Chapter 2

Review of Literature
CHAPTER – 2

REVIEW OF LITERATURE

Work done in India and abroad on the proposed aspects of coccinellids has been reviewed and summarised as follows:

2.1 Diversity of predaceous coccinellids

The family Coccinellidae comprises 5200 described species worldwide (Hawkeswood, 1987). Later, Iperti and Paoletti (1999) reported that of the coccinellids reported globally, about 90% are known to be predaceous on different insect/acarine pests. Flemming (2000) reported 4000 predatory species of coccinellids including more than 300 species from Indo-Pak subcontinent. Thirty six true aphidophagous coccinellids with 16 incidental or doubtful species and 16 unidentified species of predaceous coccinellids have earlier been reported from India by Agarwala and Ghosh (1988). A five year survey of predaceous coccinellids in Manipur and Nagaland has revealed 46 coccinellids belonging to 6 tribes distributed at various altitudes (Shanitbala and Singh, 1991).

Omkar and Pervez (2000) reviewed the distribution records and prey range of 119 coccinellid predators belonging to 13 tribes from India. The authors also mention about some ladybeetles like Scymnus, Nephus, Cryptogonous, Micrasiš, Coleophora, Oenopia etc, the specific names of which were uncertain or yet to be assigned at that time. Poorani (2002) published a checklist of the Coccinellidae of Indian sub-region in which she described 79 genera and 400 species of ladybeetles along with their distribution in the
subcontinent. Omkar and Pervez (2004) published a catalogue which provides the prey record of 261 known predaceous coccinellids of India belonging to 57 genera. Introductions of coccinellids into India have been few and far between, with a majority of them imported for controlling a single pest, namely, *Melanaspis glomerata* (Green) on sugarcane, during the late sixties and early seventies. In all, 19 species of coccinellid predators have been introduced from various countries (Poorani, 2002).

Lovei (1981) studied the composition and diversity of the coccinellid community in an insecticide-treated and an untreated block in an apple orchard situated among forests near Budapest, Hungary, from 1977 to 1979. The treated block contained 11 species while the untreated one contained 10. Diversities did not differ significantly, but the untreated block supported more beetles than the sprayed one. The most abundant species were *Coccinella septempunctata* L. (71.2% in the treated plot as compared with 66.5% in the untreated one), *Adalia bipunctata* (L.) (9.7 and 14.37%, respectively), and *Exochomus quadripustulatus* (L.) (8.03 and 14.08%, respectively). More individuals of *Hippodamia variegata* (Goeze) were found in the sprayed block (6.35%) than in the unsprayed one (1.44%), which was probably due to the neighbouring cereal field.

Verma and Joshi (1988) recorded the natural enemies of various insect pests during a survey in 1987-89 in the temperate region of India. The authors reported 9 predators including *Chilocorus infernalis* Mulsant and *Priscibrumus (Exochomus) uropygialis* (Mulsant) attacking *Quadraspidiotus perniciosus* (Comstock), and *Coccinella septempunctata, Adalia tetraspilota* (Hooe) and *Harmonia eucharis* (Mulsant) attacking *Brevicoryne brassicae* (L.) along with
many other parasitoids and pathogens. Pawar and Parray (1989) conducted regular surveys of the natural enemies of fruit pests in Jammu and Kashmir during 1983. Along with other predators, *Adalia tetraspilota* was recorded preying on *Dysaphis* sp. on apple and *Calvia punctata* (Mulsant) was recorded as a predator of *Chromaphis juglandicola* (Kaltenbach) on walnut leaves.

Irshad (2001) published a review summarising the distribution, host range, ecology and biotic potential of 71 species of predaceous coccinellids from Pakistan. Azim and Bhat (2005) published the taxonomic notes of 8 ladybeetle species from Kashmir, *Chilocorus infernalis* and from subfamily Chilocorinae and *Coccinella septempunctata, C. transversalis* F., *C. undecimpunctata* L., *Illeis indica* Timberlake, from subfamily Coccinellinae. Inayatullah et al. (2005) conducted an extensive survey district Poonch of Azad Kashmir, Pakistan, which revealed 16 species of coccinellids in 12 genera belonging to four subfamilies, Coccinellinae, Chilocorinae, Scymninae and Epilachninae from the area. The subfamily Coccinellinae was represented by 13 species while as the subfamilies Chilocorinae, Scymninae and Epilachninae were represented by single species each.

Inamullah et al. (2006) carried out an extensive survey of predatory coccinellid beetles in district Chitral, Pakistan during 2001. Twelve different species belonging to 9 genera of 3 tribes and 3 subfamilies occurred in the area. Eight species namely, *Coccinella septempunctata, Hippodamia variegata, Calvia punctata, Adalia tetraspilota, Adalia bipunctata* L. *Aiolocaria hexaspilota* (Hope), *Macroilleis hauseri* Mader and *Oenopia conglobata* L. belonging to Coccinellinae; three species i.e., *Chilocorus rubidus* (Hope), *Chilocorus
circumdatus and Priscibrumus uropygialis belonging to Chilocorinae and one species i.e., Halyzia tschitscherini Semenow of Psyloborini were collected during the survey.

Khan et al. (2007) studied the relative abundance of predaceous coccinellids in fruit ecosystem, cruciferous crop ecosystem and forest ecosystem of Kashmir during 2006-07 (district Srinagar only). A total of 15 species belonging to 13 genera were recorded. Among all, Adalia tetraspilota was found relatively most abundant followed by Hippodamia variegata, Harmonia eucharis, Calvia punctata and Chilocorus infernalis. The maximum population and species diversity of ladybeetles was noted from pear ecosystem. The species diversity and species richness was recorded greater in fruit ecosystem than vegetable and forest ecosystems. An equitable distribution of coccinellid species (species evenness) was registered in fruit ecosystem as compared to other ecosystems included in the study.

Rekha et al. (2007) studied the diversity of predatory coccinellids in horticultural ecosystems comprising citrus, guava, mango, sapota and pomegranate in Madurai and Theni districts of Tamil Nadu. Of 10 species of predatory coccinellids recorded, the dominant coccinellid species were Chilocorus nigrita (F.), Jauvaria sp. Nephus regularis Sicard and Nephus sp. The occurrence of Chellomenes sexmaculata (F.), Scymnus castaneus Sicard, Scymnus coccivora Ayyar and Pseudaspidimerus trinotatus Thunberg was low while Chilocorus circumdatus (Gyllenhal) was the rare species.

Rekha et al. (2009) studied the diversity of predatory coccinellids in agro-ecosystems comprising cereals, pulses and vegetables, besides a
comparative study in weeded and partially weeded irrigated rice and cowpea ecosystems in Madurai District of Tamil Nadu. A total of 9 species of predatory coccinellids were recorded. Most abundant species found were *Coccinella transversalis* Fabricius, *Menochilus sexmaculatus* Fabricius and *Brumoides suturalis* Mulsant. Rank abundance values revealed that *C. transversalis*, *Micraspis discolor* F. and *B. suturalis* were the dominant taxa in weeded and partially weeded rice ecosystem. *M. sexmaculatus*, *C. transversalis* and *B. suturalis* were the dominant taxa in weeded and partially weeded cowpea ecosystem. The diversity of coccinellids was greater in partially weeded plots than in weeded plots.

Tara and Feroz (2009) conducted a survey of insect fauna of family Coccinellidae from different altitudes (ranging from 2636 metres to 7135 metres above mean sea level) of Ladakh region of Jammu and Kashmir during the year 2007-08 and reported coccinellids belonging to five genera viz. *Adalia* sp., *Hippodamia* sp., *Coccinella* sp., *Coleophora* sp., and *Halyzia* sp. from the region.

### 2.2 Biology of predominant ladybird beetle species

The earliest significant report to demonstrate that larval diet has a significant effect on predator development and survival was that of Putnam (1932 and 1937). First such study with coccinellids was that of Atwal and Sethi (1963) who demonstrated that *Coccinella septumpunctata* L. attained a greater weight when feeding on *Lipaphis erysimi* (Kaltenbach) than on two other aphid species.
Prey quality is a key factor affecting the growth, development and reproduction of predatory insects (Thompson, 1999). The suitability of a prey species can be evaluated by measuring the effect on biological attributes of the predator (Kalushkov and Hodek, 2004). Hodek (1962) and later Hodek and Honek (1996) categorized prey into essential, alternative and rejected prey, on the basis of quantitative data on developmental parameters viz. rate of development, survival and reproductive capacity. There are a few published studies in which the biological parameters of predatory insects have been related to either availability of prey or consumption rate (Jervis et al., 2005).

*Hippodamia (Adonia) variegata* (Goeze) originated in the Palearctic region (Gordon, 1987) and is a widespread predator of aphids in many parts of the world (Franzmann 2002). This species is considered the most important natural enemy of aphids in many countries including Bulgaria, Ukraine, Italy, India and Turkmenistan (Kontodimas and Stathas 2005). In China, it is one of the most common species in agricultural ecosystems such as wheat, tobacco, cotton, vegetable and orchards (Wang et al. 1984; Pang 1993; Yang et al. 1997).

Obrycki and Orr (1990) studied the suitability of three prey species viz. *Acyrthosiphin pismum* Harris, *Ropalosiphum maidis* (Fitch) and eggs of *Ostrinia nubilalis* (Hubner) for the coccinellid *H. variegata*. Developmental times of Nearctic *H. variegata* were not influenced by larval prey. *A. pismum* was found to be a highly suitable larval prey for Nearctic populations of this predator. In corn, the coccinellid can develop on *R. maidis*, but first instars cannot utilize *O. nubilalis* eggs as an alternate food source.
ElHag and Zaitoon (1996) studied the biological parameters of *H. variegata* reared on *Brevicoryne brassicae* L. The total developmental time was noted as 20.1 days and per cent survival was 61.8%. The oviposition period was noted as 26.0 days, fecundity 276.3 eggs per female and per cent egg hatching as 81.8%. The adults survived for 71.8 days. Lanzoni *et al.* (2004) studied the biological traits and life table parameters of *H. variegata* on *Myzus persicae* Sulzer as prey. The reported mean developmental time of 18.1 days and pre-imaginal survival of 49.1%. The fecundity was reported as 841.7 eggs per female, and the oviposition period and adult longevity was noted as 32.2 and 36.9 days, respectively.

Kontodimas and Stathas (2005) studied some biological characteristics of *H. variegata* on *Dysaphis crataegi* (Kaltenbach) as prey and reported that the total fecundity ranged between 789 and 1256 eggs, while the mean fecundity was 959.6 eggs. The greatest proportion of eggs (45%) was oviposited in clutches of 11–20 eggs and the mean generation time noted was 34.0 days.

He *et al.* (2006) studied the influence of three aphid species on development, survival and reproduction of *H. variegata* at 25°C in the laboratory. The results indicated that there were significant differences in the durations of different developmental stages, survival, generation time, longevity, weight and fecundity of adults while reared with these three species of aphids. The generation time, adult longevity, oviposition duration, adult weight and fecundity were 22.7 days, 38.6 days, 16.2 days, 6.2 mg and 149.7 eggs, respectively, while reared with *Macrosiphum avenae* (Takahashi). They were 24.6 days, 31.5 days, 20.1 days, 6.0 mg and 100.5 eggs, respectively, while reared with *Hyalopterus amygdale* (Blanchard). The same figures for *Aphis*
gossypii Glover as prey were 28.6 days, 25.5 days, 6.2 days, 4.2 mg and 45.3 eggs, respectively. A. variegata displayed a decreasing preference on the three species of aphids in the following order: M. avenae, H. amygdale and A. gossypii.

Rebolledo et al (2009) reported that H. variegata required 190.32 ± 10.2 degree-days to complete a generation considering 10°C as the threshold temperature, the one recommended for the majority of coccinellids. H variegata showed a life cycle of 17.3 ± 0.93 days varying in a range of 16 to 21 days reared on A. pisum. The pupa stage showed the longest duration with 32% of the life cycle total time, followed by the egg stage and fourth larval stage with 17% each. There is a discrepancy between this result and the one reported by Badawy (1969) who indicates a mean duration of 10.7 days for the life cycle feeding on Aphis gossypii. Mitchels and Bateman (1986) mention duration of 15.1 days at 25 °C for the H. variegata life cycle, whereas the life cycle decreased to 7.8 days at 30 °C.

Jafari and Shoushtari (2010) studied the effect of different temperatures, 20, 25 and 30°C on developmental period of the coccinellid H. variegate under laboratory conditions, feeding on Aphis fabae Scopoli. The development periods from egg to adult were 27.75, 21.3 and 15.4 days at 20, 25 and 30°C, respectively. The threshold temperatures ranged from 2.47°C for the first instar larvae to 14.63°C for the pupae. However, the threshold temperatures and thermal constant for whole generation from egg to adult were 7.93 °C with ± 1 range feeding on A. fabae.
Hodek (1962), Badawy (1969) and Rebolledo et al. (2009) reported that mating in *H. variegata* occurred between 2 and 5 days of life, registering the first oviposition two days later. Wu et al (2010) studied the effect of five host plants of *A. gossypii* on the population parameter of *H. variegata*. They observed that *H. variegata* completed its development from egg to adult emergence in 12.6–14.5 days at 25°C, depending on the host plant of its prey. This range is shorter than those reported elsewhere at the same temperature on *M. persicae* i.e. 18.1 days by Lanzoni et al. (2004) or 20.1 days on *B. brassicae* and *R. padi* by ElHag and Zaitoon (1996). On the other hand, the pre-imaginal survival of *H. variegata* ranged from 44.06 to 58.97%, depending on the host plant of its prey and not unlike the values reported by other such as 49.1% (Lanzoni et al. 2004) and 61.8% (ElHag and Zaitoon 1996).

Among the reproductive parameters, Wu et al (2010) reported that the total fecundity of *H. variegata* ranged from 599.29 to 667.12 eggs per female, depending on the host plant, which was smaller to that of Lanzoni et al. (2004) i.e. 841.7 eggs per female and that of Kontodimas and Stathas (2005) i.e. 959.6 eggs per female on then average.

Jafari (2011) studied the biology of *H. variegata* on the black bean aphid, *Aphis fabae* and reported that the mean of total larval period (1st instar to 4th instar) was 16.5±0.13. Kontadimas and Stathas (2005) observed that the total period of *H. variegata* was 15 days using *Dyaphis crataegi* as food, which is lower than the present finding. Grigorov (1977) observed that the total larval period of *H. variegata* varied from 17 to 19 days on bean aphid.
Jafari (2011) recorded that the 1st instar period was 3 to 4 days and on an average of 3.50±0.17 days. Lanzoni et al. (2004) reported that this period was 2 to 3 days using bean aphid as host. The mean duration of 2nd instar was reported as 3.05±0.20 days by Jafari (2011). Elhabi et al. (2000) found that the duration of 2nd instar of H. variegata varied from 2.5 to 3.5 days using bean aphid as a host. Lanzoni et al. (2004) reported that the duration of final instar larvae of H. variegata was 3 days. Kontadimas and Stathas (2005) found that the duration of 4th instar larvae of H. variegata varied from 2.8 to 3.6 days on cotton aphid. Similar result was reported by Jafari (2011) using Aphis fabae as prey. The average pupal period was reported as 3.10±0.07 days by Jafari (2011) on A. fabae and 4.15±11 days by Wang et al. (2004) when larvae were reared on Diuraphis noxia (Mordvilko).

The number of eggs laid per female was 587 to 1247 with an average 943.90±53.53 as reported by Jafari (2011). About 60 to 70% of total fecundity was observed within the first 23 days of ovipositional period. The mean hatching percentage was 82.86±3.12. Lanzoni et al. (2004) reported that the number of eggs deposited per female was 900±80.23 and 70% eggs hatched. Elhabi et al. (2000) observed that the fecundity of female varied from 800 to 900 eggs with mean 870.5 and with 79% average eggs egg hatchability.

Jafari (2011) reported that the longevity of the male beetle was shorter than the female. The longevity of the male beetles varied from 30 to 62 days with an average of 50±3.2 days whereas the longevity of the female beetles varied from 30 to 70 days with average of 55.5± 3.37 days. Elhag and Zaiton (1996) reported that the adult of H. variegata lived for 32 to 60 days. Elhabi et al.
(2000) found that the longevity of male and female adults was 44±2 and 61±9.89 days, respectively.

The pre-oviposition period of *H. variegata* was reported as 7 and 6.5 days respectively by Lanzoni *et al.* (2004) and Elhagh and Zaitoon (1996). Jafari (2011) noted the pre-oviposition period as was 6 to 7 days with an average of 6.20±0.13 days. Elhag and Zaitoon (1996) reported that the oviposition period of *H. variegata* lasted from 35 to 48 days using *A. fabae* as food while Jafar (2011) reported the period to last for 37 to 48 days. Grigorov (1977), Elhabi *et al.* (2000), Lanzoni *et al.* (2004) and Jafari (2011) reported that the incubation period was 3 to 4 days for the *H. variegata* eggs.

Kalushkov (1998) studied the suitability of ten aphid species (Sternorrhyncha: Aphididae) as prey for *Adalia bipunctata*. Six of them viz., *Euceraphis betulae* L., *Cavariella konoi* Takahashi, *Liosomaphis berneridis* (Kalt.), *Acyrthosiphon ignotum* Mordvilko, *Aphis farinose* Gmelin and *Macrosiphoniella artemisiae* B. were recorded as essential prey for the coccinellid. *Eucallipterus tiliae* L. and *Euceraphis betulae* were the most suitable prey according to the rate of larval development, larval mortality and adult fresh weight. *Aphis farinosa*, *Aphis fabae* and *Aphis spiraephaga* Muller were recorded as unsuitable or less suitable prey for the predator because of high larval mortality or slow larval development.

Ozder and Saglam (2002) determined the developmental time and mortality rate of *A. bipunctata* when feeding on five aphid species namely *Metopolophium dirhodum* (Walker), *Sitobion avenae* (F.), *Rhopalosiphum padi* (L.), *Hyalopterus pruni* (Geoffr.) and *Myzus cerasi* F. Larval period varied from
10.29 to 13.4 days and the development time from 16.79 to 20.79 days for *A. bipunctata* on different prey species. Lowest mortality was noted on *M. cerasi* (18%) and highest on *H. pruni* (50%).

Rana *et al.* (2002) recorded the life history parameters of *A. bipunctata* over a period of six generations when selected for improved performance on a diet of pea aphid, *Acythosiphon pisum* (Harris) and the black bean aphid, *Aphis fabae* Scopoli, separately. On *A. pisum*, the larval period decreased from 11.58 to 10.41 days while as the male and female longevity increased from 137.4 to 142.4, and 155.44 to 160.11 days, respectively over the six generations. The fecundity increased from 927.80 to 994.06 eggs per female. The larval duration decreased from 17.18 to 11.53 days using *A. fabae* as diet. The fecundity showed impressive progress from 416.00 to 949.00 eggs per female over the six generations.

Lanzoni *et al.* (2004) studied the biological traits and life table parameters of *A. bipunctata* on *M. persicae* as prey. The reported mean developmental time of 18.4 days and pre-imaginal survival of 25.0 % for *A. bipunctata*. The fecundity was reported as 537.0 eggs per female, and the oviposition period and adult longevity was noted as 24.7 and 16.0 days, respectively.

Development, reproduction and life tables of *A. bipunctata* were studied at three temperatures (19, 23 and 27°C) on a mixture of frozen pollen and *Ephestia kuehniella* Zeller eggs as a factitious food and on the aphids *M. persicae* and *A. pisum* as natural foods by Jalali *et al.* (2009). Development time of *A. bipunctata* on all tested diets decreased with increasing temperature. Mortality was lowest at 23°C, averaging 44.5%, 42.6% and
24.3% on factitious food, *A. pisum* and *M. persicae* respectively. The shortest developmental time from egg to adult at this temperature was observed on factitious food (18.55 days). However, the factitious food was inferior to the aphid diets in terms of reproduction, yielding the longest pre-oviposition period, shortest oviposition period and lowest fecundity. The mean oviposition rate at 23°C varied from 19.94 to 25.03 eggs day) on factitious food and *M. persicae* respectively.

Bonte *et al.* (2010) examined the nutritional value of *Ephestia kuehniella* eggs plus bee pollen, pea aphids, *A. pisum* and mixtures of bee pollen and cysts of *Artemia franciscana* Kellogg and/or a lyophilized artificial diet based on bovine meat and liver on the development and reproduction of *A. bipunctata*. Over 84% of first instars fed on *E. kuehniella* eggs plus pollen or aphids survived to adulthood. Feeding predator larvae on pollen combined only with *A. franciscana* cysts or artificial diet yielded 40–55% immature survival, but survival increased to 74% when all of these components were mixed. Lifetime fecundity was superior on *E. kuehniella* eggs plus pollen (1,864 eggs) to that on the other diets (264–889 eggs).

Omkar and Srivastava (2003) studied the re-imaginal development, immature survival, and reproduction of a ladybird, *Coccinella septempunctata* Linnaeus, in response to six aphid species, *Aphis craccivora* Koch, *Aphis gossypii* Glover, *Aphis nerii* Boyer de Fonscolombe, *Lipaphis erysimi* (Kaltenbach), *Myzus persicae* (Sulzer) and *Uroleucon compositae* (Theobald) to quantify their relative suitability as prey. Pre-adult development was shortest (13.93 ± 0.12 days) when fed on *L. erysimi* and longest (22.85 ± 0.10 days) on *A. nerii*. Immature survival, adult emergence, growth index, relative growth rate,
development rate, male and female longevity, oviposition period, fecundity and hatching percent were maximal, i.e. 73.47±0.89%, 90.07±1.43%, 8.62±0.23, 1.52 0.02, 0.07, 81.10±1.26 days, 85.70±1.45 days, 69.80±1.32 days, 1764.10±8.46, and 87.88±1.05, respectively when C. septempunctata were fed on L. erysimi. The same parameters were minimal, i.e. 43.86±1.33%, 71.65±2.75%, 2.02±0.08, 0.49±0.02, 0.04, 44.40±1.39 days, 53.50±1.00 days, 16.40±0.60 days, 203.20±11.83, and 48.68±2.06, respectively on A. nerii. The weights of different ladybird life stages were maximal after feeding on L. erysimi and minimal on A. nerii. Regression analyses of the data revealed linear relationships between development rate and weight of adult; daily prey consumption and relative growth rate; log weight of adult male and female; and longevity and fecundity of female. On the basis of these findings, the order of suitability of aphid species for C. septempunctata is L. erysimi > M. persicae > A. craccivora > A. gossypii > U. compositae > A. nerii. Similar order of prey suitability has been recorded for Cheilomenes sexmaculata (Fabricius) (Chaudhary et al., 1983) and Brumoides suturalis (Fabricius) (Gautam, 1990).

Ashraf et al. (2010) studied development and reproductive potential of the Coccinella septempunctata L. under laboratory conditions to determine its fecundity and longevity on natural and artificial diets. Tests were made on laboratory rearing materials and all development stages were carefully recorded. Success ratios in these experiments were a matter of logistic and synchronization of these life cycles, the plant phytophagous and entomophagous insects. A positive correlation was obtained between food consumption and egg production, so fecundity of C. septempunctata is
affected by the type of food. *C. septempunctata* consumed highly significant (*Rhopalosiphum maidis*) 32.2 aphids per day as compared to other treatments. Oviposition response was the maximum on these beetles which consumed 1st and 2nd instars of *Macrosiphon roseae*. *C. septempunctata* reared under artificial diet showed more longevity 41.6 days on plain water.

Ali and Rizvi (2007) studied the performance of *C. Septempunctata* on five aphid species *Lipaphis erysimi, Aphis craccivora, Hyadaphis coriandri, Rhopalosiphum nymphae* and *Macrosiphum rosae* under controlled conditions (25 ± 1 °C, 70 ± 5 % RH and 12 h L: 12 h D). The overall development period of *C. septempunctata* was found significantly longer on *L. erysimi* and shorter on *M. rosae*. The grub, however, required significantly longer developmental period on *H. coriandri* and shorter on *M. rosae*. Nonetheless, the adult longevity was higher on *L. erysimi* and shorter on *M. rosae*. Between sexes, the female required longer period for its development than male with respect to all aphid species. With regard to predation, the grubs consumed maximum *H. coriandri*, whereas, adult preferred *Lipaphis erysimi*. The last larval stage (grub 4), irrespective of aphid species, devoured more aphids than the other grub stages. The predation by female of all aphid species was more as compared to male. The overall predation by *C. Septempunctata* was significantly higher on *L. erysimi* than other species. A linear correlation curve showed the dependency of predation on the developmental period of *C. Septempunctata*. 
2.3 Predation potential of predominant ladybird beetle species

In most of the studies, the functional response of *H. variegata* to different densities of aphids has been determined to be type II (Dixon, 2000). However, in a studies quoted by Jafaria and Goldaseth (2009), *H. variegata* displayed a type III functional response to *A. gossypii*.

Fan and Zhao (1988) determined the functional response of *H. variegata* to different densities of *Aphis gossypii* in the laboratory. Larvae in the 4 instars were fed daily with 5-35, 10-40, 20-50 and 30-60 aphids/larva, respectively. Predation by *H. variegata* was shown to increase with prey density, but differed according the development stage of the predator. The highest daily predation was 6.7, 36.4, 77.5 and 81.3 aphids for the 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} instar larva, respectively, and 68.0 aphids for the pre-oviposition adult.

Chen et al. (2003) worked out the predatory function of the adults and 4\textsuperscript{th} instar larva of *H. variegata* to *Aphis citricola* Van der Goot in laboratory. The results showed that the equation-II of Holling could describe the functional responses of the adults and 4\textsuperscript{th} instar larva of *H. variegata* to the density of *A. citricola*. Yang et al. (2003) studied the predatory function and mutual interference of adult *H. variegata* on *Therioaphis trifolii* (Buckton). The results showed that the functional response models belonged to the type II of Holling. The searching efficiency decreased with the increasing prey density and decreased with the increase of predator density as the predator individuals interfered one another.

Al-Doghairi (2004) evaluated the feeding rates of adults and larvae of *H. variegata* on the cereal aphid, *Schizaphis graminum* (Rondani) as prey. The
adults consumed 16.8, 17.2 and 24.2 aphids per day while the 4th instar larvae consumed 26.0, 27.8 and 36.2 aphids per day when the corresponding offered aphid densities were 30, 40 and 50, respectively. The adults were found to consume 81.7% and 50.2% of the prey when the offered prey density was 30 and 40 aphids per predator, respectively. The corresponding figures for 3rd and 4th instar larvae were 94.2, 72.5%, and 89.0 and 68.2%, respectively.

Khan and Mir (2008) determined the functional response of adult *H. variegata* feeding on the green apple aphid, *Aphis pomi* De Geer and reported a type II response. The estimated attack rate and handling time was 2.55680 and 1.20730, respectively. Jafari and Goldaseth (2009) determined the functional response of adult females of *H. variegata* on *Aphis fabae* (Scopoli). The aphid densities used where 20, 40, 60, 80, 100, 120, 140, 160 and 180. Logistic regression suggested a type II response on *A. fabae* adults. Searching efficiency and handling time were estimated as 0.00078 and 0.1774 respectively.

Farhadi et al. (2010) reported that all larval instars and adult males and females of *H. variegata* exhibited type II functional responses on different densities of the prey, *Aphis fabae* (Scopoli). The rate of searching efficiency and handling time were estimated as 0.063 h⁻¹ and 6.933 h for first instar, 0.059 h⁻¹ and 3.343 h for second instar, 0.103 h⁻¹ and 1.909 h for third instar, 0.114 h⁻¹ and 0.455 h for fourth instar, 0.159 h⁻¹ and 1.194 h for male, 0.093 h⁻¹ and 0.409 h for female, respectively. Thus, handing time decreased from first instar to female. Handling times of males were significantly greater than those of females. The most effective stages of *H. variegata* were females,
fourth instars, and males. The efficiency of females was nearly three times greater than that of males.

Saleh (2010) worked out the functional response of the adult females of the predatory coccinellid *H. variegata* to various densities of *Brachycaudus helichrysi* (Kaltenbach) aphid infesting Chrysanthemum. The predator exhibited type II response. The estimated coefficient of attack rate was 1.9505 and the handling time was 0.0034.

Khan and Zaki (2007) studied the functional response of the *Coccinella septumpunctata* Linnaeus to increasing density of aphids and numerical response with fixed density of prey (aphids) and increasing densities of *C. septumpunctata*. The functional response curve having a curvilinear rise to plateau as prey densities increased from 1 to 64 and curve predicted by the Holling disk equation did not differ significantly from the observed functional response curve. The rate of successful search and the handling time predicted by disk equation were 0.0566 and 1.473 in case of *C. septumpunctata*. The numerical response having a linear rise to a plateau as aphid density fixed (20) with varying densities of *C. septumpunctata* from 1 to 7.

Khan and Mir (2008) determined the functional response of adult females of *A. tetraspilota* on the green apple aphid *Aphis pomi* DE Geer and reported a type II response. The attack rate and handling time were noted as 2.04209 and 1.32890.

Khan (2009) conducted a study to assess the functional response of different life stages of the predacious coccinellid, *Adalia tetraspilota* feeding on various densities of cabbage aphid, *Brevicoryne brassicae* (L.) under controlled
conditions. It revealed that all stages of A. tetraspilota exhibit Type II functional response curve. The fourth instar larva consumed more aphids (28.40 aphids / day) followed by adult female (25.06 aphids / day), third instar larva (24.06 aphids / day), second instar larva (21.73 aphids / day), adult male (20.06 aphids / day) and first instar (13.06 aphids / day). The maximum search rate with shortest handling time was recorded for fourth instar larva ($r^2=0.6383$) followed by adult female ($r^2=0.6264$).