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Host-Parasitoid Interactions of Strepsipteran Parasitoids with the Degree of Host Specificity and Effects on Reproductive Potentiality of the Hosts

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Abstract: Strepsiptera is an obligate endoparasitoid with bizarre morphology, life cycle and host–parasitoid interaction. The free living males possess twisted hind wings and the fore wings are reduced to club–like appendages or pseudohaltere. Adult females are larviform (resemble larvae, rather than typical adult insects), measuring 2–6.2 mm in length, and lack antennae, mouthparts, eyes, wings, legs and external genitalia. Four normal and stylopised Homopterans species have been recorded. So far there is no record of above stated stylopised host species from India. The relative abundance of normal and stylopized host and the seasonal variation of stylopization were observed. Percentage of parasitisation was observed during the period. A comparison of oviposition scar between the normal gravid and the stylopized gravid female of *C. spectra* (host) revealed that number of stipples was far greater in those paddy plants where normal gravid females were present.

Keywords: Pseudohaltere, Strepsiptera, Stylopisation, Oviposition scar, Parasitisation, Parasitoid, Homopterans, Host specificity, Reproductive potentiality

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Introduction

The Strepsiptera (Greek *strepsi*, "twisted"; *pteron*, "wing") commonly known as "stylops" comprise a group of entomophagous, obligate endo-parasitoids with unusual morphology, life history, genetics and host–parasitoid relationship. They are cosmopolitan in distribution; largest numbers of species have been reported from the Australasian realm followed by the Oriental region. Owing to the endoparasitic life, the parasitoids are not easily noticed and remain an enigma to the entomologists. They have exhibited one of the most weird and complex life cycles with extreme sexual dimorphism. The free living males possess twisted hind wings and the fore wings are reduced to club–like appendages or pseudohaltere. The males possess wings, legs, eyes, and antennae, superficially similar to flies, though their mouthparts are not used for feeding, rather they are modified as sensory structures. They are short–lived, usually surviving less than five hours and do not feed (Kathirithamby and Hamilton, 1992). Females except those belonging to the family Mengenillidae remain inside the host and are neotenic lacking wings, legs and eyes (Kathirithamby, 1989). The virgin females are said to release a pheromone from the Nassonow gland which the male uses to locate them with the aid of the Hofender organ.

The ordinal status of Strepsiptera has been debated since Kirby (1813) erected the ordinal status. Even in the the present day, several workers, mainly Coleopterists, place Strepsiptera as a family (Stylopidae) in Coleoptera (Crowson, 1960, 1981; Amett, 1968; Ross *et al*., 1984), or as closely related to the Hymenoptera (Jeannel, 1945). They are a monophyletic group (Hennig, 1981) with a large number of the autapomorphic characters adapted to the endoparasitic life of the secondary larva, the neotenic female adult of the sub–order Stylopidia and the short–lived non–feeding adult male whose sole function is to seek and fertilise the neotenic female. The only apomorphic character uniting the Strepsiptera and Coleoptera is the use of the hind wings as the main organs for flight with consequent specialisation of the metathorax for this function. Crowson (1954) listed several other characters common to Strepsiptera and Coleoptera, including the presence of the gula and the absence of the notopleural suture on the prothorax. Kinzelbach (1971a) stated the first instar larva with a gula which is lost in the adult, but Crowson (1981) disagreed with Kinzelbach (1971a) in considering mentum as gula. The characters which separate Strepsiptera from other orders are: (a) cosmopolitan distribution; (b) wide host spectrum and high host specificity; (c) well–adjusted parasitism causing little or no harm to the host; and d) loss of the primary, secondary and tertiary sexual organs but the host carries on living parasitoid until its emergence (macrynobiont). The highly specialised adaptation to the host, e.g. the neotenic female is unusual and the dual nature of Myrmecolacidae host is unique. The earliest fossil Strepsiptera came to known in the Eocene but it was misidentified as *Pseudococcites eocaenicus* (Coccoidea). Other fossils of the stylops were found in the Baltic (Pierce, 1908) and Dominican amber (Kinzelbach, 1978, 1979, 1983). Since the brown coal is older than the Baltic amber, *S. eocaenicium* may be taken as the oldest known Strepsiptera. During the last 16 years, molecular studies have placed Strepsiptera in four different positions (Huelsenbeck, 1997; Whiting *et al.*, 1997; Wiegmann *et al.*, 2009; Longhorn *et al.*, 2010; McKenna and Farrell, 2010; Ishiwata *et al.*, 2010). Sequencing of the nuclear genome of a species of Strepsiptera and comparing it to genomic or transcriptomic data of twelve other insect species including two Coleopterans have been made by Niehuis *et al*. (2012). Tree reconstructed using either amino–acid or recoded DNA data, the Strepsiptera has emerged a phylogeny of Strepsiptera as the sister group to Coleoptera.

Kinzelbach (1971b, 1978) divided the order into two suborders (Mengenillidia and Stylopidia) and 9 families; one of which, Mengeidae, is known only from fossil males in the Eocene Baltic amber. Incorporation of a new family, Dipterophagidae by Drew and Allwood (1985) after the new species *Dipterophagus daci* from Australia is unwarranted as the species, *D. daci* is found to belong to the family Halictophagidae. The suborder Mengenillidia is considered to be the more primitive of the two suborders and the two families of this suborder, Mengenillidae and Mengeidae, differ from all other Strepsiptera (i.e. the suborder Stylopidia) in (a) short and clear labial segment, (b) well defined longitudinal vein MA_1, (c) external pupation of the females (unknown in Mengeidae) after leaving the host at the last larval instar, and d) presence of only one genital pore (unlike several ones in Stylopidia which have several). The only apterygote insects of the order Thysanura (Lepismatidae–Zygentoma) have been reported to be parasitised by Mengenillidia. The suborder Stylopidia is distinct from the Mengenillidia, in that the females are endoparasitic remaining within their larval cuticle in the host, except for the extruded cephalothorax.

The families of Strepsiptera that are widespread in distribution are: Corioxenidae, Elenchidae, Halictophagidae and Stylopidae. The genera of parasitoids are restricted to the prevalence of the distribution of the hosts though the hosts in most cases are more widely distributed biogeographically than the parasitoids. Approximately 650 species are known to exist in the globe including 31 extant species in 14 genera under 6 families from India (Mazumdar and Chaudhuri, 2004; Roy and Hazra, 2016a, 2016b, 2017; Pohl *et al*., 2017; Hui, Roy and Hazra, 2023). They are *Corioxenos* Blair, 1936; *Dundoxenos* Luna de Carvalho, 1956; *Trizocera* Pierce, 1909; *Viridopromontorius* Luna de Carvalho, 1985; *Coriophagus* Kinzelbach, 1971a; *Halictophagus* Curtis, 1832; *Tridactylophagus* Subramanian, 1932; *Elenchus* Curtis, 1831; *Myrmecolax* Westwood, 1861; *Lychnocolax* Bohart, 1951; *Stichotrema* Hofeneder, 1910; *Paraxenos* Saunders, 1872 and *Pseudoxenos* Saunders, 1872.

Adult male strepsipterans are typically short lived, dark brown or black, measuring 1.5–6 mm in length. The males are easily recognised by their conspicuous flabellate antennae, small club shaped forewings called pseudohalteres, and large fan shaped hind wings with no cross veins. The copulatory organ or aedeagus is small and pointed. Adult females are larviform (resemble larvae, rather than typical adult insects), measuring 2–6.2 mm in length, and lack antennae, mouthparts, eyes, wings, legs and external genitalia. The cephalothorax, comprising of fused head, prothorax and mesothorax, protrudes through the arthroidal membrane of the host, leaving the abdomen of the female within the host (Kathirithamby, 1989). Anterior region of the female protrudes out of the host body and the male mates by rupturing the female's brood canal opening lying between the head and prothorax. Sperm pass through the opening in a process termed hypodermic insemination (Resh and Cardé, 2003). Eggs hatch in the haemocoel of female, a process known as haemocelous viviparity and the planidium larvae move around freely within the female's haemocoel, which is unique to these animals. The female has a brood canal for communication with the outside world and the larvae escape through it (Piper, 2007). The offspring consume nourishment from their mother. Each female thus produces some thousands of first instar larvae or triungulins which emerge from the brood opening. They have a sclerotised external cuticle with highly serrated ventral regions of the head, thorax and abdomen made of microtrichia which is presumably used to clinging to hosts before entry (Pohl and Beutel, 2004). The head has a pair of antennae, mandibles, labrum and stemmata. The legs are slender with single–jointed tarsi without claws which are ventrally modified as adhesive pads. The tarsi of the pro– and mesothorax are similar but that of the metathorax is different. The abdomen has a pair or two of long cerci used for jumping. The triungulins are very active as they only have a limited amount of time to find a host before they exhaust their food reserves and are capable of jumping for distances of 2 or 3 cm with the aid of using the caudal setae of ninth abdominal segment (present on 9^{th} abdominal segment). They normally enter the host via the abdominal cuticle. The entry is gained through a combination of enzymatic (e.g. chitinase) and physical activity. A fluid is secreted from the mouth of the triungulin and appears to partially dissolve the host's cuticle and enter into the host body. Within the host body, the larva soon undergoes moult within the body of the host to a more grub like second stage, a more grub like form. They induce the host to produce a bag–like structure where they feed and grow. This structure, made from host tissue, protects them from the immune defenses of the host. Larvae go through four more instars and in each moult there is separation of the older cuticle without apolysis leading to multiple layers being formed around the larvae (Kathirithamby *et al*., 2003). Male larvae produce pupae after the last moult, but females directly become neotenic adults (Kathirithamby, 2000).

In most Strepsiptera the male extrudes and pupates and the neotenic female extrudes and becomes mature in adult hosts but there are instances when the male extrudes and pupates in fifth instar nymphal hosts. In case of stylopisation host nymphs never moult to become adults. These nymphs do not show signs of even the beginnings of a moulting cycle whereas unstylopised fifth instar nymphs show this within a few days of moulting to the fifth instar stage (Kathirithamby, 1988). Nymphs stylopised by male puparia eventually die but this may be due to fungal growth on empty male puparia left after the emergence of the adult male. In Mengenillidae at the end of the fourth instar both male and female emerge from the host to pupate externally. The free–living puparium of the male and female have antenna, mouth, eyes, legs and abdominal segments. The adult free–living male and a free–living neotenic female emerge from the free–living puparia. Unlike the Stylopidae the free–living female Mengenillidae have eyes, antennae, mouth parts, legs and a genital opening but are without wings (Hofeneder, 1910; Silvestri, 1941a, 1941b, 1943). The members of Stylopidia extrude through the cuticle of the host at the late fourth instar. These are used during extrusion of the anterior region of the intersegmental membrane of the host cuticle. After extrusion, the head region sclerotises to form the cap of the puparium (cephalotheca). The male pupates in a living host. The metamorphosis of the male takes place in two stages within the puparium (the pupal stage and pre–adult stage). During the pre–adult stage the cuticle hardens, the sperm mature, the wings expand and the flight muscles are developed (Kathirithamby, 2009). The male emerges as a free–living adult by breaking the cephalotheca along the line of weakness (Kathirithamby, 1983; Kathirithamby *et al*., 1990). The only task a free–living adult male performs on emergence from the puparium is to excrete its meconium (waste products of pupal metabolism). It then takes flight immediately in order to seek the female for fertilisation. The adult male has a very short life span (~5–6 h) and there is no teneral period (when the cuticle is incompletely hardened) after emergence from the puparium. Unlike most other insects the metamorphosis to a free–living adult male in Strepsiptera therefore occurs within the puparium, during the pre–adult stage (Kathirithamby, 2009). The female Strepsiptera, on extrusion of the anterior region, forms the cephalothorax and becomes a neotenic female without undergoing a pupal instar and the posterior region remains within the host. The cephalothorax has a brood canal with an opening. There are varying numbers of genital tubes in the brood canal which lead to the haemocoel near the oocytes. The male injects the sperm through the brood canal opening and come down to the body cavity via the genital tubes. The mature oocytes are then fertilised after which the numerous embryos develop within the viviparous female. The first instar larvae leave the female via the genital tubes and come out through the brood canal opening (Kathirithamby, 2000).

Female strepsipterans (which range in size from 2.5 mm to 3.6 cm) are neotenic and remain permanently endoparasitic in the host except Mengenillidae where adult females are wingless and free living (Silvestri, 1943). Only the cephalothorax is visible externally; the rest of the cylindrical body stays within the host and is devoid of all adult insect characters. In neotenic females that have overwintered, the gut is degenerate and filled with haemolymph (Guisti *et al*., 2007). Effects of stylopisation were studied earlier on Hymenoptera (Saunders, 1850; Perez, 1886; Wheeler, 1910; Smith and Hamm, 1914; Perkins, 1918a, 1918b; Salt, 1927). The most significant changes due to stylopisation are that male bee *Andrena* Fabricius tends to resemble normal females and the pollen basket is reduced in females and males display a marked development. The interchange of characters in stylopised bees have been referred to as “intersexes” (Salt, 1927). Like bees stylopised Delphacidae (Hemiptera) were also thought to be “intersexes” and “intermediate” forms (Otake *et al*., 1976). Esaki and Hashimoto (1940) said that the sexes converged to a “neutral form” or that the host undergoes changes to resemble the sex of the parasite (Raatikainen, 1966). Stylopisation or parasitism is known to cause many noticeable morphological, behavioral, dispersal and physiological changes in the insect hosts, even--

- Leading to the formation of intersexes by modification of the genitalia.
- The consequences of stylopisation include changes in antennae, wings, pilosity, facial colouration, pollen collecting apparatus, metasomal shapes, and digestive tract length.
- Stylopisation can also impair ovarian egg development, and cause reduction of egg number, gonadal weight, primary, secondary and tertiary sexual characters, vitality and fertility of the host.
- Stylopised host insects often become less active and may become incapable of establishing nests in the case of some Hymenoptera.

Dispersal of the parasitoids occurs mostly through the hosts including the macropterous Hemiptera. Several species of Strepsiptera are not absolutely host–specific and parasitise several genera and species of hosts. In some cases male and female hosts may differ. For example, in some members of family Myrmecolacidae, the female invades Orthopteran insects while the male parasitises hymenopterans.

The main objective of this study is to observe the life cycle and bionomics of the parasitoids in the hosts in experimental set up along with the effects of stylopization on reproductive potentiality of the hosts and host-parasitoid interactions with the degree of host specificity, percentage of parasitism including super-parasitism and multiparasitism in the host.

Materials and Methods

Both normal and stylopized host insects were collected from several locations viz., the paddy field, grassland etc. using sweep nets (Diameter-15´´; Length-42´´; Height-29´´). Sweep net was operated at ~300 times/30 min (4 days in a week). Experimental set ups were made by transplanting germinated paddy seedlings to earthen pots. The paddy plants were covered by Mylar cages made of transparent polyester sheet with windows. Adult white leaf hopper (WLH) *Cofana spectra*, were released into the cages for rearing the normal and the stylopized hoppers and life cycle of the strepsipteran parasitoid *Halictophagus australensis* (Family: Halictophagidae) surviving within *Cofana spectra* was completed in the experiment. Different insects were collected using mercury lamp (150W), battery operated CDC light trap, as simple light trap operated between 7.00 pm and 5.00 am. The oviposition scars inflicted by female WLH on paddy plant leaf sheath was recorded by lactophenol acid fuchsin test. Comparison was done between the number and pattern of stipples made by the normal gravid female host and stytlopized gravid female host. Relative abundance of normal and stylopized hosts and the seasonal variation of stylopization of *C. spectra* were observed and Percentage of parasitisation of *Halictophagus australensis* was calculated.

Area of work:

(i) State: West Bengal.

(ii) Districts: Fourteen districts of West Bengal.

(iii) Area of collection: *Darjeeling district*: Happy Valley Tea Estate (27.05° N, 88.26° E), Kalimpong (27.06°N, 88.47°E), Kurseong (26.87° N, 88.27° E), Mirik (26.88° N, 88.18° E), Ghum (27.00° N, 88.1400° E), Rohini (26.83° N, 88.30° E), Teestabazar (27.06° N, 88.43° E) , Siliguri (26.71° N, 88.43° E), Panitanki (26.63° N, 88.1° E); *Coochbehar district*: Mathabhanga (26.33°N, 89.22°E), Tufanganj (26.32° N, 89.67° E), Dinhata (26.13°N, 89.47°E); *Jalpaiguri district*: Jalpaiguri (26.70°N, 89.00°E), Moinaguri (26.57°N, 88.82°E), Dhupguri (26.58° N, 89.00° E), Birpara (26.50°N, 89.50°E); *Alipurduar district*: Alipurduar Jn. (26.48° N, 89.52° E); *Uttar Dinajpur district*: Dalkhola (25.87°N, 87.83°E), Kaliaganj (25.63°N, 88.32°E), Raiganj (25.62°N, 88.12°E), Itahar (25.45° N, 88.16°E); *Dakshin Dinajpur district*: Balurghat (25.22°N, 88.76°), Hili (25.28°N, 88.99°E), Tapan (25.28°N, 88.57°E), Kumarganj (25.4338°N, 88.7267°E), Gangarampur 25.40° N, 88.52° E), Kushmandi (25.52°N, 88.35°E); *Malda district*: Chanchal (25.39°N, 87.99°E), Samsi (25.25°N, 87.02°E), Pakuahat Gazole (25.22°N, 88.18°E), (25.00°N, 88.15°E), Kaliachak (24.80° N, 88.02°E); *Murshidabad district*: Farakka (24.82°N, 87.90°E), Dhuliyan (24.68°N, 87.97°E), Berhampore (24.10° N, 88.25° E), Azimganj (24.23° N, 88.27°E), Domkal (24.14°N, 88.52°E), Hariharpara (24.03°N, 88.45°E), Beldanga (23.95° N, 88.03°E), Kandi (23.93° N, 88.25°E); *Birbhum district*: Rampurhat (24.17°N, 87.78°E), Tarapith (24.1100° N, 87.8000° E), Mollarpur (24.10°N, 87.70°E), Bakreswar (23.88°N, 87.37°E), Bolpur (23.67°N, 87.72°E), Illambazar (23.63° N, 87.53°E); *Burdwan district*: Asansol (23.68°N, 86.99°E), Ranijang (23.62°N, 87.13°E), Durgapur (23.55° N, 87.32° E), Panagarh (23.4500°N, 87.4300°E), Galsi (23.33° N, 87.69° E), Crop Seed Multiplication Centre, Burdwan University (23.25° N, 87.84°E), Memari (23.20°N, 88.12°E), Shyamsundar (23.09°N, 87.86°E), Raina (23.06° N, 87.90° E), Jamalpur (23.06°N, 87.98°E), Khandaghosh (23.21°N, 87.68°E), Kalna (23.22°N, 88.37°E), Bhatar (23.41°N, 87.91°E), Guskara (23.50°N, 87.75°E), Katwa (23.65°N, 88.13°E); *Bankura district*: Barjora (23.43° N, 87.28°E), Sonamukhi (23.30° N, 87.42° E), Bankura (23.25°N, 87.07°E), Bisnupur (23.08°N, 87.32°E), Ramsagar (23.09°N, 87.27°E), Kotalpur (23.01°N, 87.59°E), Chatra (22.98°N, 86.85°E), Patrasayar (23.21° N, 87.51° E), Khatra (22.98°N, 86.85°E); *Hooghly district*: Chinsurah (22.90°N, 88.39°E), Mogra (22.97°N, 88.37°E), Pandua (23.08°N, 88.28°E), Bainchi (23.11°N, 88.19°E), Khanakul (22.69°N, 87.85°E), , Tarakeswar (22.88°N, 88.01°E), Champadanga (22.83°N, 87.96°E), Arambagh (22.88°N, 87.78°E); *Nadia district*: Nawadeep (23.42°N, 88.37°E), Kalyani (22.97°N, 88.43°E), Krishnanagar (23.40°N, 88.50°E), Shantipur (23.25° N, 88.43° E), Bethuadahari (23.61°N, 88.38°E); and *East Mednapur district*: Panskura (22.42°N, 87.70°E), Tamluk (22.30°N, 87.92°E), Moyna (22.12°N, 87.96°E).

Results and Discussion

Different insects were collected randomly through operation of sweep net, CDC light trap and open light trap. Insect specimens collected in light trap and sweep net are shown in Table 1. Adult males of Strepsiptera caught in light trap are: *Triozocera pugiopenis* Chaudhuri and Das Gupta, *Halictophagus australensis* Perkins, *Tridactylophagus maculatus* Chaudhuri, Ghosh and Das Gupta, *Myrmecolax pierci* (Chattopadhyay and Chaudhuri). Stylopised Homopterans species viz., *Atkinsoniella opponens* (Walker, 1851) (Cicadellidae: Cicadellinae), *Exitianus nanus* (Distant, 1908) (Cicadellidae: Deltocephalinae), *Exitianus indicus* (Distant, 1908) (Cicadellidae: Deltocephalinae), and *Empoasca* sp. (Cicadellidae: Typhlocybinae) were caught from grasslands (Table 2). Stylopized hoppers like, BPH *Nilaparvata lugens* (Stål, 1854) (Delphacidae: Delphacinae), and white leafhopper *Cofana spectra* (Distant, 1908) (Cicadellidae: Cicadellinae) were detected during the last years from the paddy fields (Table 2).

Fresh adult hoppers of different species were released separately in different growing paddy plants in the earthen tub as designed earlier for their multiplication. Other specimens were preserved in 70% ethanol. Stylopized host insects were processed, and mounted on glass slide to study the changes in morphology due to stylopisation. It was observed that *Halictophagus australensis* parasitizes *Cofana spectra* and the life cycle of the normal and parasitized hosts had been completed. Life cycle comparison between normal and stylopized *C. spectra* revealed *H. australensis* usually lengthens the longevity of *C. spectra* up to maturity (in the case of the male) or to produce progeny (in the case of the viviparous female). The first instar is a very minute (0.08 to 0.3 nm), free living larvae known as triungulin. The triungulins are active and capable to jump for distances of 2 or 3 cm and penetrate the body of the host. A fluid partially dissolves the host cuticle (e.g. chitinase)

Table 1: Insects collected in traps: light trap and sweep net

Orders	Families	Infection Status
Dictyoptera	Blattidae	×
	Mantidae	×
Orthoptera	Tettigoniidae	×
	Gryllidae	×
	Acrididae	×
	Gryllotalpidae	×
Dermaptera	Forficulidae	×
Hemiptera	Coreidae	×
	Alydidae	×
	Aphididae	×
	Cicadellidae	✓
	Dictyopharidae	×
	Pentatomidae	×
	Scutellaridae	×
	Delphacidae	✓
	Cicadidae	×
	Membracidae	×
	Tingidae	×
	Fulgoridae	×
Diptera	Ceratopogonidae	×
	Culicidae	×
	Chironomidae	×
	Tipulidae	×
	Psychodidae	×
	Muscidae	×
	Calliphoridae)	×
	Simuliidae	×
	Cecidomyiidae	×
	Sciaridae	×
	Tabanidae	×
	Asilidae	×
	Stratiomyidae	×
	Syriphidae	×
	Sarcophagidae	×
	Phoridae	×
Hymenoptera	Apidae	×
	Pompilidae	×
	Evaniidae	×
	Braconidae	×
	Mymaridae	×
	Ichneumonidae	×
	Vespidae	×
	Sphecidae	×
	Formicidae	×
	Papilionidae	×

Lepidoptera	Nymphalidae	×
	Hesperidae	×
	Pieridae	×
	Sphingidae	×
	Lasicampidae	×
	Pyralidae	×
	Bombycidae	×
	Saturniidae	×
	Noctuidae	×
	Amatidae	×
	Arctiidae	×
Coleoptera	Cicindelidae	×
	Carabidae	×
	Scarabaeidae	×
	Elateridae	×
	Lucanidae	×
	Curculionidae	×
	Tenebrionidae	×
	Cerambycidae	×
	Lampyridae	×
	Coccinellidae	×
Neuroptera	Myrmeleontidae	×
	Ascalaphidae	×
	Chrysopidae	×

Table 2: Records of stylopised homoptera

S. No.	HOST	FAMILY and SUBFAMILY	PHOTOS	POSITION OF STYLOPISATION
1	*Atkinsoniella opponens* (Walker, 1851) Male	Cicadellidae: Cicadellinae	 Body length-6.32 mm	Stylopisation mark on 6^{th} to 9^{th} sternite segments. There was no stylopisation encountered in the tergite segment till now.
2	*Exitianus nanus* (Distant, 1908) Female	Cicadellidae: Deltocephalinae	 Body length-5.71 mm	Only one stylopised host was observed. Stylopisation took place at the lateral portion of the 7^{th} sternite.

3	*Exitianus indicus* (Distant, 1908) Female	Cicadellidae: Deltocephalinae	 Body length-4.99 mm	Stylopisation mark was found at 7^{th} to 8^{th} sternite segments.
4	*Empoasca* sp. Male	Cicadellidae: Typhlocybinae	 Body length-6.56 mm	Only one stylopised host was encountered. Stylopisation mark on the 8^{th} abdominal sternite.
5	*Cofana spectra* (Distant, 1908) Male and Female	Cicadellidae: Cicadellinae	 Body length-7.17 mm	Stylopisation marks were observed on two different locations. One type encountered at the 5^{th} to 6^{th} tergite segments, considered as a male stylops and another one was encountered at the 6^{th} to 9^{th} sternite segments, considered as female stylops. Both types of stylopisation marks noticed on 15 numbers of specimens.
6.	*Nilaparvata lugens* (Stål, 1854) Female	Delphacidae: Delphacinae	 Body length-3.89 mm	Only two stylopised BPH were observed. Both stylopisation were encountered at the 4^{th} abdominal tergite.

for getting in the host. The larva immediately molts to second stage within the host (grub like) form. There were a total of four larval stages and the male extrudes and pupates. Finally the male emerged as a free living adult by breaking the cephalothoeca.

Data related to collection of *Cofana spectra* from March 2023 to February 2024 using sweep net along with temperature and humidity are shown in Table 3. The relative abundance of normal and stylopized *C. spectra* and the seasonal variation of affected *C. spectra* were observed (Fig.

Table 3: Monthly collected *Cofana spectra* from March 2023 to February 2024 using sweep net

Months (2023-2024)	Mean Temperature (at the time of collection)	Mean Humidity (at the time of collection)	Total Collected *Cofana spectra*	Infected *Cofana spectra*	Percentage (%) of Parasitisation
March	30.9	80.3	349	21	6.01
April	36.8	79.1	305	27	8.85
May	36.4	80.5	294	24	8.16
June	35.0	90.8	289	11	3.8
July	32.1	93.8	216	6	2.77
August	32.4	94.1	242	6	2.47
September	31.4	92.8	191	3	1.57
October	31.3	92.4	253	12	4.74
November	29.5	88.2	388	31	7.98
December	25.7	84.7	436	65	14.9
January	25.4	87.3	324	42	12.96
February	29.2	87.6	344	39	11.33

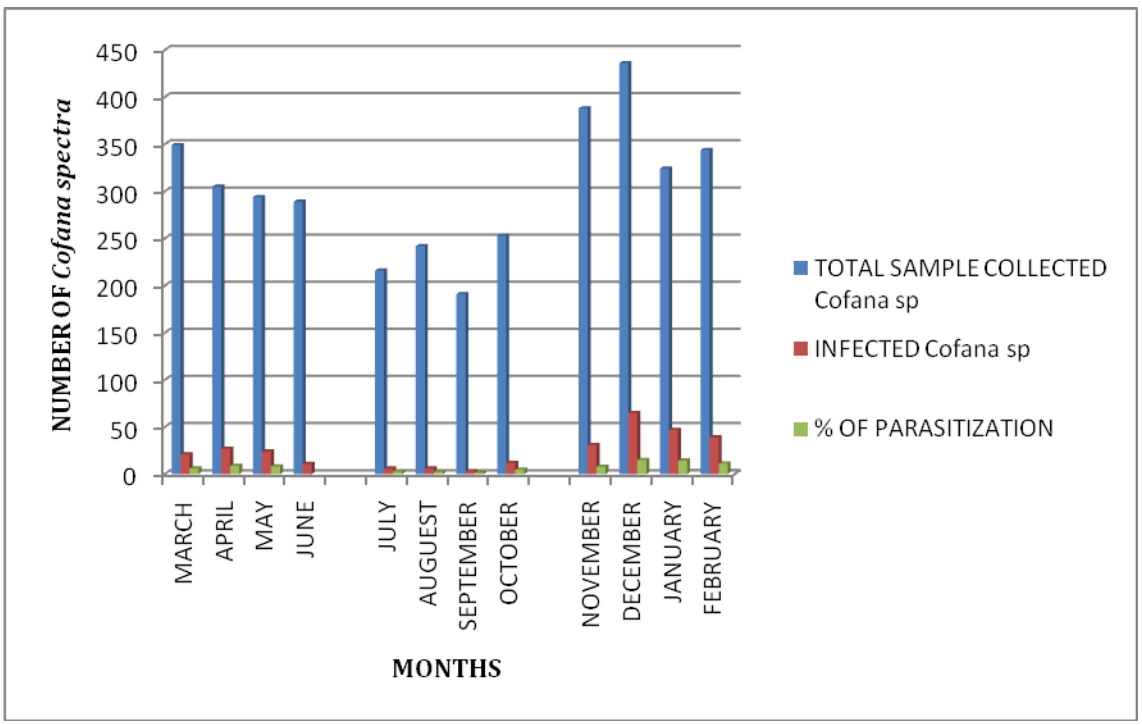

Fig. 1: Monthly variations of the number of infected and non-infected *Cofana spectra.*

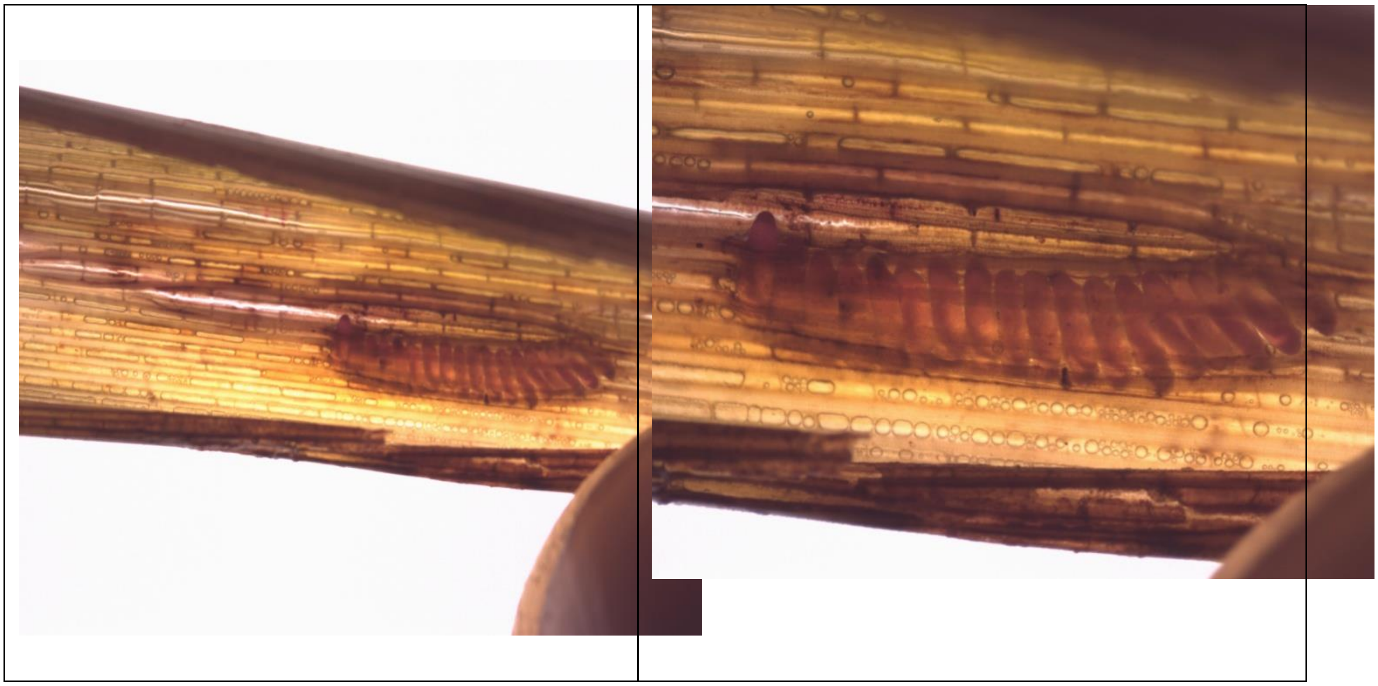

Fig. 2: Oviposition slit containing egg cluster.

1). Population of host insect decreased during the July–October (Monsoon period) while it increased during the November-February (Post-monsoon). Stylopised hosts were also lower in the monsoon period while the maximum infections got enhanced in the post-monsoon season. The ecological parameters i.e. temperature, humidity and rainfall exhibited negative correlation with the abundance of *C. spectra* in rice fields. The percentage of stylopization varied 1 to 15.

Gravid female made attempts to oviposit several sites on paddy plants through creation of many small pore-like structures (scars) where eggs were deemed to lay. They were observed after processing by the lactophenol acid fuchsin solution (Fig. 2). A comparison of oviposition scar between the normal gravid and the stylopized gravid female of *C. spectra* was done. It was observed that number of stipples was far greater in those paddy plants where normal gravid females were present.

In spite of its rare occurrence, 5 species of Strepsiptera were collected out of which life cycle of *Halictophagus australensis* had been studied in detail and was noted to be very much host specific. It parasitized only *Cofana spectra* a pest of the rice agroecosystem and the effects on host had been observed. Light traps were usually suspended from the branches of long trees usually 4-5 feet above the ground. All the infected *C. spectra* were collected from the host plants through operations of sweep nets. Stylopization might possibly degenerate the flight muscles of the host (*C. spectra*) so that they are not capable to fly. They made hopping movement only and were found unable to escape through effective flight. The relative abundance of normal and stylopized host and the seasonal variation of stylopization of WLHs were observed. Percentage of parasitisation of *Halictophagus australensis* was observed during the period. Four normal and stylopised Homopterans species viz., *Atkinsoniella opponens* (Walker, 1851) (Cicadellidae: Cicadellinae), *Exitianus nanus* (Distant, 1908) (Cicadellidae: Deltocephalinae), *Exitianus indicus* (Distant, 1908) (Cicadellidae: Deltocephalinae), and *Empoasca* sp. (Cicadellidae: Typhlocybinae) have been recorded from Darjeeling. So far there is no record of above stated stylopised host species from India. However, no adult males were emerged from the infected hosts. This in turn may lead to elucidate the host specificity of the parasitoids. In addition how suppression of host immune response occurs by the parasitoid may be deduced. Since to some extent stylops can suppress the population of homopteran paddy pests (economically important hoppers), efforts could be made to control the pests below economic injury level. The result of this investigation is expected to usher mechanism of these macrynobionts in minimizing host population of the pest insects which may be used as agents for biological control.

Ethical Statement

The author confirms that all ethical issues have been dealt with the research ethics guidelines provided by the Department of Zoology, Gushkara Mahavidyalaya, Guskara, Purba Bardhaman, West Bengal, India.

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Conflict of Interest

The authors declare no conflicts of interest.

References

Amett RH. (1968) The beetles of the United States: a manual for identification. American Entomological Institute, Cornell University, pp. 1112.

Crowson RA. (1954) The classification of the families of British Coleoptera. Superfamily 19: Stylopidae (Order Strepsiptera). Entomologist's Monthly Magazine 90: 57-63.

Crowson RA. (1960) The phylogeny of Coleoptera. Annual Rev Entomol. 5: 111-134.

Crowson RA. (1981) The Biology of Coleoptera. Academic Press, pp. 802.

Drew RAL and Allwood AL. (1985) A new family of Strepsiptera parasitizing fruit flies (Tephritidae) in Australia. Systematic Entomol. 10: 129-134.

Esaki T and Hashimoto S. (1940) Bericht über die Reispflanze schä digende Zikaden und deren natürliche Feinde. Sitzungsberichte der Gesellschaft Naturforschender Freunde 25: 72-94.

Guisti F, Dallai L, Beani L, Manfredini F and Dallai R. (2007) The midgut ultrastructure of the endoparasite *Xenos vesparum* (Rossi) (Insecta, Strepsiptera) during post–embryonic development and stable carbon isotopic analysis of the nutrient uptake. Arthropod Structure Development 36: 183-197.

Hennig W. (1981) Insect Phylogeny. Wiley and Sons, pp. 524.

Hofeneder K. (1910) Mengenilla n. g. Chobauti n. sp. Eine neue Strepsiptere aus Nordafrika. Bericht des Naturwissenschaftlich-Medizinischen Vereins in Innsbruck 31: 33-57.

Huelsenbeck JP. (1997) Is the Felsenstein zone a fly trap? Systematic Biology 46: 69-74.

Hui P, Roy S and Hazra N. (2024) Diversity and biology of the Indian Strepsiptera with a pictorial key. Indian J Entomol. 86(3): 1004-1023.

Ishiwata K, Sasaki G, Ogawa J, Miyata T and Su ZH. (2010) Phylogenetic relationships among insect orders based on three nuclear protein–coding gene sequences. Molec Phylogenetics Evol. 58: 1-49.

Jeannel R. (1945) Sur la position systematique des Strepsipteres. Revue Francaise d'Entomologie 11: 111-118.

Kathirithamby J. (1983) The mode of emergence of the adult male *Elenchus tenuicornis* (Kirby) (Strepsiptera: Elenchidae) from its puparium. Zoological J Linnean Soc. 77: 97-102.

Kathirithamby J. (1988) The twisted–winged parasitoid of Auchenorrhyncha. Proc Sixth Auchenorrhyncha Meeting, Turin, pp. 631-639.

Kathirithamby J. (1989) Review of the order Strepsiptera. Systematic Entomol. 14: 41-92.

Kathirithamby J. (1990) Descriptions of Corioxenidae (Strepsiptera) from Australia, and a checklist of world genera and species of Corioxenidae. Invertebrate Taxonomy 3: 469-481.

Kathirithamby J. (2000) Morphology of the female Myrmecolacidae (Strepsiptera) including the *apron*, and an associated structure analogous to the peritrophic matrix. Zoological J Linnean Soc. 128: 269-287.

Kathirithamby J. (2009) Host–parasitoid associations in Strepsiptera. Annual Rev Entomol. 54: 227-249.

Kathirithamby J and Hamilton WD. (1992) More covert sex: the elusive females of Myrmecolacidae (Strepsiptera). Trends Ecol Evol. 7: 349-351.

Kinzelbach RK. (1971a) Halictophagus helleri n. sp. von Ceylon. Stuttgarter Beiträge zur Naturkunde 230: 1-8.

Kinzelbach RK. (1971b) Nematodenbefall bei *Mengenilla parvula* Silvestri, 1941 (Insecta, Strepsiptera, Mengenillidae). Bollettino del Laboratorio di Entomologia Agraria 'Filippo Silvestri', 28: 190-193.

Kinzelbach RK. (1978) Strepsiptera. Die Tierwelt Deutschlands 65: 166.

Kinzelbach RK. (1979) Das erste neotropische Fossil der Facherflugler (Stuttgarter Bersteinsammlung: Insecta, Strepsiptera). Stuttgarter Beitriige zur Naturkunde aus dem Staatlichen Museum fur Naturkunde in Stuttgart B 52: 14.

Kinzelbach RK. (1983) Facherfliiger aus dem dominikanischen Berstein (Insecta: Strepsiptera: Myrmecolacidae). Verhandlungen des Naturwissenschaftlichen Vereins Hamburg 26: 29-36.

Longhorn SJ, Pohl HW and Vogler AP. (2010) Ribosomal protein genes of holometabolan insects reject the Halteria, instead revealing a close affinity of Strepsiptera with Coleoptera. Molec Phylogenetics Evol. 55: 846-859.

Mazumdar A and Chaudhuri PK. (2004) A catalogue of Strepsipteran species (Insecta) of India. Proc Zool Soc Kolkata 57(1): 43-46.

McKenna DD and Farrell BD. (2010) 9 genes reinforce the phylogeny of Holometabola and yield alternate views on the phylogenetic placement of Strepsiptera. PLoS One 5: e11887.

Niehuis O, Hartig G, Grath S, Pohl H and Lehmann J. (2012) Genomic and morphological evidence converge to resolve the enigma of Strepsiptera. Curr Biol. 22: 1309-1313.

Otake A, Somasundram PH and Abeykoon MB. (1976) Studies on populations of *Sogatella furcifera* Horvath, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) and their parasites in Sri Lanka. Appl Entomol Zoology Tokyo 11: 284-294.

Perez J. (1886) Des effects du parasitisme des *Stylops* sur les Apiaires du genre *Andrena*. Actes de la Societe Linneenne de Bordeaux 40: 21-60.

Perkins RCL. (1918a) Further work on stylops and stylopized bees. Entomologist's Monthly Mag. 54: 115-129.

Perkins RCL. (1918b) The assembling and pairing of *Stylops*. Entomologist's Monthly Mag. 54: 129-131.

Pierce WD. (1908) A preliminary revision of the classification of the order Strepsiptera Kirby. Proc Entomological Soc Washington 9: 75-85.

Piper R. (2007) Extraordinary animals: an encyclopedia of curious and unusual animals. Greenwood Press.

Pohl H and Beutel RG. (2004) Fine structure of adhesive devices of Strepsiptera (Insecta). Arthropod Structure Development 33: 33-43.

Raatikainen M. (1966) The effect of different sexes of the parasite *Elenchus tenuicornis* (Kirby) on the morphology of the adult *Javesella pellucida* (F.) (Hom., Delphacidae). Annales Entomol Fennici 32: 138-146.

Resh VH and Cardé RT. (2003) "Strepsiptera". Encyclopedia of Insects. Academic Press, pp.1094-1096.

Ross HT, Ross AC and Ross JRP. (1984) A Textbook of Entomology, 4th edn., Wiley, New York, pp. 666.

Roy S and Hazra N. (2016a) First record of a new species of the genus *Viridopromontorius* Luna de Carvalho (Strepsiptera: Corioxenidae: Corioxeninae) from India, with a revised key to Corioxenidae. Zootaxa 4154(5): 567-573.

Roy S and Hazra N. (2016b) Two new species of Halictophagidae (Insecta: Strepsiptera) including the first record of genus *Coriophagus* Kinzelbach from India. Zootaxa 4189(1): 581-587.

Roy S and Hazra N. (2017) Two new species of Myrmecolacidae (Strepsiptera) with first record of the genus *Stichotrema* Hofeneder from India. Annales Société Entomologique France 53(5): 334-343.

Salt G. (1927) The effects of stylopization on Aculeate Hymenoptera. J Exp Zoology 48(1): 223-331.

Sauders SS. (1850) Descriptions of two new Strepsipterous insects from Albania, parasitical on bees of genus *Hylaeus*, with account of their habits and metamorphosis. Transactions Entomol Soc London 1: 43-59.

Silvestri F. (1941a) Notizie, specialmente corologichee biologiche sulle specie di '*Mengenilla*' (Insecta, Strepsiptera) finora trovate in Italia. Acta Pontificia Academica Scientiarum 5(9): 57-65.

Silvestri F. (1941b) Studi sugli 'Strepsiptera' (Insecta). II. Descrizione, biologiae sviluppo post embrionale dell' *Halictophagus tettigometrae* Silv. Bollettino del Laboratorio di Zoologia Generale e Agraria dell Facolta Agraria Portici 32: 197-282.

Silvestri, F. (1943) Studi sugli 'Strepsiptera' Insecta. III. Descrizione e biologia di 6 specie italiane di *Mengenilla*. Bulletin Société Philomathique Paris 32: 197-282.

Smith MAG and Hamm AH. (1914) Studies in the experimental analysis of sex, Pt. on *Stylops* and stylopisation. Quarterly J Microscopical Sci. 60: 435-461.

Wheeler WM. (1910) The effects of parasitic and other kinds of castration in insects. J Exp Biol. 8: 377-438.

Whiting MF, Carpenter JC, Wheeler QD and Wheeler WC. (1997) The Strepsiptera problem: Phylogeny of the holometabolous insect orders inferred from 18S and 28S ribosomal DNA sequences and morphology. Systematic Biology 46: 1-68.

Wiegmann BM, Trautwein MD, Kim JW, Cassel BK and Bertone MA. (2009) Single–copy nuclear genes resolve the phylogeny of the holometabolous insects. BMC Biol. 7: 34.