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Studies on the Biology and Predatory Behaviour of *Eocanthecona furcellata* (Wolff.) Predating on *Spilarctia obliqua* (Walk.) in Mulberry Plantation

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The stink bug, *Eocanthecona furcellata* (Wolff.) is a natural and potential biocontrol agent of *Spilarctia obliqua* (Walk.). The present investigation reveals the biology, predatory efficiency and reproductive parameters of the predator which feeds on *S. obliqua* caterpillars in mulberry plantation. In order to find out the role of prey size on the biology of the predator, the predatory insects were separately fed with small and large caterpillars of *S. obliqua*. The incubation period of the eggs of *E. furcellata* was 8.37±0.44 days, while the nymphal duration varied as per the prey size. The predator when supplied with small larvae of prey, consumed 61.1 larvae and completed nymphal stage in 19.9 days; while those fed with larger prey, consumed 36.1 larvae and completed their nymphal stage in 21.55 days. The prey size also influences the reproductive parameters of the predator. The adult female predator is more voracious feeder than the adult male and consumed 41.9 ± 0.64 small larvae and 42.2 ± 0.87 large larvae during their life span. The longevity of male and female was observed as 20.7 and 29.4 days respectively. Visualization of the predator as well as the movement of the prey increases the predatory efficiency. Scanning electron microscopic studies on the feeding part explain its support in effective predation. Field observations indicated a drastic fall in the incidence of the mulberry pest, *S. obliqua* with the increased population of *E. furcellata* in mulberry plantation.

Key words : Biology, Predatory behaviour, Eocanthecona furcellta, *Spilarctia obliqua*, Mulberry, SEM

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Introduction

Mulberry (*Morus* spp.) is the only food plant of the silkworm, *Bombyx mori* Linn., which is an economically important insect for sericulture industry. Mulberry is attacked by a number of insect pests, parasites, predators and pathogens around the year which not only affect the leaf quality but also responsible for poor yield. Mulberry is reported to be attacked by more than 200 species of insects belonging to various orders (Zheng *et al.*, 1988). The total loss of mulberry foliage crop due to these natural enemies is about 20% per year (Gupta *et al.*, 2000). The Bihar hairy caterpillar has been reported as a major pest of mulberry and the average incidence of this pest was as high as 39.25% and the loss in leaf yield has been estimated to be 5481 kg/ha./year (Katiyar *et al.*, 1999). Various chemical control strategies have been recommended for the management of different stages of *S. obliqua* on various agricultural crops (Singh *et al.*, 1987; Gupta and Singh, 1988; Nagia *et al.*, 1990; Goel and Kumar, 1991; Khattar *et al.*, 1991). Several entomopathogenic microbes *viz.*, microsporidia (Narayanan, 1985), fungi (Thontadarya *et al.*, 1973), cytoplasmic polyhedrosis virus (Narayanan, 1986), Nuclear polyhedrosis virus (Battu and Ramakrishnan, 1987; Kumar *et al.*, 2000) and *Bacillus thuringiensis* (Ahmad *et al.*, 1988; Taluker *et al.*, 1989) are in use as biological control agents against *S. obliqua*.

Eocanthecona furcellata (Wolff.) a prominent, polyphagous predaceous stink bug is reported to feed on various pests of agricultural crops *viz.*, *Prodenia litura* Fab. larvae on cotton (Ballard, 1923; Kapoor *et al.*, 1973); slug caterpillar *Latoia lepida* (Cramer) on mango (Ghorpade, 1972; Senrayan, 1988); leaf roller *Diaphania pulverulentalis* on mulberry (Anonymous, 1998; Rajadurai *et al.*, 2000); *Semiothisa pervolgeta* Wlk, and *Terias hacabae* L. on Daincha (*Sesbania bispinosa*) (Cherian and Brahamchari, 1941); *Spilosoma obliqua* on soybean and sesame

(Singh *et al.*, 1989; Bhadauria *et al.*, 1999) and pests of many other crops (Rai, 1978; Gope, 1981; Srivastava *et al.*, 1987). Though *E. furcellata* feeds on many species of lepidopteran pests on diverse agricultural and horticultural crops, there is no information on its predatory impact on the pests of mulberry plantation. *E. furcellata*, a remarkable predatory member of Asopinae sub-family under Pentatomidae is found on mulberry plants, feeding on Bihar hairy caterpillars during August to January and at maximum during October to December 2000 under natural conditions. The appearance of this predator is synchronized with the occurrence of *S. obliqua* on mulberry plants which devastate the chawki leaves (young leaves) specifically used for the young age silkworm feeding during the peak silkworm rearing period in the southern parts of India. The tender leaves fed to young age silkworms play a vital role in the development, survival and economic traits of the silkworm. The adoption of chemical measures to control the pest is likely to cause deleterious effect on the silkworm due to the residual toxicity of the pesticides on mulberry leaves. Hence, biological control strategies appeared to be the most potential alternative to chemical insecticides. During a survey of natural predators for the pests of mulberry in the germplam garden, *E. furcellata* was found for the first time predating the various stages of *S. obliqua* larvae. Unlike the reduviids, *E. furcellata* is not adequately equipped with their mouth parts and fore legs to capture their prey, its prey identification, prey capture and prey acceptance are appeared to be unique. An extensive report on the biology, feeding behaviour, prey capture and predatory efficiency of *E. furcellata* that feeds on the mulberry pest *S. obliqua,* as well as the ultrastructural details on the mode of predation are discussed in this present investigation.

Materials and Methods

Insects

The nymphs and adults of the predator, *E. furcellata* were collected from the mulberry germplasm garden of Central Sericultural Research and Training Institute, Mysore, India, and reared in the laboratory at 26 ± 2°C temperature; 70 - 90% relative humidity and 16L : 8D photoperiod in different 10 cm× 5 cm sizes of plastic containers with proper ventilation. 0 day adult males and females were separated from the mass culture and reared in 10 different plastic containers to take an account of the life history parameters *viz.*, pre-oviposition, oviposition and post-oviposition periods, fecundity and egg laying patterns. Healthy larvae of different stages of *S. obliqua* were provided every day as fresh diet. Absorbant paper and water soaked cotton were placed at the bottom of the containers to maintain humidity and also to quench the thirst of the predators. The newly hatched bugs along with their empty egg shells were transferred with a fine camel hair brush into ten different ventilated plastic containers. Prey capture, predatory efficiency and feeding behaviour of the predator were observed in the laboratory by starving the test insects for several hrs before providing with different stages of live caterpillars of *S. obliqua.*

Scanning electron microscopic studies

In order to assess the feeding habit and the pattern of stylet penetration of the predator, *E. furcellata,* starved adult predators were offered to feed on caterpillars of *S. obliqua*. During the feeding the predator along with the prey was etherized and the rostrum excised off from the predator along with the prey. The cut rostrum with the prey were fixed in 2.5% glutaraldehyde prepared in 0.2 M cacodylate buffer (pH 7.2) for 2 hrs at room temperature. The fixed samples were washed in cacodylate buffer thrice and then dehydrated in graded alcoholacetone series and dried in a critical point drier (EMS - 850) using carbon-di-oxide as a transition fluid. The dried samples were carefully mounted onto copper stubs using double side sticky tape and coated (20 nm thickness) with gold using sputter coater (EMS - 550) and examined under JEOL 100 CX II ASID 4D scanning electron microscope at 20 kV.

Results

Life history parameters

Egg

The eggs are oval, dull white with shining surface and glistening white on the top surface. The eggs were laid in clusters and arranged serially in a row. In field conditions, two to three rows with 5 - 8 eggs in each row were found attached on the lower leaf surface particularly in between the veins near the petiole. The diameter of the eggs varied from 0.290 mm to 0.305 mm; incubation period varied from 7 to 10 days with an average of 8.30 ± 0.31 days. During development, the colour of the egg becomes black with a golden shining over the surface. The hatched and empty shells are colourless and they lack shining.

Predatory efficiency during post embryonic development

The newly emerged bugs were pure black in colour and they rest on the shells for more than 10 hrs. The colour of the bug slowly turns into patches of red and black which appeared like red and black colour beads. The bugs fed on empty shells and on water provided in cotton wads.

Although small and tiny caterpillars of the prey were provided, the predator did not select the prey and preferred to feed on egg shells. The duration of the instar ranges from 2-4 days with a mean of 2.90 ± 0.31 and 2.65 ± 0.31 days when fed on small and large prey respectively. Second instar predators were active and in search for the prey in their habitat. Its duration extended upto 3.90 ± 0.21 days and consumed 11.9 ± 0.57 young caterpillars or 7.2 ± 0.39 large caterpillars and completed the stage in 4.20 ± 0.16 days. The third, fourth and fifth instar bugs consumed more number of young prey, 14.0 ± 0.29, 15.7 ± 0.45 and 19.5 ± 0.55 and completed the stadial period in 3.75 ± 0.20, 4.50 ± 0.13 and 4.85 ± 0.11 days respectively whereas lesser number of large caterpillars has been consumed 7.9 ± 0.29, 9.7 ± 0.28 and 11.3 ± 0.35 to complete 3, 4, and 5th instar in 4.10 ± 0.16, 5.10 ± 0.69 and 5.50 ± 0.82 days respectively. The total nymphal duration varied with the type of prey provided to the predator and when fed on large size prey it took 21.55 days to complete its nymphal stages whereas, when fed on the small size prey it completed the nymphal duration within 19.90 days (Table 1).

Adult

Adult male is capable of mating from the 1st day onwards whereas females are ready to accept the males only 48 - 72 hrs after emergence. Adult male feed on young and large size caterpillars of *S. obliqua* and they do not show any remarkable variation in their longevity. During the adult stage, the male and female killed more number of large size prey *viz.*, 25.0 and 35.2 than the small ones (Table 1). The oviposition period extended by 2 days more in case of the large prey feeders than the small prey feeders while there is no remarkable change in the pre- and post-oviposition period. The predator which fed on large size prey laid more number of eggs 54.0 ± 1.66 (45 - 60) whereas the predator fed on early stages of prey laid less number of eggs 47.8 ± 1.96 (39 - 55). The male and female sex ratio of overall population reared under the laboratory condition was 1 : 1.5. Field observations indicated a drastic fall in the incidence of mulberry pest, *S. obliqua* with the increased population of the predator, *E. furcellata* in mulberry plantation.

Prey capture and prey immobilization

E. furcellata appeared to be active and excited when a moving prey is introduced into the container. The following observations were made on the visualization of the prey by the predator.

Few alive specimens of *E. furcellata* were painted with thick aluminum paint on one of the eyes as well as few were painted on both the eyes and some were not at all painted. These bugs were starved for 6 - 8 hrs and provided with live caterpillars in a tray (30 cm dia.). The bugs painted on either side of the eyes were unable to trace their prey while the bugs painted on one side of their eyes detected the prey within 4 - 5 min, whereas the non painted specimens identified their prey within a minute and approaches the prey for predation.

In the field as well as in laboratory, the predatory behaviour were observed and that reveals the stimuliresponse sequences of feeding. On locating the moving prey by its visual stimuli the predator raises it body from the leaf surface and moves towards the prey with continuous anten-

Table 1. Biological parameters of *E. furcellata* reared on the larvae of *S. obliqua*

	Small Prey		Large Prey	
Life history parameters	Number in days	Number of prey consumed	Number in days	Number of prey consumed
Incubation period	8.45 ± 0.44		8.30 ± 0.31	
I instar duration	2.90 ± 0.31	No feeding	2.65 ± 0.31	No feeding
II instar duration	3.90 ± 0.21	11.9 ± 0.57	4.20 ± 0.16	7.2 ± 0.39
III instar duration	3.75 ± 0.20	14.0 ± 0.29	4.10 ± 0.16	7.9 ± 0.29
Iv instar duration	4.50 ± 0.13	15.7 ± 0.45	5.10 ± 0.69	9.7 ± 0.28
V instar duration	4.85 ± 0.11	19.5 ± 0.55	5.50 ± 0.82	11.3 ± 0.35
Total nymphal duration	**19.90**	**61.1**	**21.55**	**36.1**
Adult longevity				
Male	21.0 ± 1.09	28.3 ± 0.57	20.5 ± 0.47	25.0 ± 0.88
Female	27.7 ± 0.69	41.9 ± 0.69	30.4 ± 0.61	42.2 ± 0.87
Pre-oviposition period	5.6 ± 0.38	16.9 ± 0.36	6.5 ± 0.26	16.5 ± 0.71
Oviposition period	13.1 ± 0.61	19.3 ± 0.35	15.4 ± 0.43	19.1 ± 0.54
Post oviposition period	6.3 ± 0.45	5.8 ± 0.34	6.5 ± 0.26	5.40 ± 0.47
Total number of eggs	47.8 ± 1.96		54.0 ± 1.61	
Fecundity Index	8.54 ± 0.03		8.30 ± 0.02	

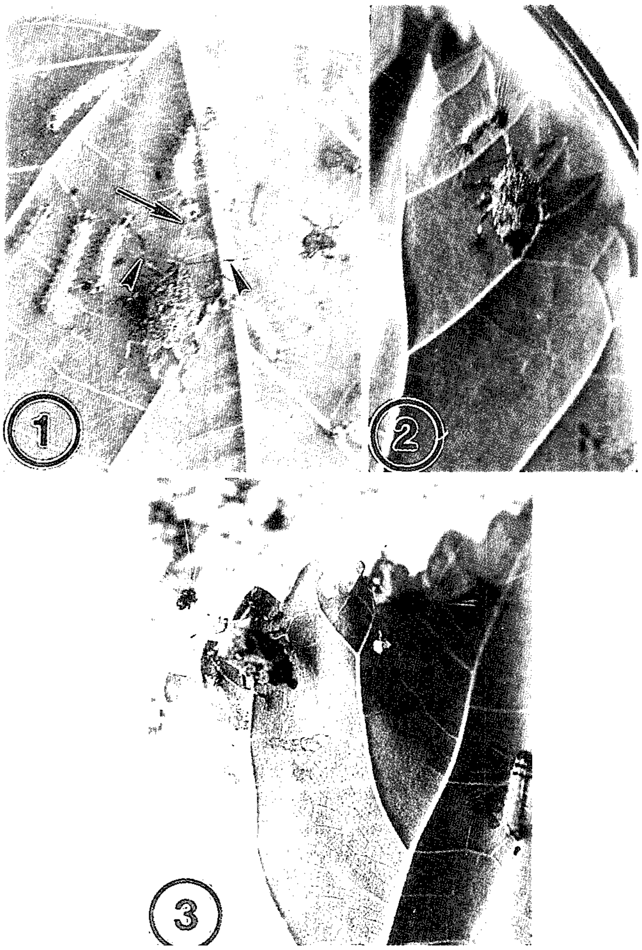

Fig. 1. Predatory behaviour of *E. furcellata* feeding on *S. obliqua* larvae.
Panel 1. Approach of the adult of *E. furcellata* towards the prey with extended antenna (arrow heads) and unfolded rostrum (arrow). Panel 2. Transportation of the prey by the predator towards the leaf margin by hanging it on its rostral tip after stylet penetration. Panel 3. Holding the prey at the rostral tip of the predator at the leaf margin and desapping the body fluid of the prey. Note the shrinkage of larval body after one hour of feeding.

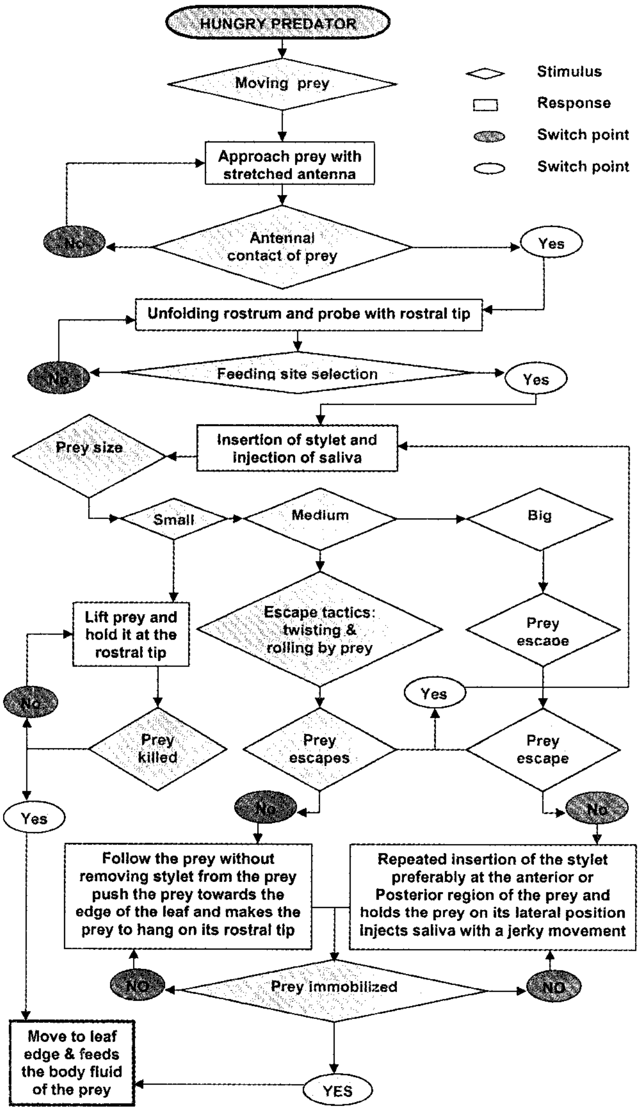

Fig. 2. Stimuli-response predatory sequence of *E. furcellata* feeding on *S. obliqua* larvae.

nal movement and holding the antenna at 45°A to its head. Once it reaches the prey it touches it and confirms the availability of the prey and swiftly unfolds its rostrum from the original position to 180°A and 90°A to its head with the straightened antenna at 45°A and jabs the prey body for the suitable site selection (panel 1 of Fig. 1). The predator prefers to select the site at its posterior end, just above the pseudopodia at the abdominal segments, of the prey (panels 1-4 of Fig. 3). In some cases, it attacked the anterior region of the prey (panels 1-3 of Fig. 1). If the prey is larger in size (IV and V instar larvae), the predator jabs the prey repeatedly with the fully extended rostrum and injects saliva. The caterpillars attacked in this manner react violently and try to escape, but are pursued by the predator and repeatedly jabs the rostrum and push the prey by its rostral tip so as to hold the prey on its lateral side and continued the stylet insertion for saliva injection (panels 1 and 2 of Fig. 1). On few occasions, it is observed that the larger prey managed to escape from such an encounter by the predator. Small and medium sized caterpillars are also made violent movement by twisting and rolling their body. Some prey vomits greenish juice through its mouth and continue the wriggling movements but the continual penetration of stylet and injection of saliva makes the prey to be immobilized within 60 to 90 seconds (panel 2 of Fig. 1). When small caterpillars are sighted, the bug after locating the site, pins the prey by its rostral tip along with sal-

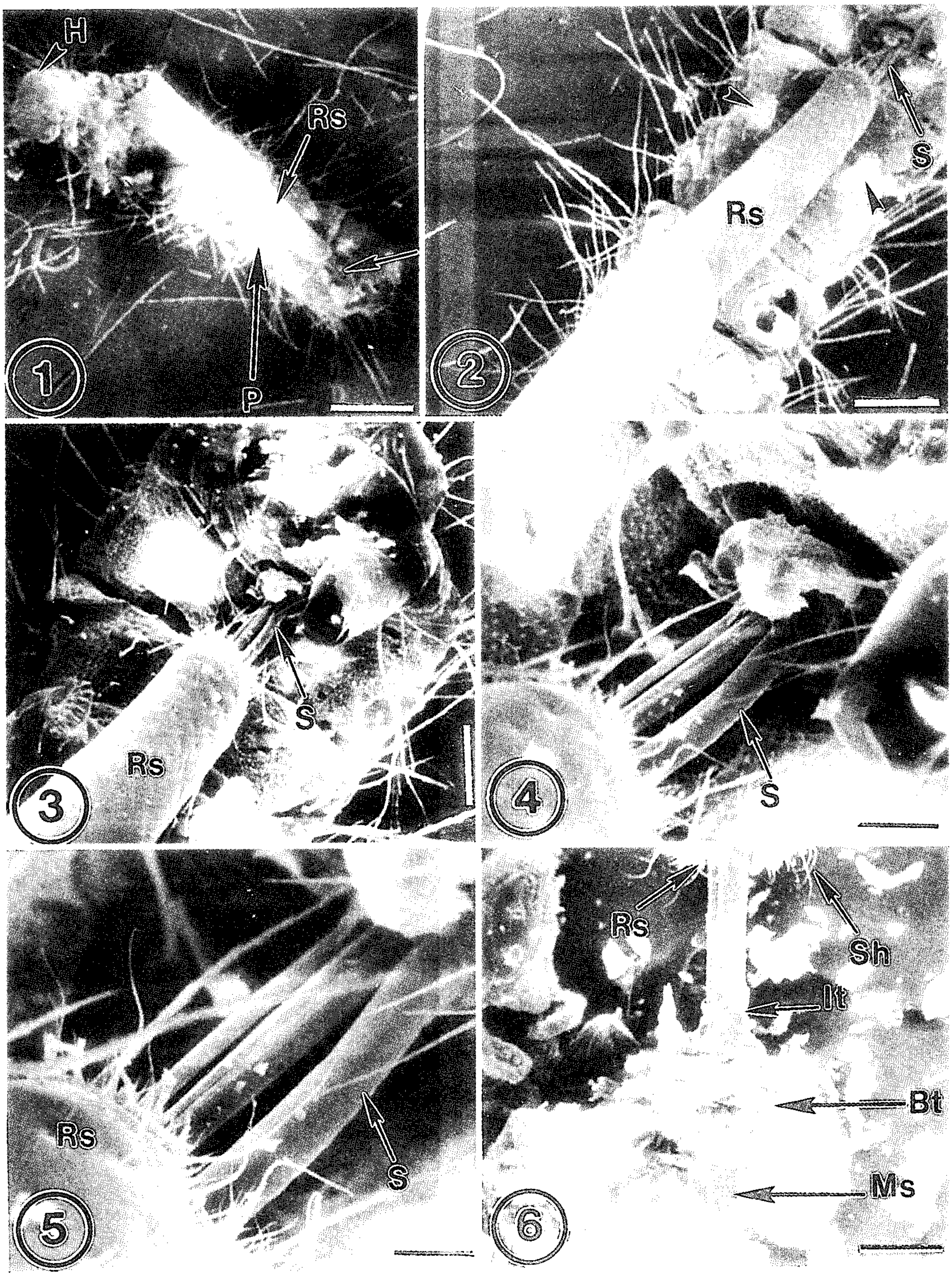

Fig. 3. Scanning electron microphotograhs of stylet bundles of *E. furcellata* and its penetration into its prey body.
Panel 1. Scanning electron microphotograph showing the stylet penetration (arrow) of the predator at the posteroventral region of the prey (P), H = Head, Rs = Rostral tip (Scale bar = 200 µm).
Panels 2-4. Enlarged view of stylet (S) penetration at the feeding site of the prey. In panel 2 arrow heads show the stylet penetration between the abdominal legs. (Scale bar = 100 µm for panel 2, 70 µm for 3 and 20 µm for panel 4).
Panel 5. The extension and penetration of stylet bundle (S) from the rostral tip of the predator. (Scale bar = 13 µm).
Panel 6. Stylet bundles protruding from the rostral tip (Rs) and penetrating the integument (It) of the prey. Note the pointed mandibular stylet (Ms) tip seen across the prey body tissue (Bt). Sensory hairs (Sh) are also visible at the tip of rostrum. (Scale bar = 40 µm).

ivary injection and lifts the prey off the leaf till the prey dies after struggling at the rostral tip. The predator, probing three or four times to select its feeding site, holds the host plant leaf by its legs and lean forward towards the prey for stylet penetration. A constant jerky movement of the predator is noticed when the stylet is inserted into the prey body. The fore, mid and hind legs of the predator are stretched out and holds the surface of the leaf. Nymphs as well as adult exhibit similar mode of prey capture sequences (Fig. 2). Newly emerged predators when they were not provided with the empty egg shell and water and if offered a tiny caterpillars, they try to kill the prey but do not consume it. When large fifth instar preys were offered the adult predators showed group feeding behaviour.

Prey transport and consumption

Transportation of the immobilized or killed prey to an isolated place before feeding is also observed in *E. furcellata*. After insertion of the stylet into the prey, the predator moves backward and side ways to drag the small and medium sized preys towards leaf margin and hangs it on their rostral tip. The small caterpillars were lifted at the rostral tip and killed while moving towards the margin of the leaf (panels 2 and 3 of Fig. 1). Feeding commences immediately after killing or immobilizing the prey. If the prey is small, after immobilizing it, the predator feeds on it without changing its feeding site till the body fluid is completely desapped. When the prey is larger, the prey changes the feeding site 3 or 4 times so as to desap the body fluid completely (panel 3 of Fig. 1). The feeding is continued till the predator is satiated and further predation commences only after 56 hrs. SEM microphotographs revealed that the rostral tip jabs at the posteroventral region of the prey particularly, in between the abdominal legs (panels 1 and 2 of Fig. 3). The stylet bundles are seen protruding from the rostral tip and penetrating into the prey body. The sensory apparatus at the rostral tip consists of several morphologically distinguishable sensilla (panels 3-6 of Fig. 3).

Discussion

The life history parameters of *E. furcellata* varies with different species of prey and the host plants of the prey. In the present investigation, the average incubation period of *E. furcellata* fed on *S. obliqua* in mulberry plantations was observed as 8.37 days. The predator has similar incubation period when preyed on *Cnaphalocrocis medinalis* and *Ostrinia furnalis* (Semillano and Corey, 1993), *Parasa philopida* (Escalona and Abad, 1998), and larval pest of *Acacia mearnsii* (Lin-Changchun, 1998). However, Bahaduria *et al.* (1999) recorded an incubation period of 6.3 ± 1.5 days while Singh *et al.* (1989) observed 6 - 14 (average 10 days) during OctoberDecember when fed on *S. obliqua*. Kapoor *et al.* (1973) reported that the incubation period of *E. furcellata* eggs varies from 5 - 7 days in September October when the predator fed on the larvae of *P. litura*. The observed difference in incubation period may possibly be due to the variation in atmospheric temperature at different geographical regions. Under laboratory conditions, the observed average nymphal duration of *E. furcellata* fed on *S. obliqua* was 20.5 days, almost similar to the nymphal duration of 21.3 days when fed on larval pest of *Acacia mearnsii* (Lin-Changchun *et al.*, 1998); 20.4 when fed on *S. litura* (Tabasa, 1991); 20 ± 1.31 days when fed on lepidopterous larvae (Semillano and Corey, 1993). But its nymphal period was found to be only 17 days when fed on *Parasa philopida* (Escalona and Abad, 1998). The life history parameters of *E. furcellata* varies with the biochemical composition of the host plant of the prey species particularly, the chlorophyll content of prey diet have an influence on the prey location and prey preference (Yasuda *et al.*, 1998; 2000). In the present study the nymphal duration, oviposition period and fecundity of *E. furcellata* are comparatively lesser when fed on young caterpillars of *S. obliqua* than those of the predator which fed on large prey. This may be due to the age specific host plant preference of the young as well as large caterpillars and this in turn influences the nutritional contents in the prey. Even though sufficient small size prey are offered to the predator, it preferred to kill more number of larger prey than the smaller one. The preference of larger prey may be due to the nutritional requirements of the predator during the egg development and oviposition period. The total number of eggs laid by a single female *E. furcellata* in its life span is 47.8 ± 1.96 when fed on small larvae of *S. litura*, whereas larger prey feeders laid 54.0 ± 1.61 eggs. Bhadauria *et al.* (1999) found a fecundity of 42.5 ± 11.5 for *E. furcellata* when fed on *S. obliqua*, but it had a higher fecundity of 68-88 eggs when preyed on larval pest of *Acacia* plant (Lin-Changchun *et al.*, 1998) and 244 eggs when fed on slug caterpillar *Achaea janata* (Gallego, 1998).

Prey searching, identification, selection, prey capturing and feeding by the predator, *E. furcellata* are appeared to be a sequential events with stimuliresponse activities. The predator, selected their prey by visual stimuli and the masking of visual organ led to non selection of prey. Antennal contact and rostral jab over the prey and the selection of feeding site indirectly revealed that the available sensory structures on the rostral tip and antenna also play a vital role in the prey selection. The extended long sword like rostrum and the long legs of the nymphs and adults of *E. furcellata* enable it to reach the prey, without holding the prey by its body. Although the prey is covered with thick hairs, the elongated rostrum with the extended stylet of the predator enables it to penetrate the prey body at desired site. The stylet penetration followed by salivary injection at the anterior end of the prey in a few cases and also at posterior end, just above the pseudopodia with a jerky movement of the predator *E. furcellata* are observed when it feeds on *S. litura* (Usha Rani and Havukkala, 1993; Usha Rani and Wakamura, 1993; Usha Rani *et al.*, 1994). Similar observation have been noticed when the predator feeds on *S. obliqua.* When attacked by the predators, larger prey exhibits wriggling movement, violent rolling and vomiting greenish juices, indicating that the saliva is injected into the prey which appeared to be toxic. Cobben (1978) enlightened that the members of Asopinae kill their prey by its toxic saliva. Usha Rani and Havukkala (1993) revealed that the predator *E. furcellata* over powered its prey *S. litura* within 3 - 10 min whereas in the present investigation small prey are immobilized within 60 - 90 seconds and the large prey is killed within 3 - 5 min. In the present study the male predator on an average consumed 26.5 ± 0.57 prey while the female consumed 42.1 ± 0.69 prey, whereas Bhadauria *et al.* (1999) observed a pray consumption of 52.3 ± 8.9 and 64.2 ± 5.3 by the male and female predators respectively on *S. obliqua* larvae. But the prey consumption was quite high as the male and female predators killed 107.27 and 121 larvae of *S. litura* respectively (Tabasa, 1991). The predatory behaviour of *E. furcellata*, particularly its prey location and stimuli-response mode of predation over *S. obliqua* is found to be coinciding with its feeding behaviour on some larvae of Lepidoptera, Coleoptera and Heteroptera (Tabasa, 1991, Yasuda, 1999). Similar to the observations of Usha Rani *et al.* (1994) in the present investigation it is found that the sensillary structures present at the rostral tip are also involved in decision making about feeding activities and in recognizing the food.

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