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Spodoptera litura (Lepidoptera: Noctuidae) rearing on artificial feed with *Chrysoperla carnea* predation (Neuroptera: Chrysopidae)

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S. litura was reared on artificial meals in a controlled laboratory setting at 26.1°C, 16:8 h L:D, and 65.5% RH at the National Agricultural Research Center (NARC) in Islamabad, Pakistan, to evaluate its premature, mature adult stage characteristics and predation by *C. cornea.* On the artificial diet, the results for various parameters, including total larval duration (19.1 days, 45 percent), pre-pupal period (3.4 days, 92 percent), pupal period (7.05 days, 83 percent), and total immature duration from eggs to adult stage (33.4 days, 33 percent), as well as percent survival rate, were recorded. On a corn-based artificial diet, data on the pre-oviposition period (2.4 days), oviposition period (5.4 days), post-oviposition period (1.63 days), female fecundity (1366 eggs), and adult longevity (8.66 days) of mature stages of *S. litura* were collected. When supplied as prey, the predator's biological parameters and predatory capacity, *C. carnea*, were tested on two stages of *S. litura* (eggs and 1st instar larvae). The studies indicated that the prey significantly affected the total larval duration, immature duration, and % survival rate. The entire larval period was greatly minimized when *C. carnea* was offered eggs of *S. litura* for feeding. Additionally, higher % survival and fecundity were observed feeding with *S. litura* eggs, followed by 1st instar larvae. *C. carnea* consumed 443 *S. litura* eggs and 395 *S. litura* larvae during its larval development. Daily consumption of *C. carnea* larvae reached a maximum of 73 eggs and 53 1st instar larvae of *S. litura.* Comparatively, *C. carnea* larvae recorded maximum egg predation compared to 1st instar larvae of *S. litura* and the shorter developmental period when eggs were offered as prey. Moreover, 3rd instar larvae of *C. carnea* were found more voracious than early instars.

Keywords: Artificial diet, biological parameters, c*hrysoperla carnea*, predatory potential, s*podoptera litura*.

INTRODUCTION

In several Asian nations, including Pakistan, a poly-phytophagous pest known as *Spodoptera litura* is responsible for causing damage to a variety of vegetable and field crops (Saljoqi *et al.*, 2015; Khan *et al.*, 2018). Armyworm, tobacco cutworm, common cutworm, cluster caterpillar, and tobacco caterpillar are all names that have been used to refer to *S. Litura*. Even though it had only been a minor threat to tobacco for many years, it has emerged as a serious insect pest in recent years and is expected to continue this trend in the years to come (Hou *et al.*, 2004; Singh *et al.*, 2014). The overuse of pesticides led to the development of resistance in the pests to a wide variety of regularly applied pesticides, mainly carbamates and pyrethroids, which ultimately led to the failure of effective control measures (Kranthi *et al.*, 2002; Shi *et al.*, 1995). *S. litura* is a kind of economically significant insect pest that may infest more than 120 different host crop plants and result in severe crop damage (Saljoqi *et al.*, 2015). *S. litura* is a destructive insect native to Pakistan that feeds on leaves. The cotton belt in Pakistan exposed 27 plant species belonging to 25 genera and 14 families as host plants for *S. litura* over two years at three separate locations. These host plants included vegetables, cultivated crops, weeds, fruits, and decorative plants (Ahmad *et al.*, 2013). Due to the abundance of *S. litura* and the need for early warning for its proper management and control of commercial crops like cotton, *S. litura* needs to be monitored regularly, particularly from March to April. This is because an early warning is necessary for proper management and control of *S. litura* (Ahmad *et al.*, 2008). It is essential to cultivate economically significant insect pests to investigate their feeding behaviors, life histories, susceptibilities and resistances to chemical pesticides and biocontrol agents and to better protect crops

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from them (Saljoqi *et al.,* 2015; Rezapanah *et al.,* 2008). In impoverished nations with inadequate research finances, it is difficult and expensive to raise insects on artificial diets. Consequently, the dangers that insect pests bring to the economy will get inadequate consideration or research (Saljoqi *et al.,* 2015). To this day, several synthetic diets have been devised and suggested to ensure the preservation and consistent raising of economically significant insect pests, the majority of which are lepidopterous pests (Castane and Zapata, 2005; Cohen *et al.,* 2001). Although there has been some success in efforts to rear succeeding generations of these insects entirely on an artificial diet, there has been a loss of both fitness and reproductive potential, which has resulted in a longer developmental period and a lower fecundity rate. This has caused the developmental period to be longer (Coudron *et al.,* 2002). As a direct consequence, the ratio of cost savings to total costs is reduced. It is essential for individuals working on life and fecundity tables of insects to be aware of the sort of food the insect was fed when it was being grown. This component impacts the accuracy of the life table, which in turn affects the accuracy of the biological features of the insect, such as growth, viability, reproduction, and population density (Bellows *et al.,* 1992). In addition, the shifting emphasis on insect control using biological entities such as predators, parasitoids, and insect pathogens (bacteria, viruses, and fungi) has increased the demand for consistent and reliable sources of such insects. This is because the demand has increased due to the shifting emphasis. In several Asian nations and under various environmental conditions, several research on the biological parameters of *S. litura* were carried out using artificial meals of varying types (Saljoqi *et al.,* 2015; Hou *et al.,* 2004; Guan and Chen, 1999). However, none of them had ever tried to cultivate *S. litura* on a diet based on maize. Insect pest control may be accomplished using a variety of approaches. Cultural, biological, chemical, and host plant resistance are included in this category. Most of the pest population is kept below the level that would cause economic damage to the natural enemies. However, if a significant number of the pests are present, it may be necessary to use pesticides to get rid of them because they may cause severe damage. Farmers mostly utilize pesticides in Pakistan to combat various insect pests. The indiscriminate use of pesticides results in several issues within the agroecosystem, including degradation of the environment, risks to human health, the eradication of beneficial insects, and resistance to harmful insects (Ansari *et al.,* 2014). Biological control plays a significant role when it comes to managing a wide variety of insect pests that are often found on horticultural and field crops. Biological control is an important aspect of integrated pest management (IPM), and it works well with the other control methods used in the IPM program. It is one of the most effective ways to get rid of pests while still being inexpensive. In addition, it does not contaminate the air, land, rivers, or sea, which is a positive for both the public and the population's health (Gutierrez *et al.,* 2013). *Chrysoperla carnea* is often considered one of the most significant generalist predators. When it reaches the adult stage, it can no longer control other organisms and is instead free to live on its own. The larvae of *C. carnea* are voracious predators on soft-bodied arthropods such as aphids, whiteflies, thrips, American bollworms, mites, armyworms, tiny larvae of beetles, eggs of lepidopterous insects, and so on. *C. carnea* larvae are omnivorous and feed on various unwanted insects (Woolfolk *et al.,* 2014). Adults of the *C. carnea* species use nectar, honeydew, and pollen for food. They have long antennae and eyes that might be golden or copper in hue. Their bodies are a pale green tint. Adults are distinguished by their fragile bodies and long, translucent, pale green wings. The adults are known to engage in risky behavior, particularly in the evening (Zhang *et al.,* 2006). Single eggs are placed on the top long, silky stalk at regular intervals. Oval in shape, the egg incubation period ranges from three to six days. The insect goes through three different stages in the larval stage. A larva resembles an alligator and is equipped with developed legs and enormous pincers that are used to siphon fluids from the bodies of its victims. The mature third instar spins itself into a cocoon-like structure in secret locations, and the pupation process often occurs within the cocoon. The appearance of the adult takes between 5 and 10 days (Atlıhan *et al.,* 2004). *C. carnea* can be mass-reared in the laboratory with relative ease and then released in the field to combat certain insect pests. As a result of its resistance to a wide variety of environmental conditions and its ease of production in large numbers, it serves as a vital biological control agent. A generalist predator can consume a wide variety of insect pests, including cotton mealybugs, aphids, and *S. litura* (Ashfaq *et al.,* 2002). In this study, we investigated the biological parameters of *S. litura* rearing on an artificial diet based on corn, as well as the biology and predatory potential of various instars of *C. carnea* fed on *S. litura* eggs and larvae. In addition, we investigated the biological parameters of *S. litura* rearing on a corn-based artificial diet.

MATERIALS AND METHODS

The current research was carried out at the Institute of Plant and Environmental Protection (IPEP), National Agricultural Research Centre (NARC), in Islamabad, Pakistan. The research focused on rearing *S. litura* on an artificial diet based on corn and investigating the predatory potential and biology of *C. carnea* fed on *S. litura.* All of the studies were conducted in a laboratory setting under controlled conditions, with the temperature held steady at 26.1 degrees Celsius, the relative humidity (RH) at 65.5 percent, and the light-dark cycle set at 16:8 h.

***Rearing of S. litura*:** *S. litura* was fed an artificial diet based on maize while growing up. Corn flour (750 grams), granulated yeast (250 grams), wheat germs (225 grams), ascorbic acid (Vitamin C) (38.5 grams), Nipagen (methyl-p-hydroxybenzoate) (8 grams), sorbic acid (9.6 grams), agar (140 grams), streptomycin as a preservative (0.5 grams), and one liter of distilled water make up the components of the diet. The dry components of the diet were kept in separate containers and subjected to meticulous weighing before being assembled. After measuring out the wet components, they were placed in their own individual containers. The total amount of agar was dispersed throughout the liquid that was brought to boil. The entire quantity of maize flour was included in addition to the agar that had been cooked. After that, each of the dry and wet components of the recipe was incorporated into the mixture. After the diets have been produced, they are put into the necessary number of sterilized plastic boxes, and then they are let to cool and solidify (Shorey and Hale, 1965). Throughout the whole process of rearing, the temperature was kept at 26.1°C, the relative humidity was maintained at 65.5 percent, and the light to dark ratio was kept at 16:8 h. Adults were cultivated in a container with a muslin cloth covering the opening at the top and were given a solution of sucrose throughout their development. A diaper liner was fastened to the interior wall of the container to facilitate the laying of eggs.

***Rearing of C. carnea*:** Adult *C. carnea* was raised in a series of rectangular cages constructed out of plastic tubes six centimeters thick and sheets of clear plastic. The cages were 35 centimeters in length, 35 centimeters in height, and 20 centimeters in width. Two circular windows, each with a diameter of 13 centimeters and covered with lids made of the same material, were placed diagonally near opposite corners of the front wall of the cage to facilitate the handling of adults, sanitation, and the provision of water in a petri dish, among other things. Small meal bowls with a diameter of 0.5 centimeters were carved on the upper side of two plastic rods, each 4 millimeters thick and 22 centimeters long. These rods contained the standard artificial foods with yeast, sugar, honey, and water. A sieve with circular holes two millimeters in diameter was drilled into the cage's sidewalls to ensure proper cage ventilation for better adult survival and fecundity; a layer of granulated black paper was placed underneath the removable top of the cage as a substitute for the oviposition substrate. The eggs were gathered from a dark sheet that was placed at the very top of the enclosure, and they were placed in clear plastic Petri plates until they hatched. After hatching, the first-instar *C. carnea* larvae were given eggs and first-instar *S. litura* larvae to consume until they reached the pupation stage.

***Developmental duration and survival rate of immature stages of S. litura fed on a corn-based diet*:** The culture of *S. litura* produced fresh eggs, which were then collected and stored in plastic containers in preparation for hatching. There were a total of three replications, and each replication included four separate batches of *S. litura* eggs. The data for the immature stages were all recorded in days. Following the completion of the hatching process, sixty *S. litura* larvae of the first instar were placed in plastic vials with artificial food and were covered with muslin fabric at the top. Diet was administered daily according to the larvae's changing needs and their growing sizes. The exuviate discovered in the plastic containers was quickly removed, indicating that the larvae had entered a new instar. The data were recorded for the incubation period; the duration of each instar (1st, 2nd, 3rd, 4th, 5th, and 6th instar); the total larval duration; the pre-pupal period; the pupal period; and the entire duration from egg to adult emergence of *S. litura* fed on a diet based on corn. Measuring the head capsule with a microscope equipped with a measuring lens is yet another way to differentiate between the various stages of larval development (Redfern, 1967). The size of the head capsule was measured on a daily basis, and the technique was carried up right up until the pupation stage. The data were then statistically analyzed to calculate the mean and standard error.

***Developmental duration and reproductive capacity of mature stages of S. litura fed on a corn diet*:** *S. litura* adults that had only just emerged from the stock culture and were one day old were separated into individual buckets after being collected. As an oviposition medium, the edges of the buckets were covered with diaper liners plastered on them. In the buckets that contained the cotton swabs that had been soaked in the sucrose solution, the Petri dishes were placed at the bottom (10 percent). Every day, a diet was given out based on what was required. There were three separate runs of the experiment, and each run included three experimental units. One male and one female participant were in each unit of the experiment. The insects were monitored daily during the pre-oviposition, and post-oviposition periods for each unit. During the oviposition phase, the eggs were retrieved from the diaper liners that had been adhered to the sides of the buckets daily for up to six days. The eggs were tallied and placed in Petri plates in preparation for their hatching. The pre-oviposition phase, the oviposition period, the post-oviposition period, fecundity, and adult lifespan were each given their own data to record. The investigation was carried out utilizing a Completely Randomized Design (CRD). The data underwent statistical examination, which determined the mean and standard error.

***Developmental duration and survival rate of immature stages of C. carnea fed on S. litura eggs and 1st instar larvae*:** Eggs laid recently by *C. Carnea* were obtained from a stock culture by using a razor to gather them. Under a binocular microscope, one hundred eggs were enumerated, and the results were recorded in Petri dishes. At the bottom of the Petri dishes was some tissue paper that had been moistened in water to prevent the dish from drying out. After hatching, sixty *C. Carnea* first-instar larvae were counted. Larvae were then placed in clear plastic vials with a diameter of 2 centimeters and a height of 4 centimeters for each treatment.

At the very top of the vials was a covering made of muslin material that was secured with a rubber band. Both eggs and larvae of the host organism in their first instar were delivered in their vials. The exuviate discovered in the plastic containers was quickly removed, indicating that the larvae had entered a new instar. The data were recorded in terms of days for the following: molting time (the duration of the first, second, and third instars), total larval duration, pre-pupal duration, pupal duration, and overall duration from egg to adult emergence. The investigation was carried out utilizing a Completely Randomized Design (CRD). The data underwent statistical examination, which determined the mean and standard error.

***Developmental duration of mature stages of C. carnea fed on S. litura eggs and larvae*:** *C. carnea* adults that had just emerged and were one day old were obtained from stock culture. The stock culture had been raised on *S. litura* larvae and eggs separately. Chimney glasses were used to house ten different males and females who had been coupled off. As an oviposition substrate, a piece of black paper was placed on top of the chimney glasses where it had been covered. Petri dishes containing an artificial food designed for adult rearing were stored in the bottom of the chimney glass. These dishes were rotated regularly to ensure that the diet remained fresh. Every treatment was given five times, and each time there was a male and a female participant in each replicate. During the pre-oviposition phase, the oviposition period, and the post-oviposition period, the insects in each replicate were monitored daily. During the period in which the female was ovipositing, the eggs were counted daily and retrieved from the black sheets placed over the chimney panes. During the adult stage of the *C. carnea* life cycle, observations were made and recorded for the following parameters: pre-oviposition period, oviposition period, post-oviposition period, fertility, and male and female lifespan. The trials were carried out in a Completely Randomized Design (CRD). The data underwent statistical examination, which determined the mean and standard error.

***The predatory potential of C. carnea larval instars fed on S. litura eggs and larvae*:** An investigation of the potential for predation by *C. carnea* larvae that had been fed on *S. litura* eggs and larvae. The freshly emerging larvae were counted and placed in separate clear vials for each administered treatment. The tops of the vials were wrapped with muslin material of the finest quality. Daily provision of a counted quantity of eggs and larvae of the species *S. litura* was made. In the beginning, 25 eggs and the first-instar larvae of *S. litura* were given to the *C. carnea* larvae to begin their development. As the larvae grew older, more hosts were available for them to feed on. The number of hosts required by *C. carnea* larvae in their second and third instars was 50 and 100.

During the course of the observation, each day, several specimens, both devoured and unconsumed, were tallied using a binocular microscope, and the instrument was updated each morning. A single experimental unit was also constructed without a predator in case of larvae predation to assess natural mortality. This unit was subtracted daily from experimental units with a predator to determine how accurately predation was measured. As soon as possible, the exuviate discovered in the plastic vials was removed, indicating that the larvae had entered a new instar. Experiments were carried out in Completely Randomized Design (CRD). The data underwent statistical examination, which determined the mean and standard error.

***Statistical Analysis*:** All of the data gathered from the studies was analyzed using the computer program Statistics 8.1, and the LSD test was utilized to differentiate the means from one another (Gomez and Gomez, 1984).

RESULTS

***Duration of immature life stages and percent survival of S. litura fed on a corn-based diet*:** The results (Table 1) stated that the incubation period or hatching time for *S. litura* fed on an artificial diet was 3.7±0.14 days. One day before hatching, the dark head of the young larva was observed inside the eggshell. The developmental duration, percent survival rate, and head capsule of the first instar for the artificial diet were 2.5±0.07 days, 83% survival, and 0.25±0.01 mm, respectively (Table 1). The recorded period of the second instar and percent survival rate and head capsule for the artificial diet were 2.8±0.06 days, 74 % survival, and 0.38±0.012 mm, respectively (Table 1). The duration, survival rate, and head capsule of the 3rd instar for the artificial diet were 2.8±0.08 days, 81% survival, and 0.68±0.014 mm, respectively (Table 1). The duration of the fourth instar for the artificial diet was found to be 3.8±0.10 days with a survival rate of 93% and head capsule 1.16±0.014 mm, respectively (Table 1). The time interval for the fifth instar fed on a corn-based diet was recorded at 3.7±0.13 days with a 96% survival rate and head capsule 1.80±0.014 mm, respectively (Table 1). The final sixth instar duration fed on an artificial diet was found to be 3.6±0.22 days with 96% survival, while the head capsule was 2.70±0.015 mm, respectively (Table 1). The total larval duration of *S. litura* fed on an artificial diet was recorded as 19.1±0.12 days, respectively; the total survival rate of *S. litura* larvae was 45%, respectively (Table 1). The pre-pupal period was recorded at 3.4±0.10 days on an artificial diet, and the survival rate on an artificial diet was 92% (Table 1). The pupal duration for *S. litura* fed on an artificial diet was 7.05±0.15 days, with an 83% survival rate (Table 1). The total developmental duration and survival rate from egg to adult stage on an artificial diet were found to be 33.4±0.13 days with 33%, respectively (Table 1).

***Duration of life mature stages of S. litura fed on a corn-based diet*:** According to the results (Table 2), the pre-oviposition period for the artificial diet was found to be 2.4±0.10 days, respectively. The oviposition period for the artificial diet was found to be 5.40±0.10 days (Table 2). The

Table 1. Developmental duration and survival rate of immature stages of *S. litura* fed on a corn-based diet.

Developmental stages	Developmental Duration (days) (n)	%Survival	Head capsule measurement width (mm) ±SE	Range
Incubation period	3.70±0.14			
1st instar	2.50±0.07 (60)	83%	0.25±0.010	0.24-0.27
2nd instar	2.80±0.06 (50)	74%	0.38±0.012	0.36-0.40
3rd instar	2.80±0.08 (37)	81%	0.68±0.014	0.63-0.74
4th instar	3.80±0.10 (30)	93%	1.16±0.014	1.10-1.20
5th instar	3.70±0.13 (28)	96%	1.80±0.014	1.67-1.94
6th instar	3.60±0.22 (27)	96%	2.70±0.015	2.30-3.00
Total larval duration	19.10±0.12 (27)	45%		
Pre-pupal period	3.40±0.10 (26)	92%		
Pupal period	7.05±0.15 (24)	83%		
Total duration from egg to adult stage	33.40±0.13 (20)	33%		

n = number of an insect used at each stage

post oviposition period for the artificial diet was 1.63±0.20 days, respectively (Table 2). Results indicated that the adult longevity of *S. litura* fed on an artificial diet was 8.66±0.33 days (Table 2). As the results showed, the total eggs laid by a single female of *S. litura* on an artificial diet for up to six days was 1366±2.33 (Table 2).

Table 2. Developmental duration and reproductive capacity of mature stages of *S. litura* fed on a corn-based diet.

Mature stages	Corn-based (Diet) (days) ±SE
Pre-oviposition period	2.40 ± 0.10
Oviposition period	5.40 ± 0.10
Post oviposition period	1.63 ± 0.20
Female fecundity (eggs)	1366.00 ± 2.33
Adult longevity	8.66 ± 0.33

Duration of life immature stages and percent survival rate of C. carnea fed on S. litura eggs and larvae. Results (Table 3) revealed that developmental durations and survival rate of the first instar were found to be 3.05±0.08 and 3.21±0.07 days, with 90 % and 95 % survival rates, respectively (Table 3). The results indicated that first instar durations were non-significantly affected by eggs and larvae. The second instar's developmental durations and survival rates were found to be 3.18±0.11and 3.46±0.12 days with 88.8 %and 78.9 % survival rates, respectively (Table 3). The result reflected that the second instar duration was non-significantly affected by eggs and larvae. The third instar's developmental durations and survival rate were found to be 4.2±0.12 and 4.6±0.13 days, with 93.7 % and 86.6 % survival rates, respectively (Table 3). The results showed that the third instar duration was non-significantly affected by eggs and larvae. Total larval durations and survival rates were also recorded in eggs and larvae of *S. litura.* Total larval durations were 10.5±0.13 and 11.3±0.14 days, with 75% and 65% survival rates, respectively (Table 3). The results showed that eggs and larvae significantly affected total larval duration. A maximum larval developmental duration of 11.3±0.14 days was found on larvae, while a minimum of 10.5±0.13 days were recorded on eggs (Table 3). The Pre-pupal and pupal durations were found to be 1.1±0.11 and 1.3±0.11 days, with the survival rate

Table 3. Developmental duration and survival rate of immature stages of *C. carnea* fed on *S. litura* eggs and 1st instar larvae.

Developmental Stages	Treatments					
	Eggs		Larvae			
	Mean developmental Duration (days) ±SE	% Survival	Mean developmental duration (days) ±SE	% Survival	LSD (ά 0.05)	*F*-value
1st instar	3.05±0.08 (60)a	90 %	3.21±0.07 (60)a	95.0	0.1775	1.89
2nd instar	3.18±0.11 (54)a	88.8 %	3.46±0.12 (57)a	78.9	0.1029	2.84
3rd instar	4.20±0.12 (48)a	93.7 %	4.60±0.13 (45)a	86.6	0.0667	3.66
Total larval duration	10.50±0.13 (48)b	75%	11.30±0.14 (45)a	65.0	0.0002	19.3
Pre-pupa period	1.10±0.11 (45)a	86.6 %	1.30±0.11 (39)a	84.0	0.3219	1.02
Pupal period	7.92±0.20 (39)a	92.2 %	7.63±0.21 (33)a	90.9	0.3429	0.94
Total days from larvae to adult emergence	19.50±0.28 (36)b	60 %	20.70±0.30 (30)a	50.0	0.0069	9.06

of 86.6 % and 84 %, respectively (Table 3). The results further showed that the developmental duration of pre-pupal duration was non-significant.

Similarly, pupal duration was 7.92±0.20 and 7.63±0.21, with a survival rate of 92.2 % and 90.9 % (Table 3). The results further indicated that the developmental duration of the pupal period was non-significant. The developmental duration from egg hatching to adult emergence was noted as 19.5±0.28 and 20.7±0.30 days, respectively (Table 3). Maximum immature duration of 20.7±0.30 days was noted at larvae. A minimum of 19.5±0.28 days was recorded at eggs. The results of the present study showed that developmental duration was significant. Similarly, the survival rate of different immature stages was 60 % and 50 % (Table 3).

***Biological parameters of adult C. carnea fed on S. litura eggs and 1st instar larvae*:** The results showed that the pre-oviposition period recorded was 4.20±0.37 and 5.60±0.24 days. A maximum pre-oviposition period of 5.60±0.24days was found on 1st instar larvae, while a minimum of 4.20±0.37 days were noted on eggs (Table 4). The results reflected that the pre-oviposition period was significantly different. The results further indicated that the pre-oviposition period significantly decreased when *C. carnea* larvae fed on *S. litura* eggs. The results showed that the oviposition period of females was 17.80±0.37 and 17.00±0.31 days, respectively (Table 4). The results showed that the oviposition period was non-significantly different at each treatment. A mean number of eggs laid per day was also calculated. The numbers of eggs laid at two treatments were 322±7.16 and 278±6.58, respectively (Table 4). Maximum numbers of eggs laid 322±7.16 were noted while *C. carnea* larva was fed on eggs of S. litura, while a minimum of 278±6.58 were found during *C. carnea* larva were fed on 1st instar larvae of *S. litura*. The results indicated that the post-oviposition period was 7.80±0.37 and 7±0.31 days (Table 4). Results indicated that the oviposition period was non-significantly affected by each treatment. The results reflected that the male longevity recorded was 17.6±0.50 and 16.2±0.37 days, respectively (Table 4). The results further showed that each treatment's male longevity period was non-significantly different. The results reflected that the female longevity was found, 29.2±0.37 and 27.0±1.26 days, respectively (Table 4). The results further showed that female longevity period was non-significantly different from each other at each treatment.

Predatory potential of C. carnea per day fed on S. litura eggs and 1st instar larvae The results showed that predatory potential per day was significantly affected. The results recorded that the predatory potential of the first instar was 13.2±0.49, and 11.6±0.481 was found on eggs and 1st instar larvae, respectively (Table 5). The results showed that maximum predatory potential per day was 13.2±0.49 noted on eggs, while a minimum, 11.6±0.481, was found in 1st instar larvae. The results showed that the predatory potential of the second instar per day was 34.688±1.00 and 30.6±1.03, respectively (Table 5). The results reflected that *S. litura* significantly affects the predatory potential of the second instar per day. The results indicated that the predatory potential per day of the third instar recorded was 70.33±1.48 and 53.69±1.59, respectively (Table 5). The results found that predatory potential per day of third was significantly affected. The results showed that maximum predatory potential per day was 70.33±1.48 noted on eggs, while a minimum, 53.69±1.59, was found for 1st instar larvae.

***Predatory potential per instar of C. carnea fed on S. litura eggs and 1st instar larvae*:** The results regarding the predatory potential of *C. carnea* fed on *S. litura* eggs and 1st instar larvae revealed that first instar *C. carnea* were 40.3±1.55 and 37.7±1.51 on eggs and 1st instar *S. litura* larvae, respectively (Table 6). The results also showed that predatory potential was non-significant. Maximum predatory potential by the first larval instar, 40.3±1.55, was noted on eggs, while a minimum of 37.7±1.51was found on larvae. The results

Table 4. Developmental duration of mature stages of *C. carnea* fed on *S. litura* eggs and 1st instar larvae.

Developmental Stages	**Treatments**			
	eggs	**larvae**	**LSD (ά 0.05)**	***F*-value**
Pre-oviposition (days)	4.2 ±0.37b	5.6±0.24a	0.0140	9.80
Oviposition (days)	17.8±0.37a	17.0± 0.31a	0.1411	2.67
Female fecundity rate (number of eggs laid)	322.0±7.16a	278.0±6.58b	0.0019	20.50
Post-oviposition (days)	7.8±0.37a	7.0±0.31a	0.1411	2.67
Male longevity (days)	17.6±0.50a	16.2±0.37a	0.0570	4.90
Female longevity (days)	29.2±0.37	27.0±1.26	0.1339	2.78

Table 5. Predatory potential of *C. carnea* day $^{-1}$ fed on *S. litura* eggs and 1st instar larvae.

Mean number of host insects consumed per day	**Treatments**			
	Eggs	**larvae**	**LSD (α 0.05)**	***F*-values**
1st instar	13.20±0.49a	11.60±0.48b	0.0268	5.34
2nd instar	34.69±1.00a	30.60±1.03b	0.0094	7.74
3rd instar	70.33±1.48a	53.69±1.59b	0.0000	58.3

Table 6. Predatory potential of *C. carnea* fed on *S. litura* eggs and 1st instar larvae.

Mean number of host insects consumed per instar	Treatments			
	Eggs	**larvae**	**LSD (ά 0.05)**	***F*-values**
1st instar	40.3±1.55a	37.7±1.51a	0.2396	1.43
2nd instar	108.3±3.40a	107.2±3.58a	0.8258	0.05
3rd instar	292.4±6.40a	249.0±6.80b	0.0001	21.3
Total larval consumption	443.9±6.90	395.2±7.40	0.0001	22.9

showed that the predatory potential of the second instar was 108.3±3.4 and 107.2±3.58, respectively (Table 6). The results reflected that *S. litura* has a non-significant effect on the predatory potential of the second instar. The results indicated that the predatory potential of the third instar recorded was 292.4±6.4 and 249±6.8, respectively (Table 6). The results found that the predatory potential of the third was significantly affected. The results showed a maximum predatory potential of 292.4±6.4 was noted on eggs, while a minimum of 249±6.8 was found in 1st instar larvae. Total larval predatory potential found was 443.9±6.9 and 395.2±7.4 on eggs and 1st instar larvae, respectively (Table 6). The results showed that total larval predatory potential was significantly affected. The results showed that a maximum Total larval predatory potential of 443.9±6.9 was noted on eggs, while a minimum, 395.2±7.4, was found 1st instar larvae.

DISCUSSION

Data regarding the developmental duration of premature stages of *S. litura* were observed for the total larval duration, pre-pupal duration, pupal period, and total duration from egg to adult stage 19.1, 3.4, 7.05, and 33.4 days, and the percent survival rates for the total larval duration, pre-pupal period, pupal period, and total duration from egg to adult stage were 45, 92, 83, and 33 percent respectively found on a diet consisting of corn. These findings are consistent with those found by (Bhattacharya *et al.*, 2005; Saljoqi *et al.*, 2015), who investigated the effects of feeding *S. litura* a diet based on grams. The overall larval duration, pre-pupal duration, pupal duration, and total immature duration were reported as 17.8, 8.5, and 31.2 days respectively by (Saljoqi *et al.*, 2015), but (Bhattachary and Chenchaiah. 2005) recorded these times as 17.2, 8.3, and 30.8 days respectively, and with 28. Both (Assemila *et al.*, 2012; Gupta *et al.*, 2005) conducted research on the feeding of *Helicoverpa armigera* (Hubner) larvae a diet consisting primarily of beans. The entire amount of time spent as a larva, the amount of time spent as a pupa, and the total amount of time spent as an immature stage by *Spodoptera frugiperda* were respectively 18.3, 7.8, and 30.7 days. These numbers are virtually identical to the present data study.

The oviposition period of *S. litura* fed on a diet based on corn was recorded to be 5.4 days, adult longevity was 8.6 days, and female fecundity was recorded to be 1366 total eggs. Data regarding the developmental duration of the different mature stages of *S. litura* were recorded. The findings of this experiment follow the same pattern as the one that was reported by (Chenchaiah and Bhattacharya, 2005). They worked on determining whether or not artificial diets may be suitable for raising *S. litura* on the gram-based diet. They reported 5.6, 8.4 days, and 1551.2 numbers of eggs (total fecundity), whereas in the present experiment, essentially identical data were recorded. When (Bhattacharya and Chenchaiah, 2005) studied the process of growing *S. litura* on a diet based on beans, they found that the oviposition duration was 5.3 days, the adult lifespan was nine days, and the total fecundity was 1434.6 eggs. These findings are consistent with the oviposition period, which was recorded to be 5.2 days, the adult lifespan of 8.7 days, and the total fecundity recorded to be 1541.8 eggs.

After feeding on *S. litura* eggs and first-instar larvae, *C. carnea* took 10.5 and 11.3 days to develop into a larva and 7.92 and 7.63 days to mature into a pupa, respectively, throughout their respective stages of development. (Geethalakshmi *et al.*, 2000), who researched the biology and predatory capability of *C. carnea* fed on *Corcyra cephalonica* eggs, found that these results were consistent with their findings. According to the results of this study, the overall developmental period from egg to adult was 22.2 days, whereas the periods spent as a larva and a pupa were 10.3 and 8.4 days respectively. *C. carnea* that consumed *S. litura* eggs and first-stage larvae had pre-oviposition, oviposition, and post-oviposition periods that lasted 4.20, 17.80, and 7.80 days, respectively, when fed on eggs. Similarly, the pre-oviposition, oviposition, and post-oviposition times of feeding on 1st instar larval stages were, respectively, 5.60, 17.00, and 7 days long. The adult biological characteristics of *C. carnea* were investigated by (Sattar *et al.*, 2011) using *H. armigera* eggs as their subjects. 4.12 hours passed before oviposition, 19.12 hours during oviposition, and 7.62 hours passed after oviposition respectively. The average number of eggs deposited by females was 322 whereas the average number of eggs laid by males was 278. The female deposited the most eggs when its larvae were fed on eggs from another species, indicating that eggs are the food source best suitable for growing *C. carnea*. The average lifespan of males fed on eggs was 17.6 days, whereas the average lifespan of females fed on eggs was 29.2 days. Similarly, the lifespan of males and females fed on *S. litura* larvae of the first instar was 16.2

and 27 days, respectively. The findings presented here were consistent with those found by (Sattar *et al.*, 2011), who investigated the effects of the adult biological parameters of *C. carnea* on a variety of cotton pests, one of which being *H. armigera* eggs. Males lived an average of 19.75 days longer than females, who lived an average of 30.87 days.

Similar to *S. litura*, the predatory potential of *C. carnea* per day of 1st, 2nd, and 3rd instars feeding on *S. litura* eggs and 1st instars was 13.2, 34.6, and 70.33, respectively. (Hassanpour *et al.*, 2011) conducted research on the functional reactions of *C. carnea* to the eggs and first instar larvae of *H. armigera*. In this study, the amount of *H. armigera* eggs that were eaten by the three larval instars of *C. carnea* was 8, 27.5, and 81.6, respectively. It was shown that the first and second instar larvae of *C. carnea* were responsible for the deaths of 7.5 and 24.4 first-instar larvae of *H. armigera*, respectively, while the third instar larvae were responsible for the deaths of 51.1 first-instar larvae. When fed on *S. litura* eggs and 1st instar larvae, the first, second, and third instars of *C. carnea* had a predatory potential of 40.3, 108.3, and 292.4 correspondingly, whereas the first instar had a predatory potential of 37.7, 107.2, and 249.0. The larval predatory potential of *C. carnea* was calculated to be 443.9 when it fed on *S. litura* eggs and 395.2 when it fed on *S. litura* first instar. The findings presented here are consistent with those of (Tavares *et al.*, 2012), who investigated the predation capabilities of *Chrysoperla externa* on Fall armyworm. The predatory potential of the first, second, and third instar on eggs one day old was 44.7, 129.9, 330.8 and 71.5, 119.9, and 176.3, respectively, while the total larval predation was 505.4 and 367.7 respectively. The size of the egg and the larvae was discovered to cause the discrepancy.

***Conclusion*:** A recent study concluded that the biological parameters and predatory capacity of *C. carnea* were significantly affected by feeding on *S. litura* eggs and 1st instar larvae under laboratory conditions. The total larval duration of *C. carnea* was minimized when fed with *S. litura* eggs instead of 1st instar larvae. Additionally, higher % survival and fecundity were also observed in *C. carnea* fed with *S. litura* eggs. However, the study should be further evaluated in the field.

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***Availability of data and material*:** The data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

***Code availability*:** Not applicable for the recent study.

***Authors' contributions*:** This work was carried out in collaboration with all authors. Ahmad Ur Rahman Saljoqi, Muhammad Munir, Amir Zaman Shah, Muhammad Salim and Javed Khan. Muhammad Munir and Amir Zaman Shah prepared all experimental materials, carried out the experimental work, and managed the literature search. Ahmad Ur Rahman Saljoqi and Javed Khan designed and supervised the project. Muhammad Salim carried out the statistical analysis. Muhammad Munir wrote the first draft of the manuscript. Ahmad Ur Rahman Saljoqi read and approved the final manuscript.

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