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Searching and Predatory Behavior of the Predator, *Sphodromantis viridis* Forskal Towards the Cotton Aphid, *Aphis gossypii Glover.*

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ABSTRACT

Searching and predatory behavior of the first, second and third nymphal instars of *Sphodromantis viridis* Forskal were examined towards all aphid stages of the cotton aphid, *Aphis gossypii* Glov. The time spent in searching, feeding and resting was recorded. The mean number of the preys consumed and the predation rate of each predator's instar was recorded. Proportion of the searching time was correlated with the predator's instars as well as the prey stage. The predator spent more time searching for early prey stages in comparison to less time searching for the late stages. The predator's instars were found preying on all the aphid stages. The high predation rates of the 1^{st}, 2^{nd} and 3^{rd} predator's instars were obtained on the 2^{nd}, 3^{rd}, and adult aphid preys, respectively. This study might provide information on the predation behavior of the predator, *S. viridis* towards *A. gossypii* that may shed more light on the predator as a biological control agent.

Key Words: Searching behavior, Predation rate, *Sphodromantis viridis*, *Aphis gossypii,* Egypt

INTRODUCTION

The cotton aphid, *Aphis gossypii* Glover is one of the major insect pests of cotton, cucumber, snake cucumber and marrow (Attia and El-Hamaky 1985, Luttrell *et al.* 1994 and Parrella *et al*. 1999). Chemical control stills a major tool for the control of aphids. Developing insecticidal resistance and growing environmental hazards due to excessive use of insecticides prompted the utilization of biological control measures. Aphids have a broad spectrum of natural enemies, such as Coccinellids, Chrysopids and Heteropters as well many species of parasitic Hymenoptera. Although they have a great control potential, in most cases, they are not available for effective pest suppression (Minks and Harrewijn 1987). Therefore, studies are needed for evaluating more aphidophagous insects because the availability of additional natural enemies of aphids would lead to an increase in successful biological control of aphids under various situations.

Generalist predators encounter several preys with different nutritional value and defensive mechanisms in which they must develop several attack strategies to exploit a variety of preys. A predator is classified as truly generalist when its prey selection is proportional to the relative abundance of the prey species in its environment (Begon *et al.* 1996). However, some predators show some preference, *i. e.,* they preferentially select a prey regardless to its relative abundance (Cock 1978, Hassell and Southwood, 1978). One of the attributes that determines predator success in locating prey in agricultural crops is their searching strategies (Price 1975, Bell 1991 and Ferran and Dixon 1993). Natural selection would be expected to favor individuals using searching strategies resulting in the most successful prey capture (Schoener 1971 and Bell 1991). The particular searching strategy employed will determine the functional response and influence the numerical and developmental responses. The predator searching strategies have been divided into extrinsic and area-restricted behaviors. Extrinsic searching is characterized by movement prior to encountering prey. Area-restricted searching, in contrast, includes a series of turns resulting from information perceived from the environment, often due to prey encounters. By searching a limited area, predators remain in the vicinity of the target prey and may encounter additional prey (Bond 1980, Bell 1991, Ferran and Dixon 1993 and Koss *et al*. 2004).

The predator species; *Sphodromantis viridis* Forskal was reared in the laboratory on different preys by Zohdy and Younes (2003). The first nymphal instar was fed on small preys while the medium and late nymphs were fed on relatively large preys.

To study the effective use of *S. viridis* in an augmentative program against *A. gossypii*, a fundamental understanding of the searching and predatory behavior towards aphids is required. Thus, the objectives of this study are to observe the searching behavior and quantify the predation rates of the first, second and third nymphal instars of the predator towards different stages of *A. gossypii* under laboratory conditions.

MATERIALS AND METHODS

Aphids Stock Culture

A stock culture of *A. gossypii* was established in the laboratory using aphids collected from cucumber fields. The aphid colony was maintained on cotton seedlings in the laboratory and kept in a 60 x 40 x 52 cm cages. Each cage had 30 x 40 cm opening for access and ventilation, over which a gauze cover was fastened with velvet, the cages were kept in a rearing room at 23 - 30° C and 60 – 80 % RH with a photoperiod of 16 : 8 (L:D). The culture was maintained by the addition of suitable seedlings at weekly intervals.

Predator's Rearing.

S. viridis colony was initiated in the laboratory using egg cases collected from different shrubs. The rearing procedures for rearing the predator were described by Zohdy and Younes (2003). The predator's colony was set up in the laboratory at 25±2° C and 70±5 RH.

Searching and Behavioral Categories of the Predator.

To determine the searching behavior of the predator, the aphids were placed into a searching arena consisting of one cotton plant. The plant was approximately 7-weeks old (20 cm tall). Each plant had 2 nodes and 5 leaflets at least. The aphid stages (nymphs or adult) were distributed as evenly as possible amongst the nodes and leaflets. For each stage (30 individuals/instar) were used. Predators were released on the middle of the plant stem and their searching behavior was observed continuously for four hours.

Eight behavioral categories were observed for *S. viridis* nymphs, these being: searching (the predator would walk at any plant surface); encounter (the predator would contact prey and inspect it with antennae and forelegs). This would either result in the prey being attacked, ignored, or the predator being repelled, resting (the predator would stand motionless and feeding (the time spent in consuming the attacked preys). Observations were made sequentially by one person and replicated five times for each predator and prey instars. The predator as well as the preys were used for only once where the time spent (minutes) during each searching behavior was calculated.

Prey Consumption and Predation Rate

To determine the prey consumption and the predation rate, the predator individuals were fed on a specific aphid instars for 24 hours. The predators were starved for 24 hours to ensure homogeny hungry before being used in the experiments. Five replicates were used for each aphid stage / predator. A small cotton plant was put in the center of 40 x 30 x 30 cm cage. Each cage had 3-glass sides while the top was covered by fastened gauze for access and ventilation. A known number of aphids of the same age were carefully introduced onto the host plant using a paint brush, the number of each aphid instars consumed was counted at the end of the day, prey consumption and predation rate were calculated. Dead aphid individuals were not considered in the counts.

Statistical Analysis

Analysis of variance (ANOVA) was used to test for differences in the behavioral aspects and also the differences in the mean of consumption rate (SAS, 2000).

RESULTS AND DISCUSSION

Behavioral Quantification

1st, 2nd, and 3rd nymphal instars of S. *viridis* were observed searching for aphid preys. The predators were often moving along the plant leaves (edges and veins over both upper and lower surfaces of the leaves). Also, they move along the stem and buds of the plant.

Table (1) shows the behavioral responses of the first *S. viridis* nymph towards aphid stages during 4-hours period. The predator showed a long period (30 minutes) searching for the 1st nymphal instar of aphids before the first attack. Significant difference ($P<0.05$) was obtained only between the time required in searching for the 1st nymphal prey and that required for the adult prey. The first nymph of the predator encountered adult prey more frequently than nymphs. Thereafter, 69.8 % of encountered adult prey were attacked compared with 88.3, 92.9 and 89 % of encountered prey in the 2nd, 3rd and 4th instars were attacked, respectively. On the other hand, only 48.8% of encountered 1st prey nymph was attacked. The probability of being attacked after being encountered was significantly different ($P<0.05$). The highest percent of prey ignored and the smallest percent of prey repelled were obtained with the 1st prey nymph. The mean time (minutes) spent in resting and in searching for the preys were not significantly different ($P>0.05$) while significant difference ($P<0.05$) was obtained concerning the feeding time.

Data in table (2) shows the searching behavior of the 2nd predator nymphs towards aphid preys. The predator required 8.2 to 17.8 minutes before the first attack. Significant differences were obtained ($P>0.05$) between different periods spent before the first attack on different aphid stages. On the other hand, significant differences ($P<0.05$) were obtained between the mean number of preys encountered and the preys attacked. After attacking, the predator examined all the preys in the same sequences so no significant differences ($P>0.05$) between the time spent in ignoring the prey while significant differences ($P<0.05$) were obtained when comparing the prey repelling in different prey stages. The predator spent times with no significant differences ($P>0.05$) in both resting and searching for all prey stages.

Regarding the time spent in feeding, the data showed that, the predator spent more time in feeding on the adult prey (47 min.) than on the 1st prey nymph (12 min.). Significant differences ($P<0.05$) were obtained when comparing different feeding periods on the different preys.

The predation behaviors of the third *S. viridis* nymphs towards aphid preys were shown in table (3). The predator showed a minimum searching time before the first attack of the 4th prey nymph or adult prey. Time spent encountering prey, prey attacked, prey ignored and prey repelled revealed no significant differences ($P>0.05$). The third predator nymphs encountered adult and 4th nymphs of the preys more than that for the others stages. 84.2% of the recorded attacks occurred against adult preys compared with 64.5% against the 1st prey nymph. The feeding periods on 1st, 2nd, or 3rd prey nymphs were differed significantly ($P<0.05$) as compared with predator feeding period on 4th prey nymphs or adult preys. The feeding periods were shorter when the predator was fed on the 1st and 2nd prey nymphs, intermediate on the 3rd prey nymph and longer on the 4th prey nymph and adult prey. No significant differences ($P>0.05$) were obtained concerning the total searching periods of the third predator nymph towards the different stages of the prey.

Because the potentiality of *S. viridis* nymphs to suppress *A. gossypii* depends on its ability to locate and kill sufficient number of aphids, the results of the present study might provide a basic understanding of *S. viridis* nymphs search strategies for *A. gossypii*. The predator nymphs spent more periods in searching before attacking the 1st and 2nd aphid nymphs. Also, prey encounters were greater for predator nymphs foraging for 3rd, 4th, and adult aphids. The most important factor influencing prey attacked was the period spent to find the first prey. With small preys (1st and 2nd aphid nymphs) the percent of prey ignored was more than that of prey repelled. The estimated total searching time observed in this study

Table (1): Searching behavior (mean ±SE) of the 1st instar of *Sphodromantis viridis* nymph towards *Aphis gossypii* stages.

Behavioral terms	Aphid nymphal instar				
	1st	2nd	3rd	4th	Adult stage
Searching before first attack (min.)	30±3.5a	25±2.7ab	21±1.9ab	18±1.6ab	14±1.6b
Prey encounter (n)	8.6±0.9a	12±1.6ab	17±0.9b	20±1.7b	27.2±1.7
Prey attacked (n)	4.2±1.1a	10.6±1ab	15.8±0.9bc	17.8±1bc	19±1.7c
(%)	48.8	88.3	92.9	89	69.8
Prey ignored (n)	3.2±1.2a	6±1.3a	8.8±1.2b	10±1.3b	8±0.7ab
(%)	37.2	50	51.7	50	29.4
Prey repelled (n)	1±0.2a	4.6±0.6ab	7±0.7b	7.8±0.9b	11±1c
(%)	11.6	38.3	41.1	39	40.4
Resting time (min.)	172±20a	164±11a	174±13a	165±11a	150±10a
Feeding time (min.)	9.8±2.3a	20.6±2.2b	25.6±2.1b	28.6±2.4b	12.2±2a
Total searching time (min.)	58.2±3a	55.4±2.6a	40.4±1.9a	46.4±3.2a	77.8±4a

- Means in the same row followed by the same letter are not significantly different (P>0.05). (Duncan's multiple range test).

Table (2): Searching behavior (mean ±SE) of the second instar of *Sphodromantis viridis* nymph towards *Aphis gossypii* stages.

Behavioral terms	Aphid nymphal instar				
	1st	2nd	3rd	4th	Adult stage
Searching before first attack (min.)	17.8±2a	17.4±3.5a	17.4±2.4a	12±1.2a	8.2±1.1a
Prey encounter (n)	17.4±2a	21±1.4a	24.2±1.6ab	27±2.6b	32±1.8b
Prey attacked (n)	7.6±0.9a	9.4±0.7a	16.2±0.7b	22±1.4bc	23±1.4c
(%)	43.6	44.7	66.9	81.4	71.8
Prey ignored (n)	6.4±0.5a	7.2±.9a	8.4±0.5a	9.2±0.8a	8.6±0.7a
(%)	36.8	34.3	34.7	34	26.9
Prey repelled (n)	1.2±0.5a	2.2±0.5ab	7.8±0.4bc	12.8±1ce	14.4±1e
(%)	6.8	10.5	32.2	47.4	46.4
Resting time (min.)	109±26a	103±9a	90±4.2a	82±6a	76±9a
Feeding time (min.)	12±1.2a	25±1.8b	35±3.4b	46±2.3c	47±2.9c
Total searching time (min.)	119±5a	112±4.6a	115±4.5a	112±4.3a	117±4.3a

- Means in the same row followed by the same letter are not significantly different (P>0.05). (Duncan's multiple range test).

Table (3): Searching behaviors (mean ±SE) of the third instar of *Sphodromantis viridis* nymph towards *Aphis gossypii* stages.

Behavioral terms	Aphid nymphal instar				
	1st	2nd	3rd	4th	Adult stage
Searching before first attack (min.)	17±1.8a	11.8±1ab	11.4±1.4ab	8.2±0.8b	6.6±1.2b
Prey encounter (n)	18.6±3a	19.8±2.2a	21.4±1.5a	24.6±1.4a	28±2.1a
Prey attacked (n)	12±1.6a	14.4±1.3a	16.6±1.7a	20.2±2a	23.6±2a
(%)	64.5	72.3	77.5	82.1	84.3
Prey ignored (n)	8±1a	10.4±1.6a	10.4±0.8a	12.2±2a	13.8±2a
(%)	43	52.5	48.5	49.6	49.3
Prey repelled (n)	4±1.2a	4±1.6a	6.2±1.4a	7.8±1.1a	9.8±1a
(%)	21.5	27.7	37.5	31.7	35
Resting time (min.)	80±9.3a	78±10a	63.6±8.1a	35±3.5b	42±5b
Feeding time (min.)	2±0.9a	7±1.1a	12.4±2.1a	29±3.4b	32±2b
Total searching time (min.)	158±13a	155±11a	164±14a	176±3.2a	166±14a

- Means in the same raw followed by the same letter are not significantly different (P>0.05). (Duncan's multiple range test).

Table (4): Prey consumption and predation rate of 1st, 2nd and 3rd instars of *Sphodromantis viridis* nymphs towards *Aphis gossypii*.

Predator nymphal instars	Prey consumption (mean ± SE) Aphid nymphal instar				
	1st	2nd	3rd	4th	Adult stage
1st nymphal instar	1.8±0.4a	11.4±0.9b	10±0.7b	6±0.7c	4.1±0.5c
2nd nymphal instar	3.1±0.6a	9.4±0.9b	11.2±0.8b	11±0.7b	10±0.7b
3rd nymphal stage	3.8±0.7a	8.6±0.5b	13.8±1.1b	14.2±0.8b	15.2±1.1b
Predator nymphal instars	**Predation rate (mean ± SE) Aphid nymphal instar**				
	1st	2nd	3rd	4th	Adult stage
1st numphal instar	6±0.88a	38±1.7b	33.3±1.6b	20±1.2c	13.6±1.2a
2nd nymphal instar	10.3±1.6a	31.3±2.7b	37.3±2.5b	36.6±2.1b	30.3±2.9b
3rd nymphal instar	12.6±0.5a	28.6±1.5b	46±2.4c	47.3±2.4c	50.6±3.6c

- Means in the same row followed by the same letter are not significantly different (P>0.05). (Duncan's multiple range test).

indicated that the 3rd *S. viridis* nymph searched for longer periods than the 1st *S. viridis* nymph. The predators spent more periods with the small preys than did with bigger ones. The long resting period may be associated with energy conservation (Wiedenmann and O'Neil 1991), the less time spent in consumption (Munyaneza and Obrycki 1998) or prey preference (Begon *et al* 1996 , Hoddle 2003 and Provost *et al*. 2006).

Prey Consumption and Predation Rate

The mean consumed number of each of the aphid (prey) stages through 24 hours by predator nymphs is shown in table (4). Statistical analysis showed differences (P<0.05) between consumed preys in different stages. The first predator nymph ate significantly more 2nd and 3rd prey nymphs than the 1st. Significant differences (P<0.05) were obtained between the consumed 1st prey nymph and those of other stages. The 2nd predator nymph ate more 2nd, 3rd and 4th prey nymphs and adult preys. The lower consumption was obtained with the 1st prey nymphs. An increase in the prey consumption was obtained with the 3rd predator nymph. The 3rd predator nymph began with lower consumption of the 1st prey nymph and then increased with the increase of prey stage where a greater consumption was obtained with the adult prey. Statistically significant differences (P<0.05) were obtained between the prey consumption of the 1st prey and those of the other prey stages.

Considering the predation rate, the predators significantly differed in their predation rates on the prey stages. The predation rates on the 3rd or 4th prey nymphs and also adult preys were greater than that on the 1st prey nymphs.

The low predation rate on the 1st aphid nymphs may be due to difficulties in attacking and catching this stage. This is understandable because the sizes of the 1st aphid nymphs are very small and so the predators can not catch them. Furthermore, low variation in prey consumption and predation rate on the 3rd or the 4th prey nymphs indicate that those stages were more preferable stages.

Some authors suggested that many factors affect predator's ability to suppress pest population. Among these are the searching activity of the predator (Coll and Ridgway 1995), density and distribution of the prey (Flaherty and Huffaker 1970, Hassell 1978, Kareiva and Perry 1989, Kareiva and Sahakian 1990 and Symondson *et al*. 2002). Encounter rate between predators and prey will be influenced by both number of prey present and size of the plant upon which prey are located (O'Neil 1997). Distribution of prey individuals can also affect their encounter rate with predators (Evans 1976).

This laboratory-estimated searching and predation of *S. viridis* nymphs may not exactly correspond to the field situations. However, this study has value as a first step in evaluating *S. viridis* as a biological control agent of *A. gossypii*. To develop a biological control program of aphids using *S. viridis*, further studies should be conducted under both laboratory and field conditions on the functional responses, prey selection, dispersal within and among plants and population dynamics among others.

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