the efficiency of a natural enemy is evaluated are searching capacity and feeding rates. Such information, concerning other Coccinellidae, is readily available (BANKS, 1954, 1956; DIXON, 1959; HAGEN, 1962; HODEK, 1957, 1967; KADDOU, 1960; SMITH, 1965); however, with regard to *Pharoscymnus numidicus*, our knowledge is extremely limited.

MATERIALS AND METHODS

The searching capacity of the insect was determined by studying its mobility, its longevity and its power of perception.

In the experiments designed to study mobility, a larva or adult was released in the approximate center of a uniformly illuminated searching area (50 × 50 cm) and its path was traced with a pencil. The total period of each test was 5 min. The length of path was measured and the speed was calculated in cm/min.

In order to study the power of perception, the behaviour of the coccinellid was observed in the searching area, where *Parlatoria* scales were randomly distributed.

The phototactic response and attraction of adults to different wave lengths of

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the spectrum were recorded by keeping adults, which had been starved for 24 hours, in cages (5 cm diam., 10 cm long) illuminated through a 2 mm hole with different filters (Fig. 1). The percent transmission of the different wave lengths through the different filters was recorded by a Beckman apparatus. After 1½ hours the number of individuals attracted through the hole was counted. The temperature in the cages fluctuated between 31 and 34° C; the average global radiation of sunlight during the experiments was 181—195 g/cal/cm^2/min.

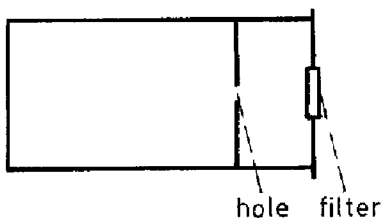

Fig. 1. Cage used for determining the attraction of adults to different wage lengths of the spectrum.

The starvation longevity of larvae and adults was determined by caging them singly, and keeping them without food until death. All larvae and adults used in the experiments had just hatched, moulted or emerged and had no access to food immediately thereafter. All cages (plexiglass, 10 mm diam., 6 mm high) were ventilated and maintained at constant levels of temperature (27° C) and relative humidity (75%).

Increase of survival by feeding on alternative nutrients was examined by offering different prey insects. Also experiments were conducted studying the difference between rates of cannibalism among the different stages by confining them together in small cages. To investigate cannibalism of newly hatched larvae on eggs, single larvae were supplied with certain numbers of eggs, and the larval delevopment was followed. In experiments on larval cannibalism on other larvae of the same age or on pupae, only two individuals were put in a cage. Cannibalism tests involved mobile larvae only. Therefore the results may not reflect further cannibalism when some of the larvae are moulting.

The feeding capacity was examined by rearing single larvae and adults of the predator on females or nymphs of *P. blanchardi* in cages illustrated in Fig. 2. The rate of prey consumption was recorded under conditions of both food abundance and food scarcity.

RESULTS AND DISCUSSION

Searching behaviour

As the adults of *P. numidicus* usually do not fly, the searching ability of this predator depends mainly on the speed of its crawling. First instar larvae being

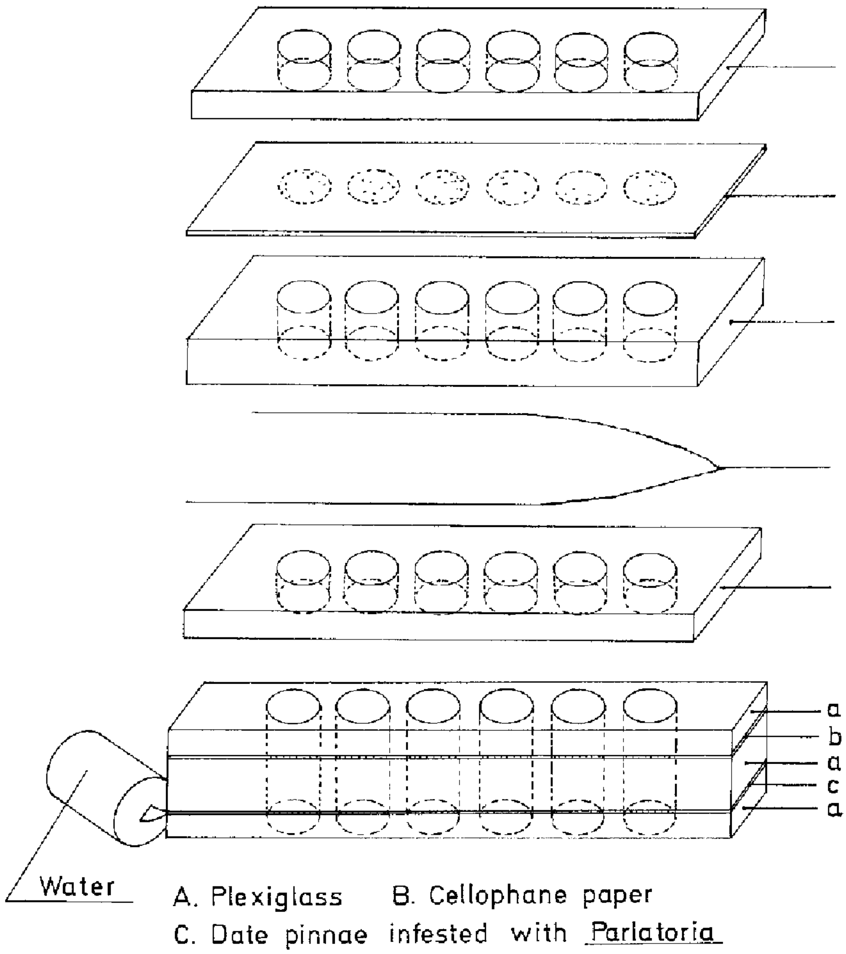

Fig. 2. Diagram illustrating the construction of the cells used for determining the feeding capacity of *Pharoscymnus numidicus*.

very slow crawling, are somewhat limited in finding the prey and consequently may easily starve to death. The mobility and consequently the efficiency of prey searching increased with larval development and was highest in the adult stage (Table I). In the absence of flight, this predator is therefore somewhat restricted in its ability to disperse and to find new sources of food, but, on the other hand, very dense populations of the predator are attained once it reaches its prey.

The searching pattern is random. The larvae and adults often searched rather thoroughly in areas already visited by them, and left some others unvisited. There were no directional movements which led the predator toward its prey, and chance played the main role. Both larvae and adults found the prey only after physical contact had been made. It seems that the predator lacks the power of host percep-

TABLE I

Speed of crawling (cm/min.) of Ph. numidicus *larvae and adults (27° C, 75% R.H.)*
(10 individuals of each stage were examined)

Stage	Average	Range	Stage	Average	Range
First instar larvae	4.8	4.1— 6.8	Fourth instar larvae	24.0	21.0—29.0
Second instar larvae	15.0	11.0—17.0	Starved adults[1])	33.0	30.0—40.0
Third instar larvae	20.0	19.0—21.0	Well-fed adults	hardly moves	

[1]) Starved for 24 hours before the test.

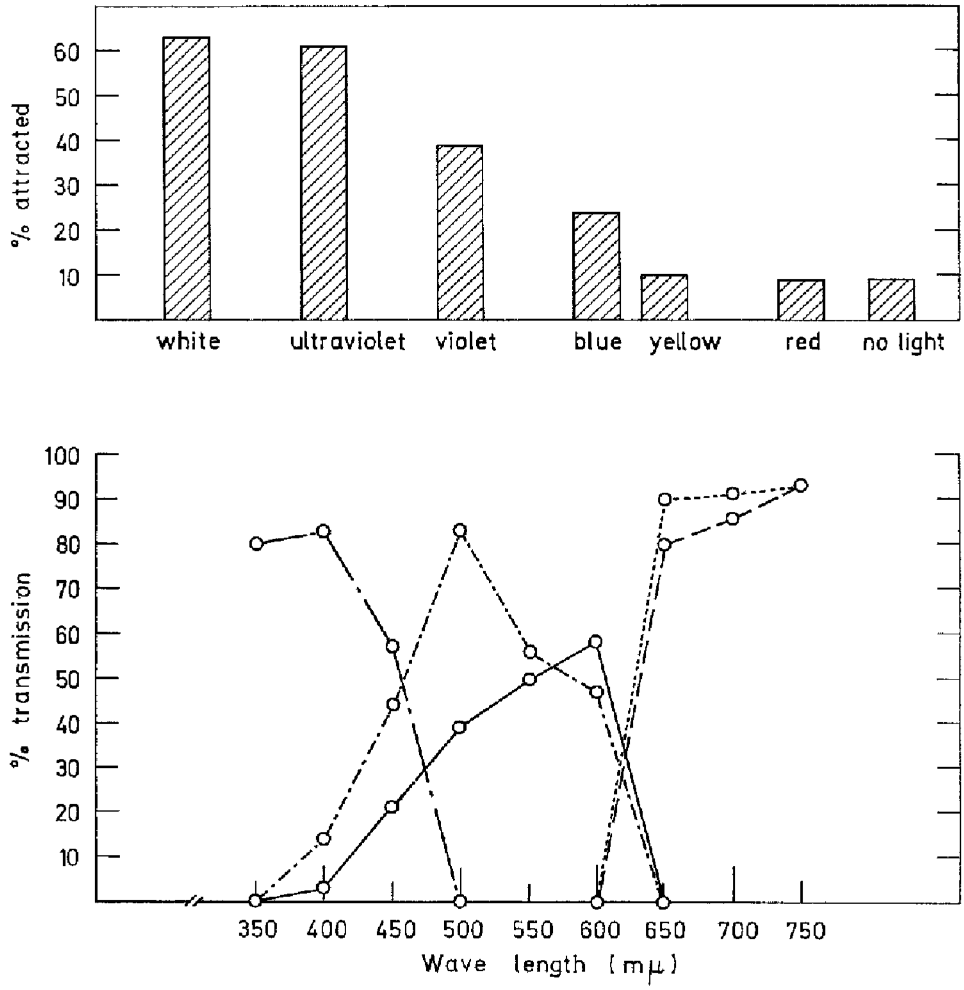

Fig. 3. Percent transmission of different wave lengths through the filters used in the experiment (bottom) and percent of beetles attracted to different wave lengths (top).

tion over distances. This has also been shown for some other Coccinellidae (BANKS, 1954; DIXON, 1959; HAGEN, 1962; HODEK, 1967 and KADDOU, 1960).

The direction of movements may be influenced by light. The adults were positively phototropic to the short rays of the spectrum. There was some attraction also to violet and blue rays but this was due to the transmission of some UV rays through these filters. The percent of beetles attracted was always higher as the rate of the UV rays transmitted through the filter rose (Fig. 3).

Starvation survival

The starvation survival increased with age of larvae. Short longevity, in addition to the larvae's slowness, is also a factor restricting the searching capacity of first instar larvae. When starved, fourth instar larvae showed a higher survival rate than adults (Table II).

The survival of the adults was negatively correlated with temperature (Table III). The shortening of the adult's longevity at higher temperature need not necessarily restrict its searching capacity, as its higher activity at those temperatures may compensate for its shorter life.

TABLE II

Starvation longevity of larvae and adults of Ph. numidicus (27 C, 75% R.H.)
(15 individuals of each stage were examined)

Stage	Average (days)	Range (days)	Stage	Average (days)	Range (days)
First instar larvae	3.4	3—4	Fourth instar larvae	11.3	8—14
Second instar larvae	5.1	5—6	Adults	6.5	5— 8
Third instar larvae	6.5	6—7			

TABLE III

The influence of temperature on the longevity of starved Ph. numidicus *adults (75% R.H.)*
(At each temperature, 15 individuals were examined)

Temperature (°C)	Average (days)	Range (days)	Temperature (°C)	Average (days)	Range (days)
15	15.2	9—24	27	6.5	5—8
20	11.2	9—16	29	5.0	4—7

Alternative food

In the absence of its natural prey, the predator was capable of increasing survival by feeding on alternative food such as *Prodenia litura* eggs, aphids (*Brachycaudus amygdalinus* Schout), mites (*Tetranychus cinnabarinus* Boisd.), and aphid honeydew. These types of food were nutritionally deficient for egg production. When feeding on *Prodenia* eggs, the insect could develop from first instar to the adult stage. This has also been shown for *Coccinella 11-punctata* (IBRAHIM, 1955).

Under conditions of food scarcity, cannibalism is of particular importance for survival. A high degree of cannibalism was observed only in those experiments in which larvae or adults were kept together with eggs. Pupae were highly resistant to larval or adult attacks, apparently due to their protective integument. The degree of cannibalism between larvae of the same instar was small (Table IV). Feeding on eggs, even when larvae were supplied with only a small number of eggs, increased the survival rate of the first-instar larvae (Table V), and enabled larvae,

TABLE IV

Rate of cannibalism between the different stages of Ph. numidicus *(27° C, 75% R.H.)*

Cannibalism	Combinations of cannibalism examined: Cannibalistic stage	Stage exposed to cannibalism	No. of replicates	% cannibalism[1])
Between the mobile and sessile stages	First instar larva	egg	10	100
	Second instar larva	egg	10	100
	Third instar larva	egg	10	100
	Fourth instar larva	egg	10	100
	Adult	egg	10	100
	First instar larva	pupa	15	0
	Third instar larva	pupa	30	33.3
	Adult	pupa	34	41.1
Between the mobile stages themselves	First instar larva	First instar larva	20	10.0
	Second instar larva	Second instar larva	18	5.5
	Third instar larva	Third instar larva	15	6.6
	Fourth instar larva	Fourth instar larva	15	0
	Fourth instar larva	Second instar larva	20	80.0
	Adult	Adult	15	0
	Adult	Third instar larva	15	0

[1]) % of replicates in which cannibalism occurred.

TABLE V

Survival of newly hatched larvae of Ph. numidicus *cannibalizing a limited number of eggs (27° C, 75% R.H.)*

(Each trial included 10 individuals. In no case was second ecdysis completed)

Total number of eggs offered	Total number of eggs devoured by the 1st instar larva	Duration of 1st instar larva (days)	First ecdysis completed	No. of eggs devoured by 2nd instar larva	Duration of 2nd instar larva (days)	Total duration of life as 1st and 2nd instar larva (days)
0	0	3.2	—	—	—	3.2
1	1	5.8	—	—	—	5.8
2	2	4.0	+	0	3.0	7.0
3	3	4.0	+	0	4.5	8.5
4	3—4	4.0	+	0—1	7.5	11.5
6	3—5	4.0	+	1—3	11.0	15.0

when supplied with an abundant number of eggs to develop to the fourth instar, but did not allow them to pupate. The larval mortality rate increased with age probably as a result of nutritional deficiencies becoming more critical. On the other hand, the developmental rate remained the same as on normal food (Fig. 4). These findings are in contrast to date on *Coccinella 7-punctata* larvae (KOIDE 1962 - in HODEK's 1962 review) which were shown to behave similarly as regards mortality and developmental rate, but completed development and pupated, when feeding on their own eggs.

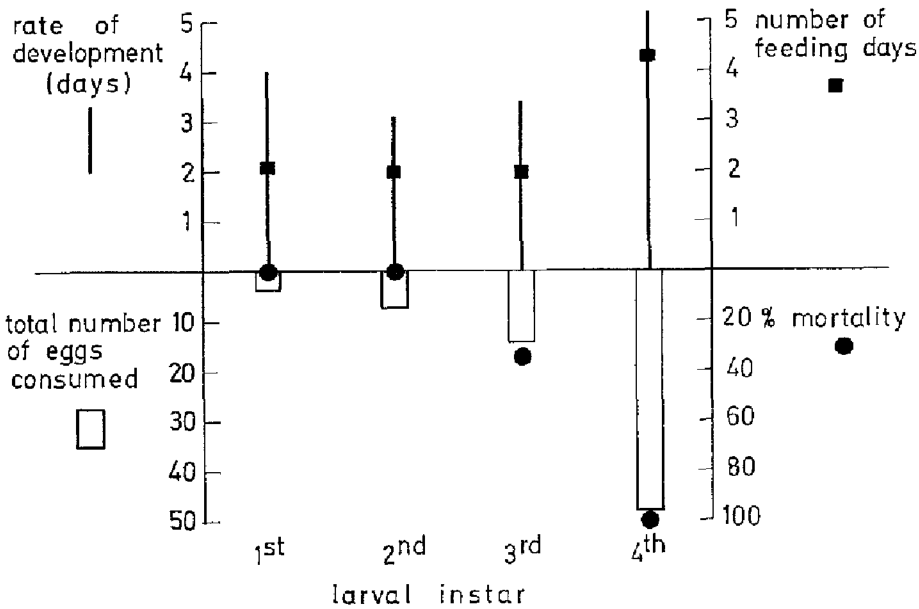

Fig. 4. Cannibalism of *Ph. numidicus* larvae on an abundant number of eggs (27° C, 75% R.H.). (Each trial included 15 individuals).

Cannibalism only was thus not enough, and to complete its development the larva had to feed also on its natural prey. Feeding on *Parlatoria* in the early larval instars allowed completion of development even when the late larval instars lived only by cannibalism on egs. On the other hand, when the larva fed on eggs in its early instars it could complete its development only if it was later given *Parlatoria*. Larvae which had fed by cannibalism on eggs in their first three instars, and had consumed less than about 38 eggs in their fourth instar when later fed on *Parlatoria* succeeded in pupating, apparently due to a sufficient consumption of *Parlatoria*. If they ate more than about 38 eggs they were unable to pupate even when offered *Parlatoria*. It seems that the larvae had to consume a critical number of *Parlatoria* scales to allow them to pupate (Fig. 5).

The total number of eggs consumed by the fourth instar larva, subsisting in previous instars either on its natural prey or by way of cannibalism, was the same

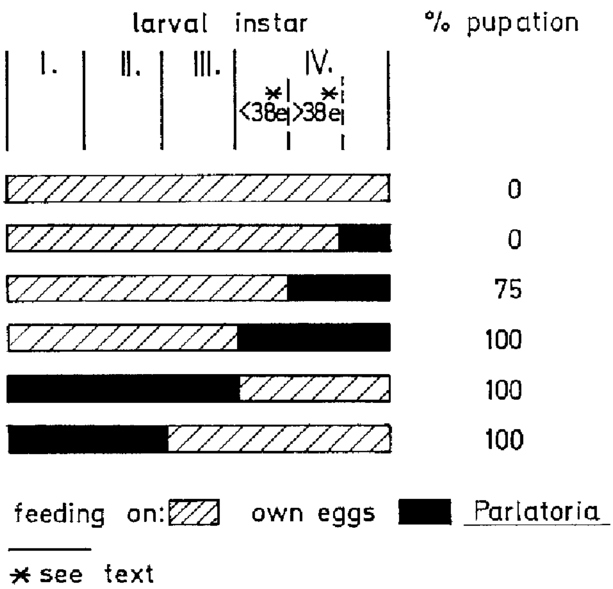

Fig. 5. Likelihood of *Ph. numidicus* pupating with the aid of cannibalism. (Each trial included 15 individuals).

(40—61 eggs). This indicates that the larva's inability to pupate after living by cannibalism throughout its life is not due to an insufficient number of eggs consumed in the fourth instar, but to nutritional deficiency. Nevertheless, increased survival through feeding on eggs is in itself important for the existence of the species (BANKS, 1956).

Feeding rate

The feeding rate was influenced by the following factors:

Stage of development — The total number of scales consumed and the daily rate of feeding increased with age of larvae. This rise remained almost unaffected by the nature of the food given, whether nymphs or females of *P. blanchardi*. Of the different larval instars, the fourth instar was the most voracious; this was due to an increase in the daily rate of consumption and the number of feeding days (Table VI). The larvae did not feed during the inactive periods - shortly before and after ecdysis. Feeding was required at every instar, and no instar reached the next stage when food had been completely lacking.

Sex — Female larvae were more voracious than male larvae. With adults, too, the rate of feeding differed — egglaying females had a higher daily feeding rate than non-egglaying females, and the latter consumed more than males. Of the different stages of the insect the egglaying female was the most voracious. (Table VI, Fig. 6).

TABLE VI

The feeding capacity and duration of development of Ph. numidicus *larvae (27° C, 75% R.H.)*
(In each stage, 12—15 individuals were examined)

Larval sex	Larval instar	Mean duration of development (days)	Average number of feeding days	Average number of *Parlatoria* females consumed		Average number of *Parlatoria* nymphs consumed	
				daily	total	daily	total
	First	4.0	2	3.0	6.1	18.0	36
Male	Second	3.1	2	8.1	16.3	40.0	80
	Third	3.5	2	15.8	31.6	76.0	152
	Fourth	7.6	4	21.0	84.0	102.5	410
	Total	18.2	10		138.0		678
	First	4.0	2	4.0	8.0	20.0	40
Female	Second	3.2	2	9.0	18.0	46.0	92
	Third	3.4	2	18.6	37.3	90.0	179
	Fourth	7.7	4	24.7	99.1	129.5	518
	Total	18.3	10		162.4		829

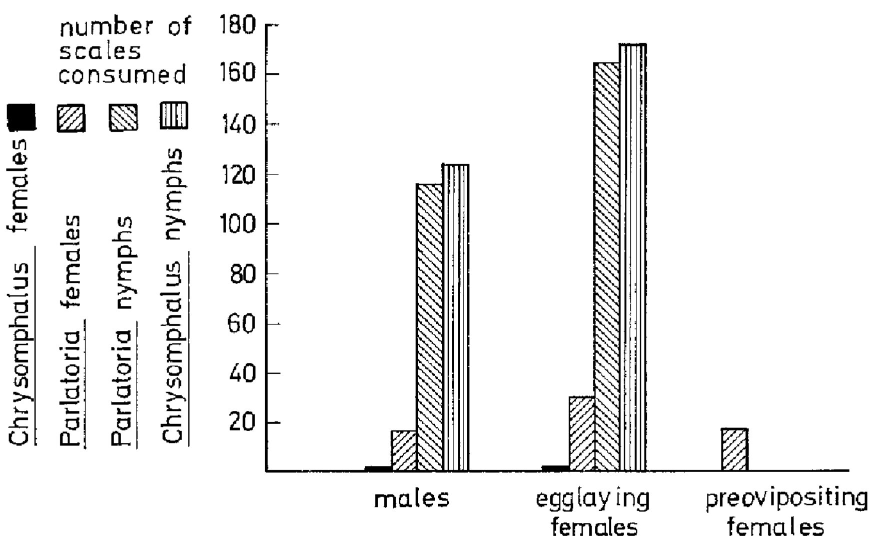

Fig. 6. The daily feeding capacity of adult *Ph. numidicus* (27° C, 75% R.H.). (Each trial included 10 adults; duration of experiments — 10 days with males and egglaying females, 5 days with preovipositing females).

Food specifity — The total number of scales consumed was influenced by the nature of the food. Thus both larvae and adults of *Ph. numidicus* devoured 5—7 times more *Parlatoria* nymphs than adults. The total consumption was also affected by the species of the host consumed. Thus adults of *Ph. numidicus* consumed about 10 times more *Parlatoria* females than *Chrysomphalus aonidum* females, which may be due to the differences in size or nutritional value between the females of these two scales. No such differential consumption was observed when nymphs of the two scale species served as prey (Table VI, Fig. 6). Furthermore, *Asterolecanium phoenicis* females (another pest of date palms) were highly immune to attack by *Ph. numidicus* larvae or adults, apparently due to their hard scale coverings, whereas the nymphs of this scale were devoured readily. Even with *Parlatoria,* the first instar larvae of the predator had some difficulties with feeding on the female scales (22% of these larvae died before reaching the next instar), whereas they readily devoured the other stages of the scale. Eggs of *Parlatoria* or *Chrysomphalus,* situated beneath the scales, were not attacked by adults of *Ph. numidicus.* This behaviour permits the re-establishment of the host insect and serves as a mechanism for maintaining the predator.

Temperature — The total feeding capacity was not affected by temperature, whereas the average daily rate of consumption and the number of feeding days were (Fig. 7). This has also been shown for *Coccinella 7-punctata* (Hodek, 1957; Hukusima & Sakurai, 1963 - in Hodek, 1967).

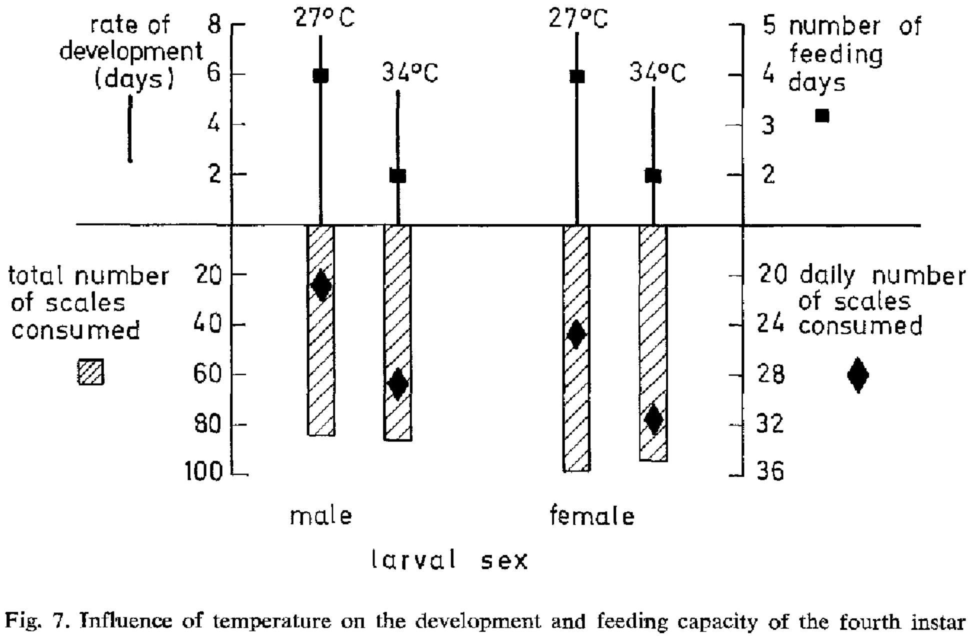

Fig. 7. Influence of temperature on the development and feeding capacity of the fourth instar larvae of *Ph. numidicus* feeding on *P. blanchardi* females (75% R.H). (Each trial included 12—15 larvae).

Scarcity of food — For fourth instar larvae feeding under conditions of food scarcity, the overall rate of development was lengthened, the number of feeding days increased, the mortality rate rose, and the total food consumption dropped. Very small differences in the extremely suboptimal daily food supply brought about very important changes in mortality, and in developmental rate, but not so in the total consumption or in size. On the other hand, the enormous differences in the daily food supply near the optimum did not appreciably change either mortality or developmental rate, but significantly influenced the total consumption and the size of adults (Fig. 8). The developmental rate of the pupa was not influenced at all by the changes in the daily food supply and was in all cases, about 7 days.

The minimal amount of food which allowed completion of larval development was about seven times less than the normal consumption (see Fig. 8); this indicates

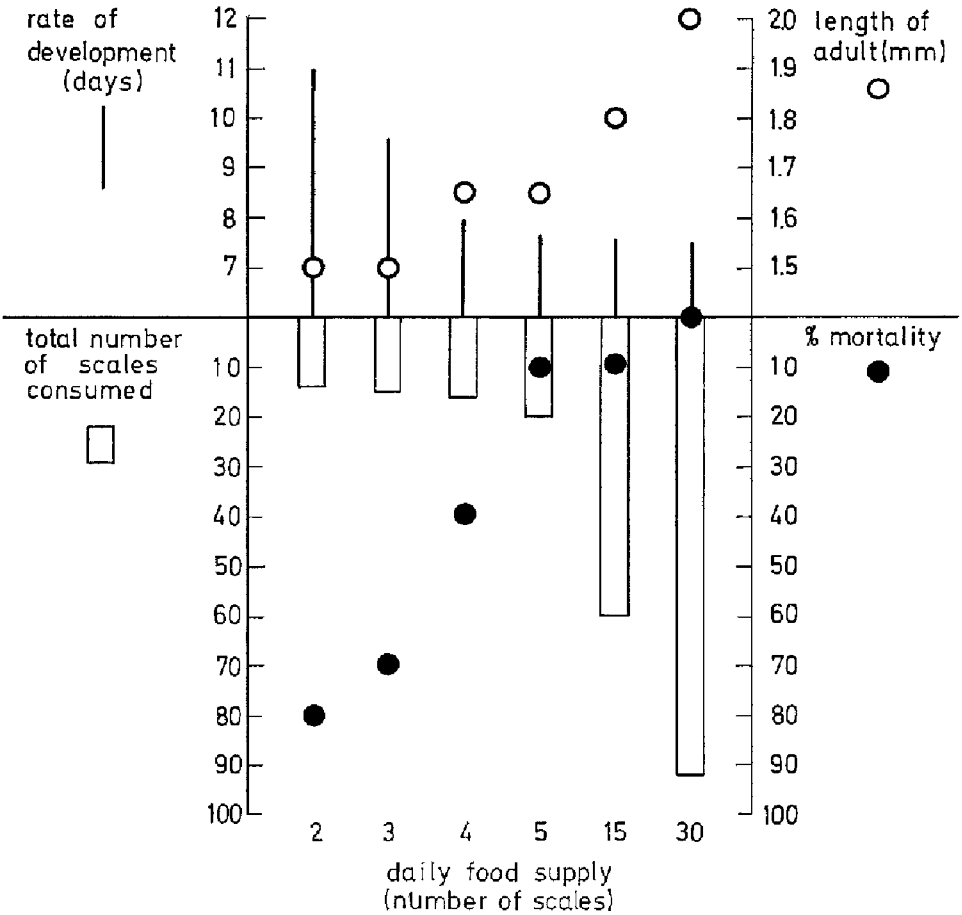

Fig. 8. Development and feeding of fourth instar larvae of *Ph. numidicus* under conditions of food scarcity (27° C, 75% R.H.). (Each trial included 10 individuals. *Parlatoria* females served as food supply).

a well developed tolerance to starvation in this insect. The capacity to survive at very low host densities on the one hand, and the ability to destroy large numbers of host insects at high host densities on the other hand, are of primary importance for the efficiency of a natural enemy.

Fourth instar larvae, under conditions of food scarcity, developed into small adults (see Fig. 8); well-fed larvae developed into voracious fourth instar larvae which required and were capable of consuming a larger number of scales (Fig. 9).

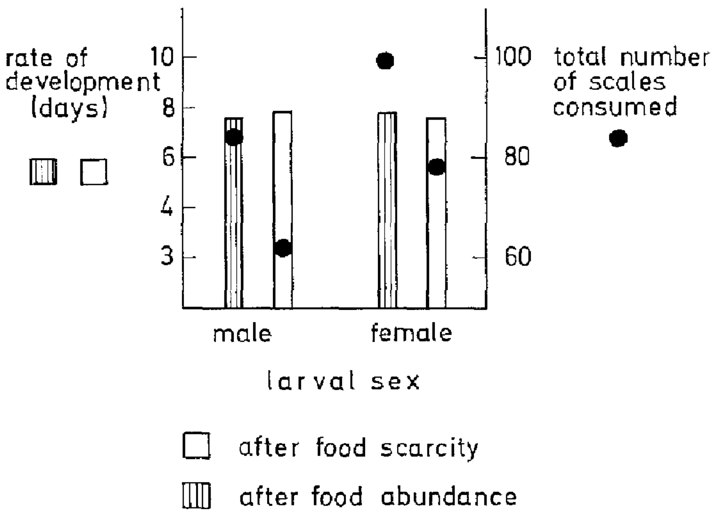

Fig. 9. The effect of starvation in all preceding instars on the development and feeding rates of fourth instar larvae of *Ph. numidicus*. (Each trial included 10 individuals. *Parlatoria* females served as food supply. Food scarcity — 50% of the consumption under conditions of food abundance was offered to the predator.)

This suggests that the feeding capacity of larvae at high host densities is higher than at lower host densities, as has been shown in some other Coccinellidae (Hodek, 1957; Smith, 1965). The predatory activity is therefore host-density dependent.

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RÉSUMÉ

COMPORTEMENT ALIMENTAIRE DE PHAROSCYMNUS NUMIDICUS *(COCCINELLIDAE), PRÉDATEUR DE LA COCHENILLE DU PALMIER DATTIER,* PARLATORIA BLANCHARDI

La capacité de *Ph. numidicus* de trouver la proie, determinée par la mobilité et le degré de survie, s'améliore avec l'âge des larves. Les mouvements de recherche sont de nature aléatoire; le prédateur ne possède pas le pouvoir de percevoir la proie, et les directions de son mouvement sont déterminées par des facteurs physiques, comme la lumière. La possibilité de se nourrir

sur des aliments non-spécifiques augmente les chances de survie dans les conditions d'une pénurie de nourriture naturelle. De ce point de vue le cannibalisme possède une importance particulière pour la survie. La capacité de se nourrir dépend du stade, du sexe, de la nourriture précédente, de la température atmosphérique et de la densité de population de l'insecte-hôte.

REFERENCES

BANKS, C. J. (1954). The searching behaviour of coccinellid larvae. *Brit. J. Anim. Behav.* **2** : 37—38.

——(1956). Observations on the behaviour and mortality in Coccinellidae before dispersal from the egg shells. *Proc. R. ent. Soc. Lond. A.* **31** : 56—60.

DIXON, A. F. G. (1959). An experimental study of the searching behaviour of the predatory coccinellid beetle *Adalia decempunctata* L. *J. Anim. Ecol.* **28** : 259—281.

HAGEN, K. S. (1962). Biology and ecology of predaceous Coccinellidae. *Ann. Rev. Ent.* **7** : 289—326.

HODEK, I. (1957). The larval food consumption of *Coccinella 7-punctata* L. (in Czech. with English and Russian Sum.). *Folia Zool.* **6** : 3—11.

—— (1967). Bionomics and ecology of predaceous Coccinellidae. *Ann. Rev. Ent.* **12** : 79—104.

IBRAHIM, M. M. (1955). Studies on *Coccinella undecimpunctata aegyptiaca* Rche. II. Biology and life history. *Bull. Soc. ent. Egypte* **39** : 395—423.

KADDOU, I. (1960). The feeding behaviour of *Hippodamia quinquesignata* Kirby larvae. *Univ. Calif. Publ. Ent.* **16** : 181—232.

KEHAT, M. (1966). Ladybirds as predators of date palm pests. (Doctoral thesis, Hebrew Univ. of Jerusalem).

—— (1967a). Survey and distribution of common lady beetles (Coccinellidae) in date palm trees in Israel. *Entomophaga* **12** : 119—125.

—— (1967b). Studies on the biology and ecology of *Pharoscymnus numidicus* Pic. (Coccinellidae), an important predator of the date palm scale *Parlatoria blanchardi* Targ. *Ann. Soc. ent. Fr.* **3** : 1055—1067.

SMITH, B. C. (1965). Differences in *Anatis mali* Auct. and *Coleomegilla maculata lengi* Timberlake to changes in the quality and quantity of the larval food. *Can. Entomologist* **97** : 1157—1166.

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