

Journal of Biological Control, 39(2): 210-218, 2025, DOI: 10.18311/jbc/2025/48799

Research Article

Predatory efficiency and development of *Chrysoperla carnea* (Stephens) on eggs and larvae of *Spodoptera frugiperda* (J. E. Smith)

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ABSTRACT: The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is recognised as a serious insect pest in Egypt due to its extensive host plant species and rapid adaptation to climatic conditions. The green lacewing, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), is known as a promising multi-trophic predator that is extensively utilised in the biological control of numerous pests. This study may represent the first research in Egypt to evaluate the impact of *S. frugiperda* eggs on certain biological parameters of *C. carnea* across larval and adult stages over two generations, second generation (G2) and fourth generation (G4), compared to a control group in which larvae were fed with *Sitotroga cerealella* eggs. Additionally, it evaluates the consumption rates of *C. carnea* larval stage on eggs, the newly hatched, and the second instar larvae of *S. frugiperda*. The findings revealed no significant difference in duration of first and second larval instars in two generations, but there were significant differences in 3rd and whole larval instars. Moreover, the average number of eggs laid by each female in the G2 and G4 generations was 371±14.70 and 390.8±3.40, respectively, compared to the control (398.9±6.18). In contrast, the findings indicated that the larval instar of *C. carnea* did not consume the 2nd larval instar of *S. frugiperda*, and the 1st instar larvae of *C. carnea* refrained from feeding on the newly hatched *S. frugiperda*. The 1st, 2nd, and 3rd larval instars of *C. carnea* consumed 35.32±1.06, 87.88±1.31, and 201.80±2.55 eggs of *S. frugiperda*, respectively. However, the 2nd and 3rd instar larvae consumed 68.20±1.49 and 157.44±2.52 newly hatched *S. frugiperda*. Moreover, higher survival rates (97.6% and 93.6%) were noted for larvae feeding on eggs and newly hatched *S. frugiperda*, respectively. These findings suggested *C. carnea* as a potential agent of biological control for a wide range of insects, particularly *S. frugiperda,* the recently introduced invasive pest.

KEYWORDS: Biological control, biology, fall armyworm, food consumption, green lacewing

(Article chronicle: Received: 03-03-2025; Revised: 16-06-2025; Accepted: 18-06-2025)

INTRODUCTION

The Fall Armyworm (FAW), *S. frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is an insect pest that consumes the leaves and stems of over 80 plant species in significant quantities, resulting in extensive harm to crops such as maize, sorghum, rice, sugarcane, as well as cotton and various vegetable crops (Gamil, 2020). FAW cannot undergo diapause (Du Plessis *et al*., 2020), leading to its continuous spread of plant hosts in regions distant from extreme cold temperatures. This insect was first observed in Egypt in 2019, after entering from Sudan. The discovery was first made on maize plants in a village located in Kom-Ombo city, Aswan governorate. Subsequently, it has expanded to the Luxor, Sohag, and Qena regions, with the most recent appearance recorded in Assiut governorate in 2021 (Dahi *et al*., 2020; Mohamed *et al*., 2022) after that translocation from the governorates of Upper Egypt to the Nile Delta (Rashed *et al*., 2022). *S. frugiperda* prefers maize as its host plant in the countries where it has been documented, and its presence can lead to a significant reduction in crop plants, 21-53% (Huang *et al*., 2020). FAW has a powerful ability to propagate to new regions in the absence of natural predators (Mohamed *et al*., 2022). Currently, a variety of pesticides are used extensively to control *S. frugiperda*. Chemical pest control frequently fails because many *S. frugiperda* field populations have become very resistant to both conventional and modern insecticides (Wan *et al*., 2021; Mohamed *et al*., 2024; Togola *et al*., 2025). A viable and environmentally friendly alternative for controlling *S. frugiperda* is biological control through the utilisation of natural predators. Biological control has been effectively utilised as a crucial element of integrated pest management against a wide array of agricultural pests worldwide (Bale *et al*., 2008). The utilisation of biological control methods involving parasitoids and predators, whether through classical or augmentative releases, plays a crucial role in the strategies for Integrated Pest Management (IPM) employed by small-scale farmers to combat invasive pests.

Moreover, Zanzana *et al*. (2024) reported the importance of promoting biological control agents, including parasites, predators, and entomopathogenic agents, as a fundamental component of a climate-responsive IPM strategy.

Chrysoperla carnea (Stephens) is a highly effective natural predator that supports the control of insect pests of economic importance in agriculture. The larvae of *C. carnea* are an influential predator of various soft-bodied arthropods, such as aphids, thrips, whiteflies, mites, scale insects, and leafhoppers, in addition to eggs and tiny larvae of Lepidoptera and Coleoptera (Saljoqi *et al*., 2022; Ismail *et al*., 2023). The use of *C. carnea* in IPM programs has seen a rise in recent years due to various reasons. One of the key factors contributing to this trend is the potential advantage that this valuable predator possesses in comparison to other established or introduced natural enemies. In particular, it exhibits a relatively wide resistance to numerous pesticides, especially during its immature stages (Saljoqi *et al*., 2022; El-Dessouki & Korish, 2023). *C. carnea* was commonly found in all environments, contingent upon the availability of its favoured prey (Paredes *et al*., 2024). Comprehending the dynamics of predator-prey relationships is crucial for effective pest management through the utilisation of predators, particularly in controlling newly introduced invasive pests.

The primary objective of the current study was to evaluate the efficacy of *S. frugiperda* eggs on certain biological parameters of larval and adult *C. carnea* for two generations. The specific objective was to assess the consumption rates of *C. carnea* larval stages raised on eggs, newly hatched larvae, or second instar larvae of *S. frugiperda* is necessary because it may help to use in fall armyworm integrated management programs.

MATERIALS AND METHODS

Insect Culture

Rearing of the S. frugiperda

Larvae of *S. frugiperda* were obtained from infested maize plants in Ayat, Giza Governorate. Rearing was conducted at the Plant Protection Research Institute, Agricultural Research Centre, Doki, Giza, Egypt. The larvae were maintained under controlled environmental conditions in an incubator with a temperature of 25±2°C, a relative humidity of 65±5%, and a photoperiod of 16 h light and 8 h dark. The dimensions of the plastic box are 20×15×10cm. Daily, the larvae were supplied with ample clean castor bean leaves (*Ricinus communis* L.). The newly emerged third larval instar was reared and placed individually in 7cm×6cm plastic containers with gauze covers until the onset of pupation. The pupae were stored in clean jars (1000ml) until the emergence of adults. Ten adults (male-female) were placed in jars (2000ml) for egg laying and then kept at the temperature and relative humidity specified above. Each jar contained a piece of cotton wool in a small bottle with 40% honey solution as food and a piece of paper folded in a zigzag shape as an egg laying site. The egg masses deposited on the paper were transferred to place in the rearing containers, then incubated under the aforementioned conditions until the larvae hatch and then could be used in investigation experiments.

Rearing of the predator C. carnea

Chrysoperla carnea adults were placed in 20x15x10cm plastic containers covered with black gauze for egg laying. A semi-artificial diet consisting of 4g of yeast, 8g of honey, and 4cm of filtered water was presented on an adhesive tape on the gauze for adult nourishment. Eggs were taken every 24h, and the containers were changed every two days. Eggs were taken every 24h, and the containers were changed every two days. Eggs of *C. carnea* were placed in plastic containers until hatching occurred, at which point the larvae were fed with *Sitotroga cerealella* eggs, which were provided from the Mass Production Unit of *S. cerealella* eggs at the Bollworm Research Department, Plant Protection Research Institute, ARC, Dokki, Giza, Egypt. Before starting the experiment, newly hatched *C. carnea* larvae on *S. frugiperda* eggs for several generations were reared (Figure 1).

(i) Developmental period and mortality percentage of C. carnea immature stages

Newly hatched larvae from the second generation (G2) and fourth generation (G4) of *C. carnea* are individually kept in small plastic boxes (2.5cm×2.5cm). In this experiment, treatment as well as control include five replicates, each consisting of 5 *C. carnea* larvae. Daily, the larvae were provided a suitable amount of either *S. frugiperda* eggs as treatment prey or *S. cerealella* eggs as control prey and monitored constantly to record the data. The following data were recorded over the day: the duration of each larval instar, pupal duration, pupation percentage, adult emergence percentage, and life cycle.

(ii) Biological parameters of the C. carnea adult stage

Adults emerged from treatments or control, ten replicates (males and females) from treatments or control were confined, each in a small plastic box (7cm×6cm) covered with black muslin to serve as a place to lay eggs. The semi-artificial diet supplied *C. carnea* adults. Drops of this rather synthetic nutritional diet were applied on wax paper that was affixed to the black muslin. In order to give them water, pieces of wet cotton wool were also put on the bottom of each box. The adult pairs were moved to new containers three times a week when the first eggs were deposited, and the quantity of eggs was counted daily. Many parameters recorded included adult longevity, pre-oviposition, oviposition, post-oviposition



Figure 1. *C. carnea* larvae feeding on *S. frugiperda* eggs.

periods, and hatchability percentage of eggs.

(iii) Assessment of the predatory ability of C. carnea larvae fed on eggs, newly hatched larvae and second larval instar of S. frugiperda

The predation abilities of *C. carnea* larval instar that had been fed on *S. frugiperda* eggs, newly hatched larvae, or second instar larvae were examined to evaluate their ability for predation. Newly hatched *C. carnea* larvae were counted and individually placed in a small plastic box measuring 2.5cm×2cm. A total of 25 *C. carnea* larvae were used, representing five replicates for each treatment group. Daily, a specific quantity of *S. frugiperda* eggs and larvae was provided, with the amount varying according to each *C. carnea* instar. For the first-instar larvae, 20 eggs or newly hatched larvae or second larval instar of *S. frugiperda* were supplied for each replicate to initiate their development. As the larvae matured, the availability of hosts increased, requiring 50 and 100 prey for the second and third instars, respectively. Every 24h, *C. carnea* larvae and their prey were moved to new boxes using a slip-away brush. Observations were recorded daily to assess *C. carnea* larval survival, the duration of each larval instar, and prey consumption. (Note: *C. carnea* larvae in their first instar who were unable to feed on newly hatched *S. frugiperda* were fed on eggs of *Sitotroga cerealell*. After the second larval instar began, they were fed on newly hatched *S. frugiperda* and recorded the larval duration).

STATISTICAL ANALYSIS

Data were analysed statistically by an Analysis of Variance (ANOVA), with the averages separated by Duncan's Multiple Range test (Duncan, 1955) ($p<0.05$) across all treatments. The F-value and Duncan's tests were performed by the SAS software (SAS, 1999) to evaluate the significance between treatments.

RESULTS

(i) Developmental period and mortality percentage of C. carnea Immature stages

Data presented in Table 1 show that the developmental durations of the 1st larval instar for second generation (G2) and fourth generation (G4) were recorded as 3.04±0.10 and 2.88±0.06 days, respectively, whereas the control group exhibited 2.32±0.09 days. The 2nd larval instar was noted as 3.48±0.10, 3.28 ±0.09, and 2.92±0.11 days for G2, G4, and control, respectively. These findings suggest that the durations for the 1st and 2nd instars in the G2 and G4 generations were not significantly different from each other; on the contrary, they were highly significantly different from the control. The developmental period of the 3rd instar reached 4.64±0.09 and 4.36±0.09 days in G2 and G4, respectively, while the control recorded 4.24±0.10 days. The results of the current study indicated that both the G2 and G4 generations of *C. carnea*, which were nourished with *S. frugiperda* eggs, had

a notable impact on the total duration of larval development. The G2 larvae exhibited the longest developmental period, averaging 11.16±0.13 days, whereas the control recorded the shorter duration of 9.48±0.19 days. Similarly, pupal duration was 7.52±0.10, 7.68±0.11, and 7.36±0.15 days in G2, G4, and control, respectively. The results also showed no significant difference in pupal durations between G2, G4, and control. Furthermore, there are notable variations in total developmental periods from egg to adult, with G2 and G4 generations recording 22.08±0.19 and 21.2±0.20 days, respectively, compared to 19.64±0.18 days for the control. However, the pupation percentage recorded 80, 92, and 96% in G2, G4, and control, respectively. Moreover, the emergence percentage recorded 94.4, 95.2, and 100% in treatment and control, respectively. As for larval and pupal mortality, data in Table 2 revealed that the mortality percentage in the first larval instar and pupal stage was 4% in G2 and G4 generations, while it was 0% in the control. However, the high mortality percentage in the 2nd and 3rd larval instar was recorded in G2 at 4% and 12%, respectively. Moreover, there is no significant difference in the mortality rate in the 2nd and 3rd larval instar between the G4 generation and the control.

(ii) Biological parameters of the C. carnea adult stage

The biological characteristics of adult *C. carnea* for the G2 and G4 generations, which emerged from larvae fed on *S. frugiperda* eggs, compared to the control group that was fed on *S. cerealella* eggs, as presented in Table 3. The findings indicated that the G2 generation exhibited the maximum pre-oviposition period of 3.6±0.34 days, whereas the control group recorded the minimum of 2.3±0.15 days. The G4 generation showed a pre-oviposition period of 3.3±0.15 days. The analysis revealed that there was no significant difference in the pre-oviposition period between the G2 and G4 generations. However, highly significant differences were evident between the control and both second and fourth generations. Regarding the oviposition periods, females reared on *S. cerealella* eggs showed significantly longer durations (37.8±0.99 days) than those on *S. frugiperda* eggs

Table 1. Biological parameters of *C. carnea* fed on *S. frugiperda* eggs

C. carnea			**Duration (day)**				**Pupa-tion%**	**Adults emergence %**	**Life cycle**
	Incubation periods	**1st larval**	**2nd larval**	**3th larval**	**Total Larval**	**pupal**			
G2*	3.04±0.16 [a]	3.04±0.10[a]	3.48±0.10[a]	4.64±0.09[a]	11.16±0.13[a]	7.52±0.10[a]	88±2.82±[a]	94.4±2.03[b]	21.8±0.19[a]
G4**	3±0.21 [ab]	2.88±0.06[a]	3.28±0.09[a]	4.36±0.09[ab]	10.52±0.10[b]	7.68±0.11[a]	92±3.34[a]	95.2±2.33[ab]	21.2±0.20[b]
Control***	2.8±0.14 [b]	2.32±0.09[b]	2.92±0.11[b]	4.24±0.10[b]	9.48±0.19[c]	7.36±0.15[a]	96±1.26[a]	100±0.0[a]	19.64±0.18[c]
F	3.15	17.11	7.58	4.19	32.48	1.68	2.30	3	40.66
p	0.058	0.000	0.001	0.0189	0.0001	0.193	0.141	0.096	0.0001
LSD 0.05	0.49	0.257	0.290	0.282	0.419	0.348	8.11	5.51	0.546

Data presented are mean ± standard error
Different letters in the same column indicate significant differences at ($p<0.05$).
*:The second generation of *C. carnea* fed on *S. frugiperda eggs.*
***: The fourth generation* of *C. carnea* fed on *S. frugiperda eggs.*
*** *C. carnea* fed on *S. cerealell*a

Table 2. Mortality percentage of *C. carnea* immature stages fed on *S. frugiperda* eggs

C. carnea		**Percentage mortality of larval and pupal (%)**			
	1st larval	**2nd larval**	**3th larval**	**Total**	**Pupal**
G2*	4±1.26[a]	4±2.19[a]	12±2.82[a]	20±3.79[c]	4±1.26[a]
G4**	4±1.26[a]	0±0[b]	4±1.26[b]	8±2.19[b]	4±1.26[a]
Control***	0±0[b]	0±0[b]	4±1.26[b]	4±1.26[a]	0±0[b]
F	5	3.33	5.71	10	5
p	0.026	0.07	0.018	0.00278	0.026
LSD 0.05	3.18	3.9	6	8.11	3.18

Data presented are mean ± standard error
Different letters in the same column indicate significant differences at ($p<0.05$).
*:The second generation of *C. carnea* fed on *S. frugiperda eggs.*
***: The fourth generation* of *C. carnea* fed on *S. frugiperda eggs.*
*** *C. carnea* fed on *S. cerealell*a

Table 3. Biological parameters of the *C. carnea* adult stage

C. carnea		Duration of adults (Day)				No. eggs/female	Hatchability %
	Pre-	Ovi- oviposition	Post-	Female age	Male age		
G2*	3.6±0.34[a]	26.4±0.84[c]	5.2±0.32[a]	35.2±0.91[c]	28.6±1.73[b]	371±14.70[a]	93.67±0.55[a]
G4**	3.3±0.15[a]	30.3±0.68[b]	4.0±0.25[b]	37.8±0.57[b]	29.1 ±0.67[b]	390.8±3.40[a]	94.01±0.76[a]
Control***	2.3±0.15[b]	37. 8±0.99[a]	1.3±0.33[c]	41.4±0.77[a]	33.5±1.24[a]	398.9±6.18[a]	95.44±1.27[a]
F	8.57	8.57	41.92	16.26	4.36	2.18	1.05
p	0.001	0.0013	0.0001	0.0001	0.0228	0.1324	0.36
LSD 0.05	0.674	2.4729	0.8952	2.231	3.7453	27.33	2.65

Data presented are mean ± standard error
Different letters in the same column indicate significant differences at ($p<0.05$).
*:The second generation of *C. carnea* fed on *S. frugiperda eggs.*
**: *The fourth generation* of *C. carnea* fed on *S. frugiperda eggs.*
*** *C. carnea* fed on *S. cerealell*a

(26.4±0.84 days) in G2 (30.3±0.68 days) in G4. Additionally, the post-oviposition period was significantly extended when *C. carnea* larvae were fed *S. frugiperda* eggs. The results also indicated that female longevity varied significantly across generations and the control, while male longevity did not show significant differences between the G2 and G4 generations. The number of eggs laid in the G2 and G4 generations was 371±14.70 and 390.8±3.40, respectively (Table 3). Overall, the fecundity did not demonstrate a significant difference across all treatments. Moreover, there were no significant differences in the hatchability of eggs between G2, G4 and control.

(iii) Assessment of the predatory ability of C. carnea larvae fed on eggs, newly hatched larvae, or the second larval instar of S. frugiperda

The findings revealed that the larvae of *C. carnea* did not consume the second larval instar of *S. frugiperda*. Additionally, the 1st instar larvae of *C. carnea* also refrained from nourishment on the newly hatched *S. frugiperda*. The present results relating to the predatory capacity of *C. carnea* when fed on eggs and newly hatched larvae of *S. frugiperda* indicated that the first instar of *C. carnea* exhibited a predatory potential of 35.32±1.06 on the eggs of *S. frugiperda* (Table 4). The data revealed that the highest predatory ability in the second larval instar, recorded at 87.88±1.31, was observed on the eggs, while the lowest, 68.2±1.49, was noted on newly hatched larvae. Furthermore, the predatory ability of the third instar was reached at 201.80±2.55 and 157.44±2.52 on eggs and newly hatched larvae of *S. frugiperda,* respectively. The obtained results suggest that *S. frugiperda* has a highly significant impact on the predatory ability of the 2nd and 3rd instars. Throughout their developmental period, the larvae consumed a total of 325.00 ±3.47 eggs. The durations for the first, second and third larval instars were 2.92± 0.05, 3.32±0.09, and 4.36±0.09 days, respectively (Figure 2). Additionally, the larvae consumed a total of 225.64±2.88 newly hatched larval individuals during their developmental phase. The durations for the second and third larval instars were 3.73±0.18 and 4.73±0.11 days, respectively. The results of this research demonstrated that the developmental duration was varied significantly ($F=4.92$, $p=0.032$) ($F=5.71$, $p=0.021$) in the second and third larval durations, respectively. On the contrary, the survival rates of various immature stages (97.6% and 93.6% (Figure 3) on the eggs and newly hatched of *S. frugiperda*, respectively) did not reveal a significant difference.

DISCUSSION

Currently, G2 and G4 generations of *C. carnea*, which fed on *S. frugiperda* eggs, exhibit a three-larvae instar comparable to that of the predator fed with different prey (Alghamdi & Sayed, 2017; Rana *et al*., 2020). Findings

Table 4. Predation capacity of *C. carnea* larvae fed on *S. frugiperda* eggs and larvae

Prey-type	(Mean±S.E) of consumed individuals			Total No. consumed individuals
	1st	2nd	3th	
Eggs	35.32 ±1.06[a]	87.88 ±1.31[a]	201.80 ± 2.55[a]	325.00 ± 3.47[a]
Newly hatched	0.00[b]	68.20 ±1.49[b]	157.44 ±2.52[b]	225.64 ±2.88[b]
Second larval	0.00	0.00	0.00	0.00
F	1098.41	97.70	152.38	484.19
p	0.0001	0.0001	0.0001	0.0001
LSD 0.05	2.1427	4.0033	7.2253	9.079

Data presented are mean± standard error. Different letters in the same column indicate significant differences at ($p<0.05$).

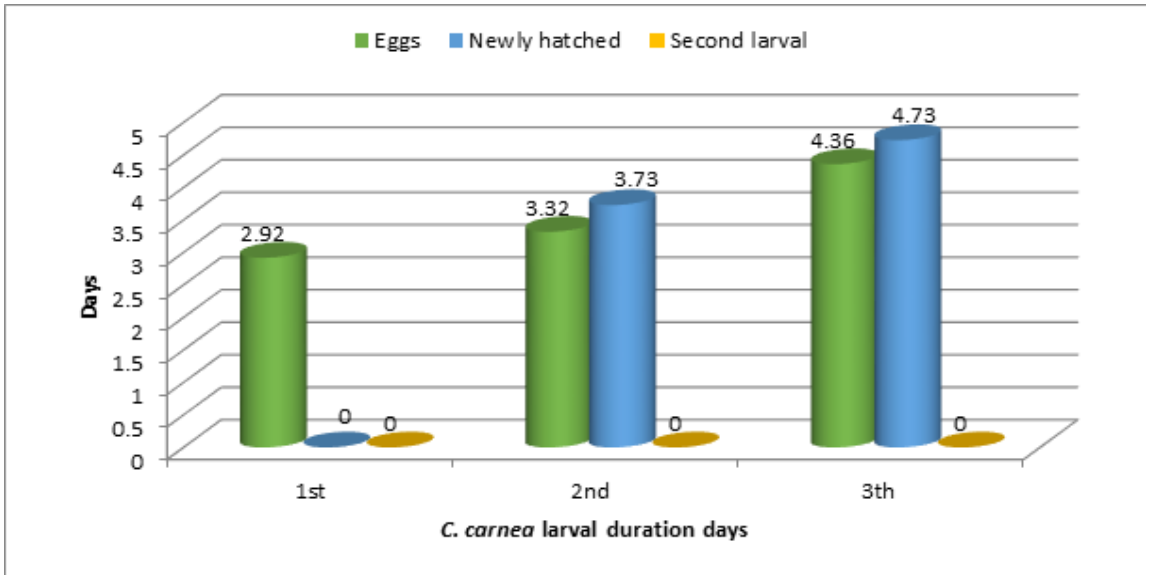


Figure 2. Larval duration of *C. carnea* fed on eggs and larvae of *S. frugiperda.*

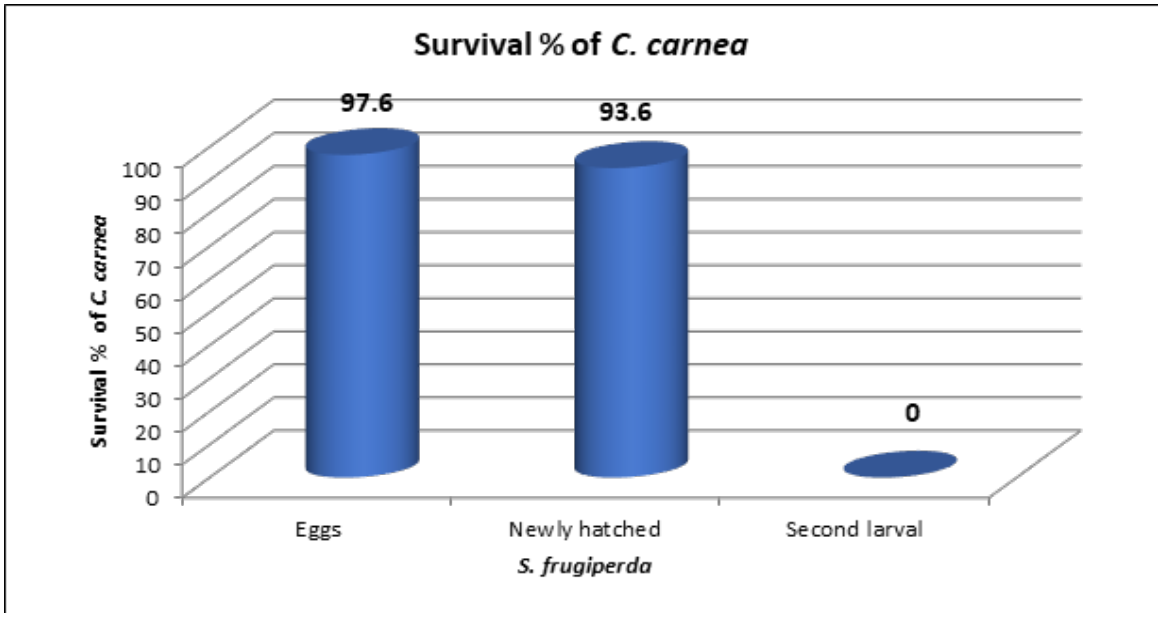


Figure 3. Survival % of *C. carnea* larvae fed on eggs and larvae of *S. frugiperda.*

indicated that the eggs of *S. frugiperda* are suitable for *C. carnea*, because the presence of inappropriate prey or adverse ecological circumstances may influence the quantity of instars to either reduce or increase (Michaud, 2005; Tavares *et al*., 2012). Results indicated that no significant difference in the 1st larval duration across G2 and G4 generations. Regarding the mortality of the 1st larval instar fed on *S. frugiperda* eggs, 4% in G2 and G4 generations compared to the control (0.0% mortality) might be related to the design of the egg masses, which are often associated with a protective layer of scales that serves to deter natural enemies. (Beserra & Parra, 2004; Souza *et al.*, 2008). The short duration in second, third, and total larval instars in G4, Moreover, the high rate of mortality in both second and third larval instar recorded in G2 beside no variations in mortality rate in second and third larval instar in G4 and control might be due to the occurrence of start adaptation to the prey. This is beneficial when the predator is used to control the prey in the field, and localisation of this predator occurs. According to the results of this study, no significant difference between the pupal duration in G2, G4, and control. The complete developmental period from egg to adult in G2 and G4 generations is compatible with the numerous previous findings. Geethalakshmi *et al*. (2000) studied the biology of *C. carnea* larvae fed on *Corcyra cephalonica* eggs. Authors indicated the duration larval stage at 10.3 days and the pupal stage at 8.4 days, but also recorded 22.2 days as the total duration of development from egg to adult. Moreover, Sattar *et al.* (2011) studied the effects

of different preys *Pectinophora gossypiella*, *Phenacoccus solenopsis*, *Helicoverpa armigera*, *Aphis gossypii*, and *Sitotroga. cerealella* on biology of *C. carnea*. The author found that the minimum survival (50%) was to the adult stage of *A. gossypiella* and the maximum (100%) of *S. cerealella.* Similar results were also noted by Abd El-Atty (2015), who stated significant differences among the total developmental periods of 26.9, 20.6, 23.0, 19.8 days when larvae of *C. carnea* reared on *T. tabaci*, *G. ficorum*, *A. durantae*, and *S. littoralis*, respectively, compared with (15.4±0.4) days *in A. craccivora*. Also, Hassan (2016) studied the larvae of *C. carnea* feeding on *S. littoralis* eggs, He mentioned that the three larval instars of *C. carnea* took 4.27±0.13, 4.86±0.17, and 5.50±0.16 days, respectively. Additionally, Saljoqi *et al*. (2022) stated that when *C. carnea* larvae fed on *S. litura* eggs and first-instar larvae, the larval duration was 10.5 and 11.3 days, respectively and 7.92 and 7.63 days for the pupa.

On the other hand, results indicated that the oviposition periods, post-oviposition periods, and female longevity varied significantly across generations and the control. Overall, the fecundity and hatchability of eggs did not demonstrate a significant difference across all treatments. Similar findings were reported by Sattar *et al*. (2011) who studied utilizing eggs of *S. littoralis* by *C. carnea larvae* and found that the pre-oviposition, oviposition, and post-oviposition periods were 4.12, 19.12, and 7.62 days, respectively, while Females laid an average of 322 eggs per female. Saljoqi *et al*. (2022) stated that no significant difference in pre-oviposition, oviposition, and post-oviposition periods when larvae of *C. carnea* fed on eggs and 1st instar larvae of *S. litura.* Meanwhile, the females that were fed on *S. cerealella* eggs recorded maximum fecundity per female (503.3±9.17) of eggs.

Results of the predatory ability of *C. carnea* larvae instars fed on eggs or larvae of *S. frugiperda* showed that all instars of larvae of *C. carnea* that fed on the second larval instar of *S. frugiperda* died, indicating that the predator was unable to effectively prey on the larger larvae. According to Auad *et al*. (2003), there was a suggestion that the older *S. frugiperda* larvae might have lower nutritional quality or stronger physical barriers against *C. externa* larval predation. Additionally, the first instar larvae of *C. carnea* also refrained from feeding on the newly hatched *S. frugiperda* may be these instars have weak mouthparts. The findings agree with those of Tavares *et al.* (2012) observed that *Chrysoperla externa* did not develop into pupae when fed *S. frugiperda* larvae that were one or two days old. Additionally, El-Dessouki and Korish (2023) reported that the larvae of *C. carnea* did not feed on the larvae of *S. littoralis* during their first instar. A highly significant difference was observed in the feeding capacity of the second and third larval instars of *C. carnea* when feeding on eggs and newly hatched larvae of *S. frugiperda*. These results suggest the difference was caused by the sizes of the eggs and larvae. There are no studies available on the feeding capacity of *C. carnea* on *S. frugiperda*. However, many studies are available against the feeding capacity of *C. carnea* on different prey, which agrees with this study. Sattar *et al*. (2011) studied the daily predatory potential of *C. carnea* for feeding on *S. littoralis* eggs. They recorded 13.2, 34.6, and 70.33 prey for 1st, 2nd, and 3rd larval instars, respectively. Meanwhile, Tavares *et al.* (2012) indicated that the predatory capacity of the first, second, and third instars of *Chrysoperla externa* on modern or one-day-old eggs of *S. frugiperda* was 44.7, 129.9, and 330.8, and 71.5, 119.9, and 176.3 eggs, respectively, with total larval predation recorded at 505.4 and 367.7 eggs. Similarly, Saljoqi *et al*. (2022) stated that the 1st, 2nd, and 3rd larval instars of *C. carnea* consumed 40.3, 108.3, and 292.4 eggs of *S. littoralis*, respectively. In comparison, the predatory potential of the first instar was 37.7, 107.2, and 249.0. When *C. carnea* fed on *S. littoralis* eggs, its larval predatory potential was predicted to be 443.9, and when it fed on *S. littoralis* first instar, it was calculated to be 395.2 larvae. Furthermore, El-Dessouki and Korish (2023) found that the 1st, 2nd, and 3rd larval instars of *C. carnea* consumed 35.53±7.82, 35.82±3.21, and 701.75±135.6 eggs of *S. littoralis*, respectively. Furthermore, the 2nd and 3rd larval instar consumed 166±39.1 and 729.91±120.50 larvae of *S. littoralis,* respectively.

CONCLUSION

The present study concluded that the biological parameters of *C. carnea* were better across multiple generations when fed on *S. frugiperda* eggs and compared to *Sitotroga cerealella* eggs, the eggs of *S. frugiperda* found to be the suitable food source for *C. carnea*. The results revealed that the predatory efficacy of *C. carnea* on *S. frugiperda* eggs and 1st instar larvae was promising under laboratory conditions and *C. carnea* is found to be a effective biological control agent for managing *S. frugiperda*. Further research is needed to investigate *C. carnea*'s foraging capacity, developmental performance, prey selection, numerical response, and release methods both in the laboratory and in the field.

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