

Investigations on the cannibalistic behavior of ladybird beetle *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) under laboratory conditions

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Abstract: Cannibalism or intraspecific predation, where one species feeds on individuals of its own species, is a widespread phenomenon in most aphidophagous coccinellids. Laboratory studies were conducted on the cannibalistic behavior of various developmental stages of *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) in the presence and absence of natural food, *Acyrtosiphon pisum* (Harris) (Hemiptera: Aphididae). In both the presence and absence of aphids, the eggs and 1st and 2nd instars of *C. septempunctata* were cannibalized by the adults, and the level was inversely related to the availability of aphids. The same was also true for cannibalism of eggs by larvae and within the larval stages, with older larvae consuming significantly higher numbers of eggs and younger larvae in the absence of aphids. The adults and 4th instar larvae also consumed a considerably higher number of eggs, even in the presence of aphids. Within the same stage/age of larvae, the level of cannibalism increased with each larval stage from minimum among 1st instars and maximum among 4th instars. The studies showed that a low density or scarcity of prey was the main cause of cannibalism in *C. septempunctata*.

Key words: *Coccinella septempunctata*, cannibalism, aphids, developmental stages, consumption

1. Introduction

Ladybird beetles (Coleoptera: Coccinellidae) are the most commonly known of all beneficial insects (Dixon, 2000; William, 2002). They are important voracious predators of many economically important pests, like aphids, jassids, whiteflies, mealy bugs, scale insects, thrips, leaf hoppers, mites, lepidopteron insects, and other soft-bodied insects in natural and agricultural habitats (Khan et al., 2009; Silva et al., 2009; Shah and Khan, 2014).

The seven-spotted ladybird beetle, *Coccinella septempunctata*, is a polyphagous generalist predator both in larval and adult stages, which devour most of the aphid species and some other soft-bodied insects that they come across (Hodek, 1996; Sharma and Joshi, 2010; Agus et al., 2013). It has been efficiently used in biological control programs against a number of insect pests, especially aphids. Cannibalism is a well-known behavioral feature of predaceous coccinellids, including *C. septempunctata*, and is one of the important mortality factors of coccinellids (Osawa, 1989; Khan et al., 2003; Rondoni et al., 2012; Jafari, 2013). In aphidophagous coccinellids, cannibalism is an important evolutionary behavior during times of food scarcity that enables them to survive and complete their development. Aphidophagous coccinellids are usually more prone to cannibalism compared to coccidophagous

coccinellids as the latter encounter each other less frequently and more likely complete their development before the population collapse of their prey (Agarwala and Dixon, 1992; Dixon, 2000). The eggs and younger larvae are more vulnerable to cannibalism by older larvae and adults (Dimetry, 1974; Hodek, 1996; Nakamura et al., 2006; Pervez et al., 2006). Cannibalism of eggs, younger larvae, prepupae, and pupae by older larvae and adult males and females is a common phenomenon in the field and laboratory. Sibling cannibalism where newly hatched larvae in the same egg cluster cannibalize unhatched sibling eggs is also very well known in ladybird beetles (Agarwala, 1991; Hodek, 1996). This sibling egg cannibalism in ladybirds minimizes starvation risks before dispersion. These adaptive traits benefit ladybirds by providing essential nutrients and critical energy required for initial survival and development (Kawai, 1976; Wratten, 1976; Omkar et al., 2007; Roy et al., 2007).

The rate of cannibalism is inversely proportionate to the availability of natural food. The abundance of prey also lowers the relative frequency of encounters of adults and older larvae with eggs and smaller larvae, leading to minimization of the rate of cannibalism (Agarwala and Dixon, 1992; Dixon, 2000; Aleosfoor et al., 2014). However, some studies also revealed cannibalism even

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in the presence of extraguild prey, which shows that the scarcity of food may not be the absolute reason for cannibalism in *C. septempunctata* (Agarwala and Dixon, 1992; Rosenheim et al., 1995; Lucas et al., 1998; Hindayana et al., 2001; Omkar et al., 2007; Rodoni et al., 2012). Similarly, the rate of cannibalism in *C. septempunctata* is found to be greater and more frequent compared to other coccinellid predators (Khan et al., 2003; Al-Ansari, 2010; Aleosfoor et al., 2014). A variety of research studies have been conducted on various other aspects of cannibalism in *C. septempunctata*. However, the present study was designed to conduct detailed investigations on cannibalism in controlled conditions through skillful and refined procedures to provide a complete set of information on the cannibalistic behavior of *C. septempunctata* under laboratory conditions.

2. Materials and methods

2.1. Rearing of pea aphid, *Acyrtosiphon pisum* (Harris)

Pea aphids (*Acyrtosiphon pisum*) were collected from alfalfa and clover and brought to the laboratory. Rearing was maintained on broad bean (*Vicia faba* L.) planted in sterile soils in pots of 500 mL under laboratory conditions (22 ± 1 °C and $65 \pm 5\%$ relative humidity).

2.2. Rearing of *Coccinella septempunctata* L.

Adults of *C. septempunctata* were collected from different crops and brought to the laboratory. They were kept in plastic jars (height 20 cm, diameter 15 cm) with ventilation holes, two on the side and one in the lid screened with fine mesh. The jars were kept in wooden framed cages (100 × 70 × 75 cm), each having a controlled light system for provision of a photoperiod of 16 h L : 8 h D. The natural hosts (aphids) were provided regularly on host leaves. The eggs laid by females were collected gently with a camel hairbrush and transferred to other jars for hatching. Similarly, the larvae that emerged from eggs were transferred to plastic jars with an abundant supply of aphids on the leaves. The rearing was maintained at 24 ± 1 °C, $65 \pm 5\%$ relative humidity, and 16 h L : 8 h D photoperiod. The cannibalistic behavior of *C. septempunctata* was also studied under these controlled conditions. Adult beetles of similar ages (male and female), different larval instars, and eggs used in the experiments were taken from the stock culture.

2.3. Cannibalism of eggs and larvae by adults

Cannibalism of eggs and larvae by adults was accomplished by keeping unmated adult male and female beetles of 15 days old (Agarwala and Dixon, 1992) individually in petri dishes (9 cm diameter for eggs and 15 cm diameter for larvae) and deprived of food for 24 h. Each adult (male or female) was offered 100 conspecific eggs only (T1), 100 conspecific eggs with 100 aphids (T2), 60 fresh first instar larvae alone (T3) or in combination with 700 aphids (T4),

and 35 second instar larvae alone (T5) or in combination with 700 aphids (T6) for 24 h. This experiment was repeated 10 times for each sex and petri dishes were inspected after 24 h to record observations on cannibalism.

2.4. Cannibalism of eggs by larvae

To study cannibalism of conspecific eggs by larvae, larvae of all four larval instar stages (1st, 2nd, 3rd, and 4th) were kept individually in petri dishes (9 cm in diameter) and starved for 12 h to standardize their appetites (Yasuda et al., 2001; Khan et al., 2003). Known numbers of conspecific eggs were transferred with the help of a soft camel hairbrush to these petri dishes. The numbers of conspecific eggs offered to larvae of each instar were: first instar, 20 eggs; second instar, 30 eggs; third instar, 50 eggs; and fourth instar, 100 eggs. These treatments were replicated 10 times for each instar. The number of eggs consumed by larvae was recorded after 24 h. In another experiment the same instars were used and the same numbers of conspecific eggs were offered to all four larval instars along with different numbers of aphids (20, 30, 60, and 100 for 1st, 2nd, 3rd, and 4th instars, respectively) in order to record cannibalism in the presence of natural food.

2.5. Cannibalism within larvae

This study of cannibalism within larval instars was accomplished in two stages. In the first stage, cannibalism of younger larvae by older larvae was investigated in the presence and absence of aphids. The 4th, 3rd, and 2nd larval instars were kept individually in petri dishes of 15 cm in diameter and starved for 12 h in order to induce the same level of hunger. The prescribed number of well-fed 1st and 2nd larval instars (60 and 35, respectively) were offered to 4th instar larvae in separate petri dishes in the presence and absence of aphids. Similarly, 1st and 2nd instar larvae (35 and 20, respectively) were offered to 3rd instar larvae, and 20 larvae of the 1st instar stage were offered to 2nd instar larvae ($n = 10$), with and without the provision of aphids. Observations on cannibalism were recorded after 24 h. In the second experiment 10 larvae of the same age of each stage (1st, 2nd, 3rd, and 4th) were starved for 12 h, as described earlier, and then kept together for 24 h in the presence and absence of aphids to determine the level of cannibalism. The numbers of aphids provided were 100, 150, 300, and 700 for 1st, 2nd, 3rd, and 4th instars, respectively.

2.6. Statistical analysis

The data collected on the cannibalistic behavior of *C. septempunctata* were subjected to analysis using IBM SPSS Statistics 24 (IBM Corp., Armonk, NY, USA). The means were compared using the Duncan multiple range test. Data on egg and larval cannibalism in the presence and absence of aphids were entered in the software and one-way ANOVA was used to determine t-tests and

P-values for checking significant differences within means ($P \leq 0.05$). Means are presented with standard errors. All values given in figures are averages of 10 replications with standard error bars.

3. Results

3.1. Cannibalism of eggs and larvae by adult

3.1.1. Cannibalism of eggs by adults

Results on the cannibalism of eggs by adult males and females of *C. septempunctata* revealed that the females consumed significantly higher average numbers of eggs (99.1 ± 1.3) compared to males (72.1 ± 1.3) when there were no aphids provided (Figure 1). The presence of aphids caused a significant decrease in the amount of egg consumption; however, egg consumption was still considerably higher in the case of females, which consumed significantly more eggs (42.1 ± 1.2) than males (28.9 ± 1.5).

3.1.2. Cannibalism of 1st instar larvae by adults

Results on the cannibalism of 1st instar larvae by adult males and females revealed that both sexes were voracious towards 1st instar larvae. However, the females consumed significantly higher numbers of 1st instar larvae (55.5 ± 1.3) compared to males (45.7 ± 0.95) in the absence of natural food (Figure 2). This is probably because females need more energy for reproduction and have greater body sizes than males. The presence of aphids caused a significant reduction in larval consumption and negligible amounts of 1st instar larvae were consumed by adults (1.4 ± 0.1 and 1.8 ± 0.3 by adult males and females, respectively)

3.1.3. Cannibalism of 2nd instar larvae by adults

The ladybird females were found more voracious, consuming significantly higher amounts of 2nd instar larvae (33.4 ± 2.2) compared to males (28.1 ± 1.3) in the absence of aphids. The presence of aphids caused a drastic reduction in cannibalism and only a fraction of larvae were cannibalized (0.5 ± 0.01 and 0.9 ± 0.03 by adult males and females, respectively). This means that the cannibalism of larvae by adults and larvae is inversely proportionate to prey availability (Figure 3).

3.2. Cannibalism of eggs by larvae

Observations on the cannibalism of eggs by different larval instars of *C. septempunctata* revealed that all the larval stages showed different levels of cannibalism towards eggs (Figure 4). The 4th instar larvae consumed significantly higher numbers of eggs (98.9 ± 4.6), followed by 3rd instars (37.6 ± 2.3) in 24 h in the absence of prey ($P \leq 0.05$). The presence of aphids caused a significant reduction in egg consumption by the 4th instars, which showed that the presence of aphids is inversely related to cannibalism. However, it was also clear from the data that the older larvae (3rd and 4th) showed some degree of preference for

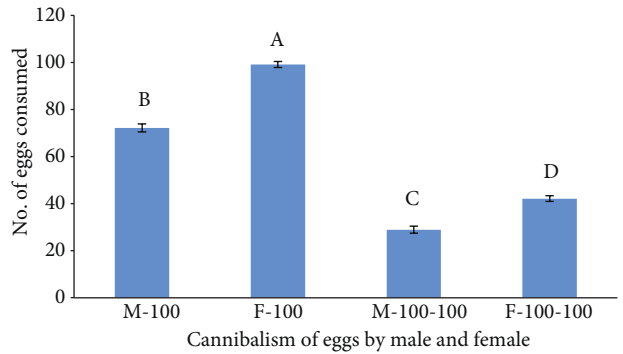


Figure 1. Cannibalism of conspecific eggs by adult males and females of *C. septempunctata*. Each bar represents mean (\pm SE) of egg consumption (M-100 = 100 eggs offered to adult males, F-100 = 100 eggs offered to adult females, M-100-100 = 100 eggs along with 100 aphids offered to males, F-100-100 = 100 eggs along with 100 aphids offered to females). Different letters indicate that means are significantly different ($P \leq 0.05$).

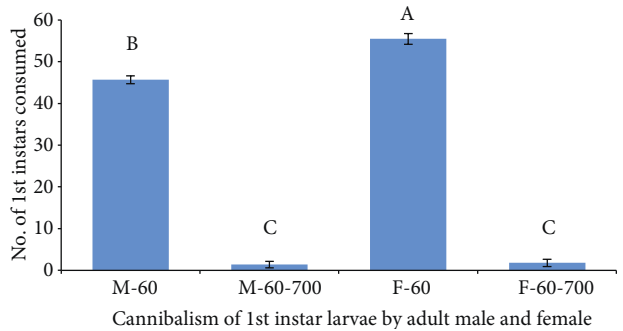


Figure 2. Cannibalism of 1st instar larvae by males and females of *C. septempunctata*. Each bar represents mean larval consumption (M-60 = 60 first instar larvae offered to adult males, F-60 = 60 first instar larvae offered to adult females, M-60-700 = 60 first instars along with 700 aphids offered to males, F-60-700 = 60 first instars along with 700 aphids offered to females). Different letters indicate that means are significantly different ($P \leq 0.05$).

the eggs even in the presence of aphids, consuming 13.4 ± 1.4 and 42.2 ± 2.3 average number of eggs, respectively (Figure 4). The results also showed a significant difference between the cannibalism of eggs and growth stages both in the presence and absence of aphids ($P \leq 0.05$).

3.3. Cannibalism within larvae

3.3.1. Cannibalism of younger larvae by older larvae

Studies on the cannibalism of younger larvae by older larvae revealed that all the starved older stages of larvae voraciously fed on the younger larvae (Figure 5). The 4th instar larvae consumed significantly higher numbers of 1st and 2nd instar larvae (59.3 ± 2.33 and 34.5 ± 1.26 , respectively) in the absence of prey, followed by the 3rd instar (27.7 ± 1.84 and 12.6 ± 1.65 , respectively) ($P \leq 0.05$).

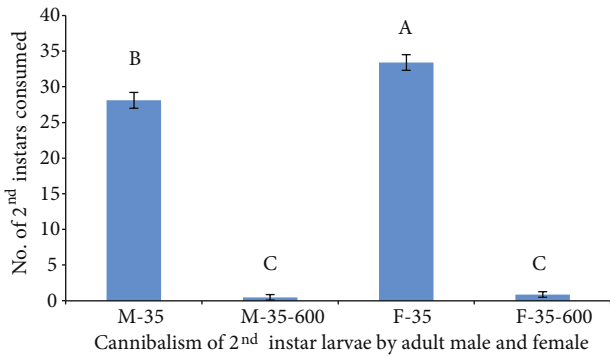


Figure 3. Cannibalism of 2nd instar larvae by adult males and females (M-35 = 35 second instar larvae offered to adult males, M-35-600 = 35 second instars along with 600 aphids offered to males, F-35 = 35 second instar larvae offered to adult females, F-35-600 = 35 second instars along with 600 aphids offered to females). Different letters indicate that means are significantly different ($P \leq 0.05$).

Larval consumption was greatly reduced in the presence of aphids for all the 2nd, 3rd, and 4th instars (0.1 ± 0.0 , 0.2 ± 0.03 , and 1.3 ± 0.34 , respectively), which means that cannibalism in larvae is related to sufficient food availability (Figure 5).

3.3.2. Cannibalism in same-age larvae

Cannibalistic behavior within larvae of the same age of *C. septempunctata* in the absence of aphids increased with

successive larval stage (Figure 6). It was minimum in the 1st larval instars (3.2 ± 0.32), followed by 2nd instars (3.7 ± 0.36). The highest cannibalism rate was recorded in the 4th instar larvae (7.1 ± 0.57) followed by 3rd instars (5.6 ± 0.45). This showed that there is a relationship between cannibalism and larval stage, showing a successive increase in cannibalism from younger to older larval stage. In the presence of aphids, cannibalism was found to be nil within same-age larvae of all 4th instars, which justified the results of our previous experiment as mentioned above.

4. Discussion

Most researchers agree that cannibalism in coccinellids takes place mainly when there is scarcity of food. Under such circumstances the younger larvae, especially 1st instars, and eggs are at a higher risk of cannibalism by older larvae and adults (Hemptinne et al., 1990; Agarwala, 1991; Hemptinne and Dixon, 1991; Khan et al., 2003). The numbers of eggs and larvae that were offered to different developmental stages of lady beetles for cannibalism in the present studies were set after performing a series of pretrials to reach a certain threshold. In all our experiments, none of the starved developmental stages showed any reluctance to feed on the conspecifics, which signifies that scarcity of food triggers cannibalism. It also shows a tendency towards the ability of ladybirds to complete development even if food is scarce. It is important to mention that the presence of aphids greatly reduced the cannibalism of larvae by adults and within larvae; however, egg cannibalism,

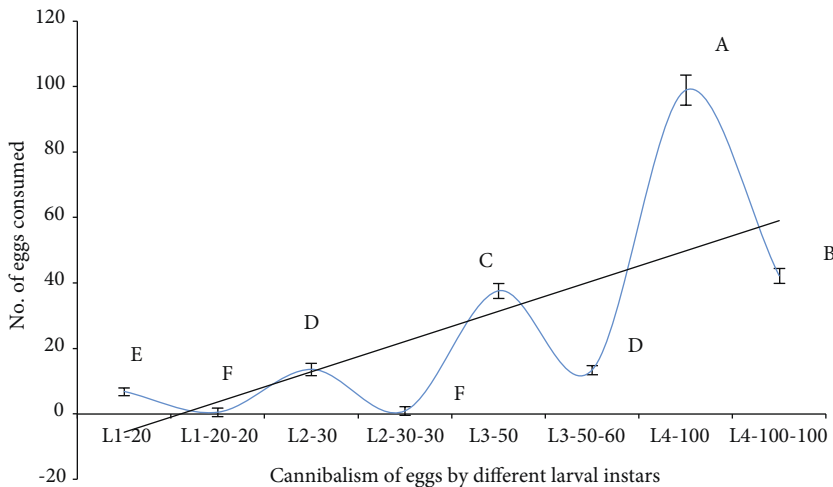


Figure 4. Cannibalism of eggs by different larval instars of *C. septempunctata* in the presence and absence of aphids (L1-20 = 20 eggs offered to 1st instars, L1-20-20 = 20 eggs along with 20 aphids offered to 1st instars, L2-30 = 30 eggs offered to 2nd instars, L2-30-30 = 30 eggs along with 30 aphids offered to 2nd instars, L3-50 = 50 eggs offered to 3rd instars, L3-50-60 = 50 eggs along with 60 aphids offered to 3rd instars, L4-100 = 100 eggs offered to 4th instars, L4-100-100 = 100 eggs along with 100 aphids offered to 4th instars). Different letters indicate that means are significantly different ($P \leq 0.05$).

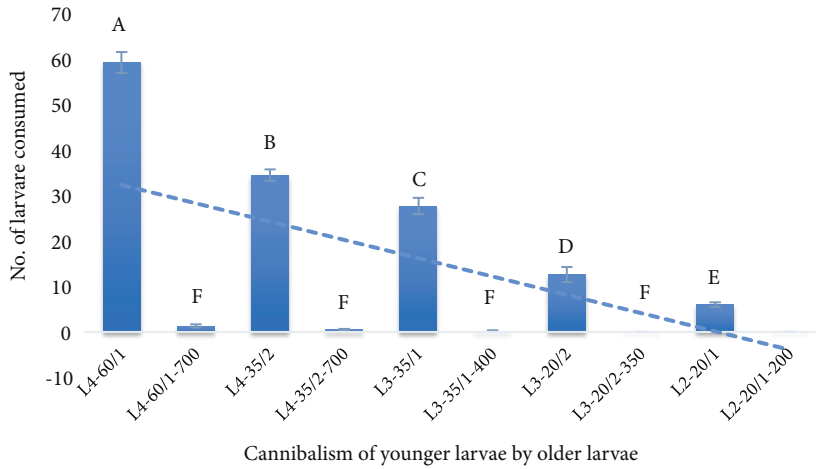


Figure 5. Each bar represents mean (\pm SE) larval consumption (L4-60/1 = 60 first instars offered to 4th instars, L4-60/1-700 = 60 first instars offered to 4th instars with 700 aphids, L4-35/2 = 35 second instars offered to 4th instars, L4-35/2-700 = 35 second instars offered to 4th instars along with 700 aphids, L3-35/1 = 35 first instars offered to 3rd instars, L3-35/1-400 = 35 first instars offered to 3rd instar with 400 aphids, L3-20/2 = 20 second instars offered to 3rd instars, L3-20/2-350 = 20 second instars offered to 3rd instars with 350 aphids, L2-20/1 = 20 first instars offered to 2nd instars, L2-20/1-200 = 20 first instars offered to 2nd instars along with 200 aphids). Different letters indicate that means are significantly different ($P \leq 0.05$).

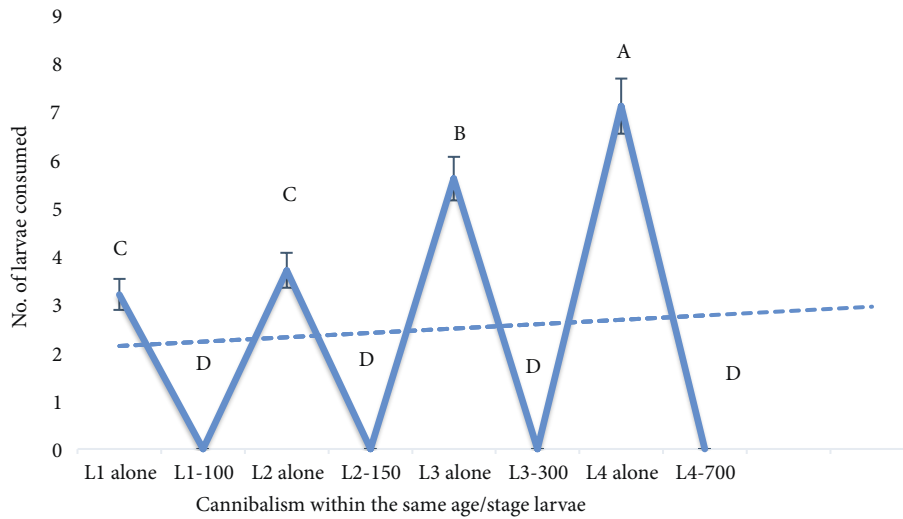


Figure 6. Each bar represents mean (\pm SE) of larval consumption (L1 alone = 10 first instars alone, L1-100 = 10 first instars along with 100 aphids, L2 alone = 10 second instars alone, L2-150 = 10 second instars along with 150 aphids, L3 alone = 10 third instars alone, L3-300 = 10 third instars along with 300 aphids, L4 alone = 10 fourth instars alone, L4-700 = 10 fourth instars along with 700 aphids). Different letters indicate that means are significantly different ($P \leq 0.05$).

especially by adult females, adult males, and 4th instar larvae, was still considerably higher even in the presence of natural food (Mills, 1982; Osawa, 1989; Al-Ansari, 2010). This could be attributed to the static condition of eggs, which cannot move to escape, and the presence of some

essential nutrients. Moreover, nonsibling cannibalism of eggs in ladybirds mostly happens without any influence of the availability of prey (Mills, 1982; Osawa, 1989). Poor diet quality also exerts pressure on predators to feed on conspecifics. However, higher aphid densities may result in

a lower encounter rate of ladybirds with eggs than aphids and may lead to reduced egg consumption (Snyder et al., 2000; Turnipseed et al., 2015). Agarwala (1991) stated that egg cannibalism in ladybirds occurred at all aphid densities but was more pronounced at lower densities. The higher egg consumption by females in the presence of prey represents that the females are more sensitive than males in term of resource utilization and hence get maximum benefit from egg cannibalism. Another reason could be the higher amount of energy required by females for reproduction (Michaud and Grant, 2004). However, some earlier workers (Agarwala, 1991; Khan et al., 2013) reported that females are reluctant in consuming conspecifics. The 4th instar larvae were also found very rapacious in consuming eggs and younger instars, which was obvious because of their higher food requirements for completion of larval development and preparation for pupation. All the larval stages showed different levels of cannibalism for eggs. The older larvae consumed higher numbers of eggs compared to younger ones, which is due to increase in body size and hence increased requirements for food (Cottrell, 2005;

Sato et al., 2011; Jafari, 2013). Cannibalism within larvae also produced more or less the same results. The presence of natural food caused a drastic reduction in cannibalism, which showed that the level of cannibalism within larvae is inversely proportionate to food availability. Same-age larvae manifested a continuous increase in cannibalism from 1st instars towards 4th instars in the absence of food. However, food availability produced the same results, i.e. cannibalism was found to be negligible. The study showed that extraguild prey scarcity is an important factor in the triggering of cannibalism in all developmental stages of seven-spotted ladybird beetle, except for egg cannibalism by adults and 4th instar larvae, which occurred even in the presence of aphids.

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