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Bionomics and two sex life table of *Coranus siva*: A new potential predator of Fall armyworm (*Spodoptera frugiperda*)

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ABSTRACT

A new generalist predatory bug, *Coranus siva,* was observed to feed on invasive fall armyworm [*Spodoptera frugiperda* (J E Smith)], which is currently creating a havoc in maize (*Zea mays* L.) cultivation. Though it's naturally balancing the *S. frugiperda* population, its economic utilization is under bleak due to unavailability of scientific evidences on its bio-control potential. The present study was carried out during 2020–22 at ICAR-Indian Agricultural Research Institute, New Delhi to delineate its biology, life table and functional response to understand its bio-control potential. The bugs had total longevity of 52.7 ± 5.19 days with 90.14 ± 4.3% fecundity. The intrinsic rate of increase (r)/time unit was 9.59, the finite rate of increase (λ)/time unit was 1.10, the net reproductive rate (R0) was 63.10 and the mean generation time is 43.21, respectively. The *C. siva* exhibited Type II functional response against *S. frugiperda.* These findings gave the pragmatic clues and insights on utilization of *C. siva* as a promising bio-control agent for the management of *S. frugiperda* sustainably through integrated pest management.

Keywords: Biology, Distribution, Invasive pest, Life table, Population, Predation

Fall Armyworm [*Spodoptera frugiperda* (J E Smith)], is a transboundary pest native of America, but was first reported from Africa (Goergen *et al.* 2016) outside its native range during 2016 and now invaded India since 2018 (Sharanabasappa *et al.* 2018) either by natural dispersal or by extensive trade and travel between Africa and India. It is widely distributed throughout the country and causing serious economic damage in maize (*Zea mays* L.) and other cereal crops. The characteristics like rapid dispersal ability, absence of diapause, short generation time, high fecundity, polyphagy, insecticide resistance, and adaptability to adverse climate made this pest to become more invasive (Wan *et al.* 2021). Insecticides are being extensively used for management of Fall armyworm (FAW). Fodder maize, sweet corn and baby corn are consumed with high perishability, usage of insecticides could leave high residue on them. FAW is also known to have developed resistance to pesticides in China (Zhang *et al.* 2020) and America (https://www.pesticideresistance.org), therefore, there is greater need to search for cost-effective, socially acceptable and environment friendly management. Despite being an invasive pest on most of the crops, very limited information is available on its indigenous natural enemies which is required for devising sustainable management strategy against it. The only economical and sustainable option available is biological control.

An array of native parasitoids and predators have been identified from the order Hymenoptera (Shylesha *et al.* 2018, Sharanabasappa *et al.* 2019) and Heteroptera (Pradeep *et al.* 2022) in India but their basic bio-ecological studies requires a detailed attention. These studies are necessary to develop standard methodologies for their mass production, conservation and field release. Among the reported bioagents, the heteropteran predators belongs to the family Reduviidae and subfamily Harpactorinae can be used to control FAW as they are distributed in all ecosystems and proved to be the potential biological control agents (Ambrose 1999, Weirauch *et al.* 2014, Bhagyasree 2019), *Coranus siva* (Kirkaldy) (Harpactorinae: Reduviidae: Hemiptera) was one of the most prevalent and novel predator frequently observed predating on *S. frugiperda* in maize fields of ICAR-Indian Agricultural Research Institute, New Delhi but no information is available on its basic bionomics. Therefore, the present study was undertaken to know in detail about its distribution, biology, life table and functional response

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of newly reported predator to decipher its potential role in controlling the pest.

MATERIALS AND METHODS

Distribution mapping of C. siva: Mapping of the predator was done by collecting the data on geographical coordinates, viz. latitude and longitude was retrieved from the label data of *C. siva* specimens deposited at the insect repositories like National Pusa Collection, Division of Entomology, Indian Agricultural Research Institute, Pusa, New Delhi (https://npc.iari.res.in) and collections of Division of Entomology, University of Agricultural Sciences, Gandhi Krishi Vigyana Kendra, Bengaluru (Bhagyasree 2017). The distribution mapping was done using the open access software DIVA-GIS (https:// diva-gis.org).

Biology and two-sex life table analysis of bugs: Adult bugs were collected from maize fields of Indian Agricultural Research Institute, New Delhi (28.6377° N, 77.1571° E; at an elevation of 228.61 m amsl) and reared under optimum laboratory condition (30 ± 2°C temperature and 75 ± 5% relative humidity) in small netted rearing cages (12 inch × 12 inch) for one generation on 4th instar *Corcyra cephalonica* (Stainton) larvae in toxicology laboratory, Division of Entomology, Indian Agricultural Research Institute, then taken for further studies during 2020–2022. The factitious host *C. cephalonica* was mass reared by following the method of Kumar *et al.* (2019) and Kumar and Kumar (2001). The adults male and female of *C. siva* emerged in the laboratory were paired and allowed to mate in insect breeding cages. After mating, adult females were separated and placed individually for egg laying, it was observed and counted daily during morning hours to record the number of eggs/batch and total number of egg batches. When nymphs started emerging they were provided with *S. frugiperda* as a prey reared on tender maize cobs. Newly emerged nymphs were placed individually in order to record the biological parameters, viz. time duration required for development of each nymphal instar and their survival. All the observations were recorded for two generations as per the methodology given by Truong *et al*. (2020) with minor modification with respect to rearing boxes. Polystyrene insect breeding dishes of Himedia with 90 mm × 40 mm dimension were used for the study. The emerged adults were sexed by looking at the genital structures, paired and placed in insect breeding dishes for mating. The biological parameters such as number of eggs laid/female, longevity of adult male, longevity of adult female, pre-oviposition period of female (days) were observed. From the recorded life-history data of bugs, each population parameter was calculated using the TWOSEX-MS Chart 2024 software (available at http://140.120.197.173/Ecology/prod02.htm). The mean values, standard errors, and variances of population parameters were determined using the bootstrapping technique (100,000 repeats) (Efron and Tibshirani 1993). Graphs were generated using MS Excel. The life tables were constructed by using 'TWOSEX-MS Chart' software. According to the age-stage, two-sex life table principle (Chi 1988, Huang and Chi 2011) and method (Tuan *et al.* 2014) all the parameters were calculated.

Functional response: Functional response of II, III, IV, V instar nymphs and adult male and female were calculated separately on early 3rd instar larvae of *S. frugiperda* with varying prey density of 2, 4, 6, 8, 10 and 12. Individual male and female adults were starved for 12 h and nymphs were starved for 4 h in a small insect culture boxes prior to the experiments. Each set was replicated 8 times after 24 h, number of prey eaten or killed were recorded. The type of relationship between the predator and its prey (functional response) was determined by polynomial logistic regression (SAS/STAT, CATMOD procedure) (Taylor *et al.* 2001). When type 2 functional response was evident, holing disc equation was used to calculate attack rate (a') and handling time (T*h*) using R software with FRAIR package (Pritchard *et al.* 2017).

RESULTS AND DISCUSSION

If the parasitoid/predator is distributed in all the agroclimatic zones, it can be successfully deployed for area-wide biocontrol programmes (Kumaraswamy *et al.* 2024), hence the geographic and topographic distribution of *C. siva* was mapped before conducting bionomic and life table studies, as this is the first report of *C. siva* feeding on FAW and a first study on understanding the feasibility of *C. siva* for management of *S. frugiperda*. Habitat of generalist predator hugely depends on climate than a prey (Sunde *et al.* 2014), generalist predators are adapted to prey across the wide taxonomic group. Compared to augmentative biological control, conservation biological control helps in enhancing the population of generalist predators, mapping is imperatively necessary for protection of predators, as the operation of conservation biological control is spatial. Distribution mapping shows that, *C. siva* is distributed in almost all the climatic zones of India, viz. Delhi, Gujarat, Uttar Pradesh, Manipur, Maharashtra, Chhattisgarh, Andhra Pradesh, Telangana, Tamil Nadu, Kerala and Karnataka. It demonstrates the climatic adaptability and suitability of predator for planning biological control.

Biological parameters: The female bugs laid brownish eggs on the walls of rearing boxes in laboratory under optimum condition, eggs were elongated, barrel shaped with sculptured white operculum which breaks open during the emergence of nymph, the incubation period of *C. siva* was 5.4 ± 0.34 days under laboratory conditions. Fecundity of the predator was 90.14 ± 4.3%. Bugs had 5 nymphal instars, and the duration of I, II, III, IV, and V instar was 4.6 ± 0.33, 5.7 ± 0.22, 6.3 ± 0.44, 7.5 ± 0.60 and 8.3 ± 0.60 days, respectively. The total pre-adult/nymphal period was 38.0 ± 1.5 days. The longevity of the adult was 19.3 ± 1.65 days and the total longevity of the bugs were 52.7 ± 5.19 days, respectively (Supplementary Table 1). Our results demonstrated that successful completion of biology on *S. frugiperda* is an evidence for its suitability as a biocontrol agent for management of *S. frugiperda*. Reduviids are generalist predators, however, some species of bugs exhibit preference for particular prey once at the same time provided with completely different species, change in prey preference is well documented in reduviids (Sahayaraj 2007). Even though *S. frugiperda* is invasive and new to *C. siva* as a prey, it is providing the necessary nutrients like sugars, proteins, lipids and other micronutrients to meet the metabolic necessities of *C. siva*, hence it is efficiently foraging on FAW in field and laboratory. The bugs belongs to the same genus were studied for their suitability for management of *Spodoptera litura* (Claver and Reegan 2010) and *Hypothenemus hampei* (Ferrari) (Venkatesha and Kiran 2024) had shown similar results. Fitness of predator in terms of longevity, survival, fecundity, growth and development on *S. frugiperda* gave an initial clues on using *C. siva* as one the candidate biocontrol agent for management of *S. frugiperda.*

Life table parameters: Several criteria's and methods are used for selection and evaluation of best biocontrol agents. Life table characteristics are diversely used for understanding the predator prey relationship in biological control. Demographic statistics quantify the life history attributes like fecundity, developmental time and survival under optimal conditions (Reed *et al.* 1992). Age-stage-specific survival rate (S_{xj}) shows the probability that a newly laid egg of the predator survived to each age-stage unit (Fig. 1). The survivorship curve and stage differentiation among individuals showed the survival rates of nymphal instars were high at N_1, N_2, N_3, N_4 and N_5 stages, and females also had shown better survival rates compared to males. The fecundity matrix proposes the number of female offspring per female of age x and stage j. The highest number of eggs laid were observed to be 22.33 at the age of 39 days (Fig. 2). Fecundity in the study was probable low and delayed due to multitude of factors which are required for growth and fitness were limited in the laboratory. The age-stage-specific life expectancy (E_{xj}) described an expected lifespan of bugs individuals of age x and stage j. The life expectancy observed maximum in first three nymphal instars and adult stage (Fig. 3). The reproductive value (V_{xj}) of the bugs, indicates the contribution of a bug individuals at age x and stage j to the future populations.

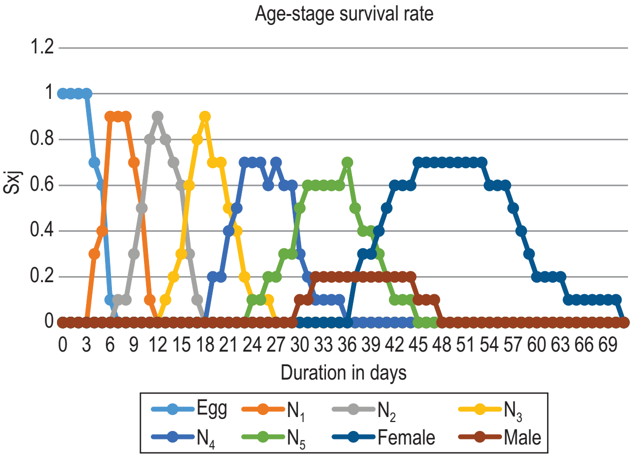

Fig. 1 Age-stage-specific survival rate (S_{xj}) of *C. siva* fed on *S. frugiperda.*

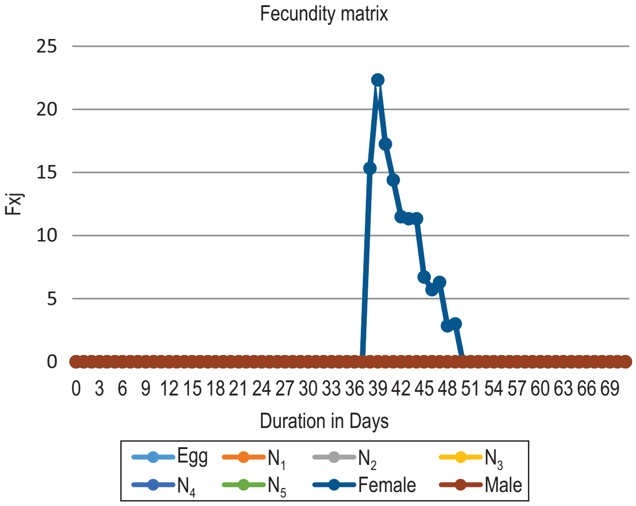

Fig. 2 The female age-specific fecundity.

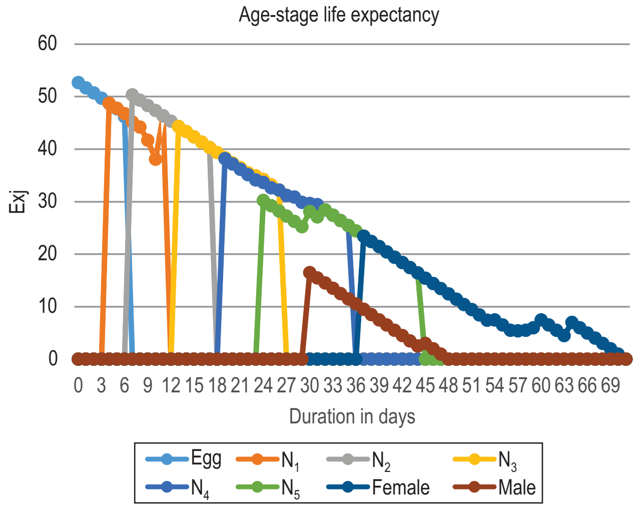

Fig. 3 Age-stage life expectancy (e_{xj}) of *C. siva* fed on *S. frugiperda.*

The reduced longevity of adults (19.3 ± 1.65) of *C. siva* compared to *Coranus fuscipennis* Reuter (80.12 ± 4.29) (Lam 2016) and *Coranus spiniscutis* Reuter (83.72 ± 2.45) (now synonymized as *C. siva*) (Claver and Reegan 2010) may be attributed to biological parameters of bugs impacted by biotic and abiotic factors such as ambient conditions, nutritive quality of egg yolk, poor prey handling and food conversion efficiency. To identify the reasons for reduced longevity, there are no much evidences/studies in the genus *Coranus*. Reproductive values of the bug spiked to 92.0 at the 38th day of the age (Fig. 4). Demographic parameters reflect the general impact of prey on growth and development, survival and fecundity of predator. Under the population/demographic parameters, the intrinsic rate of increase (r)/time unit was 9.59, the finite rate of increase (λ)/time unit was 1.10, the net reproductive rate (R0) was 63.10 and the mean generation time is 43.21. These results provide a complementary data on utilization of *C. siva* for management of *S. frugiperda*. The computed finite rate of increase of 1.10/female/day shows that each female contributed 63.10

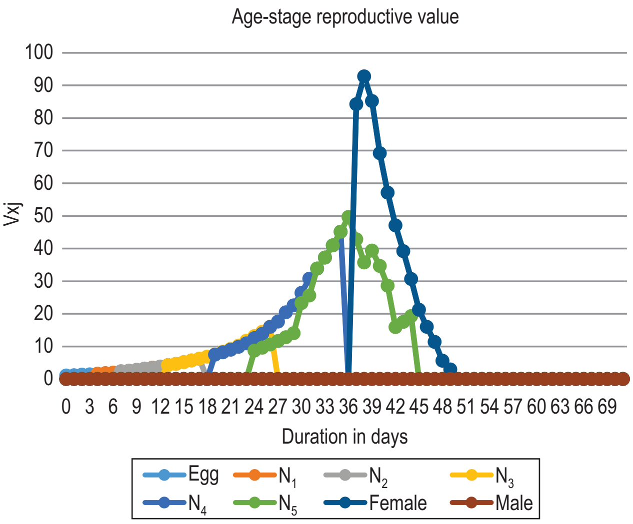

Fig. 4 Age-stage reproductive value (v_{xj}) of *C. siva* fed on *S. frugiperda.*

female offspring to the population over mean generation time of 43.21 days. To our knowledge, this is the first life table studied conducted on reduviids against FAW. Sahayaraj and Paulraj (2021) constructed the life table of *R. marginatus* Fabricius (Hemiptera: Reduviidae: Harpactorinae) on *Spodoptera litura* Fabricius a serious pest of many cultivated agricultural and horticultural crops. Results indicated that total developmental period of *R. marginatus* was 46.71 ± 1.58 days, intrinsic rate of increase was 0.063 female/day and in the generation of 103.9 days the population multiplied 292 times. Similar life table was constructed on hetropteran predator by Jiménez *et al.* (2019) using *Zelus vespiformis* Hart (Hemiptera: Reduviidae: Harpactorinae) on *Galleria mellonella* Linnaeus (Lepidoptera: Pyralidae) showed that number of days required from egg to adult development was 112.65 ± 0.76, the net reproductive rate (R0) was 5.19, mean generation time (T) was 106.75 days, finite growth rate (λ) was 1.015 and intrinsic growth rate (rm) was 0.015. These findings gives the insights on utilization of reduviids as a potential biocontrol agents for conservative and augmentative biological control.

Functional response: The present findings showed that nymphal instars, male and female *C. siva* exhibited Type II functional response against *S. frugiperda* which is evidenced by the proportion of *S. frugiperda* consumed by all life stages at initial prey densities (Fig. 5 and Table 1). Other species of reduviids, viz. *Ectomocoris tibialis* Distant and *Neohamatorhhophus therasii* (Sahayaraj 2014); *Coranus fuscipennis* Reuter (Lam *et al.* 2020); and *Rhynocoris fuscipes* (Fab.) (Thomson 2021, Claver and Yadav 2024) exhibited same response. The maximum prey consumption was restricted by *C. siva* at high prey density, female bugs have good predatory potential and vigorous than males which is similar to results of Manimuthu *et al.* (2011) and Jesu *et*

Table 1 Co-efficient of attack rate, and handling time of *C. siva* against *S. frugiperda*

Stage	Attack rate (a')	Handling time (T_h)	Maximum predation (T/T_h)
II Instar	0.20	0.01	05
III Instar	0.38	0.006	09
IV Instar	0.40	0.004	09
V instar	2.34	0.04	10
Male	0.67	0.14	16
Female	0.87	0.87	21

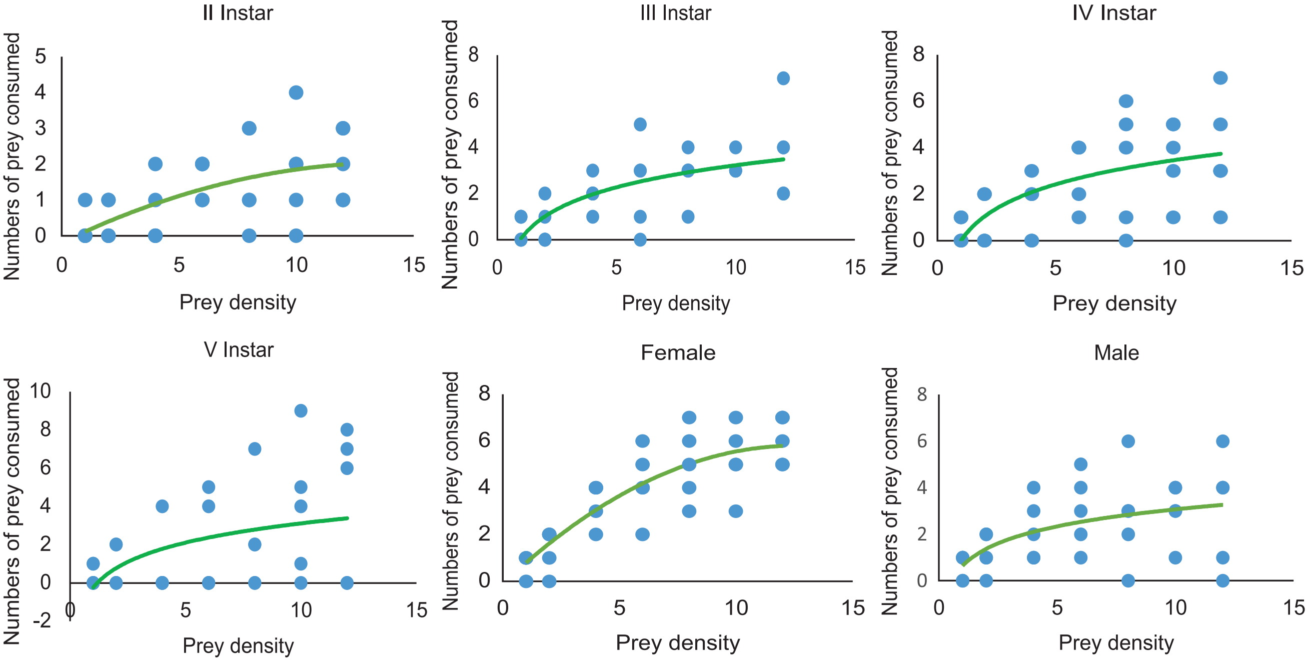

Fig. 5 Functional response II, III, IV, V instar, male and female predators of *C. siva* fed on different prey density of *S. frugiperda.* Points shows average prey foraged by predator at different prey density.

al. (2011). During immature stages, consumption increased with increase in age. Degree of functional response was significantly more in adult stages than immature predators. This could be due to the fact that conceptive/ reproductive make up began at adult phase, adult capacity to react to increasing prey indicated faster physiological senescence of adults compared to nymphs. The attack rate was more in 5th instar nymph, followed by female (0.87), male (0.67), 4th (0.40), 3rd (0.38) and 2nd (0.20) instar nymphs. Variation in the attack may be due to more requirement of prey, as the females need to consume more prey they searched more and covered more distance in the act of predation. Highly efficient attack rate of 5th instar nymph may be attributed to optimum body size and well developed predatory organs similar to adults. Unlike adults, 5th instar nymphs are not involved in any reproductive activity, dedicated only for consumption of prey and building their organs, hence, their searching efficiency was higher, for confirmation there are no other research evidences on this phenomenon. There was a gradual increase in number of larvae foraged by the bugs with the progression of nymphal instars. Adults had more intake of prey than nymphs. Maximum predation was more in female (21) compared to male (16). In immature stages maximum predation was more in V instar (10), followed by IV (09), III (09) and II (05) instar nymphs (Table 1). Early instars might probably experience trouble in handling the prey due to poor development of predating forelegs, mandibles, mobility of large and active prey, impenetrable integuments (Ambrose *et al.* 1990, Claver and Ambrose 2003, Sahayaraj 2014). Lam *et al.* (2020) studied the predatory ability and functional response of 2nd, 3rd, 4th, 5th nymphal instars and adult male and female *C. fuscipennis* on *C. cephalonica* in Vietnam. The results indicate that adults and nymphs of the predator foraged more number of prey at increased prey density and less prey at reduced prey density which resulted in type 2 predator and prey response. Though this is the first study of *C. siva* on predatory parameters against invasive fall armyworm. The predator had shown to be a promising biocontrol agent. Efforts for further utilization in terms of augmentative release or conservation need further studies on field evaluation, bioceology, standard mass multiplication techniques and subsequent monitoring of bugs and *S. frugiperda*.

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