Biodiversity, Biology and Predation of Coccinellids in Horticulture Ecosystem

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(2010-A-844-M)

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Sher-e-Kashmir

University of Agricultural Sciences & Technology of Kashmir

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THESIS

Submitted **to**

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2012

Dedicated
to
the
environment

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Entomology,
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CERTIFICATE – I

This is to certify that the thesis entitled, **“Biodiversity, Biology and Predation of Coccinellids in Horticulture Ecosystem”** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science in Agriculture (Entomology)** to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Mohd Abas Shah (Regd. No. 2010-A-844-M)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

(Dr. Akhtar Ali Khan)
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Endorsed

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CERTIFICATE – II

We, the members of the Advisory Committee of **Mr. Mohd Abas Shah (Regd. No. 2010-A-844-M)**, a candidate for the degree of **Master of Science in Agriculture (Entomology)** have gone through the manuscript of the thesis entitled, **"Biodiversity, Biology and Predation of Coccinellids in Horticulture Ecosystem"** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the award of the degree.

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CERTIFICATE – III

This is to certify that the thesis entitled, **“Biodiversity, Biology and Predation of Coccinellids in Horticulture Ecosystem”** submitted by **Mr. Mohd Abas Shah (Regd. No. 2010-A-844-M)** to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Master of science in Agriculture (Entomology)** was examined and approved by the Advisory Committee and External Examiner on …………….

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ABSTRACT

The biodiversity of predaceous coccinellids was worked out in major fruit (district Baramulla) and vegetable (district Budgam) growing belts of Kashmir valley during the cropping season of 2011. Two locations from each district, with both pesticide-treated and pesticide-free orchards of fruit crops including apple, pear and cherry and vegetable fields including kale, knolkhol, cabbage and cauliflower were sampled for adult coccinellids. The study revealed the presence of 17 and 12 species of predaceous coccinellids in fruit and vegetable ecosystems, respectively. Higher values of biodiversity indices were noted for fruit orchards as compared to those of vegetable fields. Less intensively cultivated crops like pear, kale and knolkhol were found to be comparatively rich in ladybeetle diversity. *Coccinella septempunctata*, *Hippodamia variegata* and *Adalia tetraspilota* turned out to be the predominant ladybeetle species in fruit orchards in decreasing order while as *A. tetraspilota* was noted as the predominant species in vegetable ecosystems followed by *H. variegata* and *C. septempunctata*. Pesticide treated ecosystems were found to support less number of ladybeetle species. The sprayed orchards were found to have 14 species of ladybeetle as compared to 17 in unsprayed ones. Similarly, only 10 species were recovered from the sprayed vegetable gardens as compared to 12 from unsprayed gardens. The biodiversity indices indicated appreciable effect of pesticide application on the coccinellids assemblages.

The studies on the biology of *Adalia tetraspilota* and *Hippodamia variegata* revealed that both *Aphis pomi* and *Brevicoryne brassicae* were suitable preys for the two predators in question however, the predators performed better when fed upon *B. brassicae*. The prey densities also affected the developmental parameters of the two predators appreciably and the optimal growth and development was noted in the prey density range of 40-80 aphids per day per predator. The larval period lasted for 20.91 and 16.07 days on *A. pomi* and *B. brassicae*, respectively for *H. variegata*, and 17.38 and 14.7 days, respectively for *A. tetraspilota*. For *A. tetraspilota*, the larval period was limited to duration of 13.04 days at the highest prey density (160) and extended to a period of 21.0 days at the lowest prey density (10). For *H. variegata*, the larval period increased from 13.27 to 28 days as the prey density decreased from 160 to 10. The eggs of the parents that were fed on *B. brassicae* hatched earlier as compared to those fed on *A. pomi*. Appreciable variation in survivorship of larvae, prepupal and pupal period was noted by varying the prey species and prey abundance. The longest reproductive period (oviposition period) with shortest non-reproductive periods (pre-oviposition and post-oviposition periods) were noted for females fed upon *B. brassicae* as compared to those fed upon *A. pomi*. . Reproductive output was appreciably higher for females fed on *B. brassicae* (more suitable prey) and the fecundity drastically decreased under food shortage conditions. Hatchability of eggs was found to be strongly dependent on the feeding history of the.

Studies on functional response of various predatory stages of *A. tetraspilota* and *H. variegata* on three different prey species *Aphis pomi*, *Aphis craccivora* and *Brevicoryne brassicae* using different prey densities revealed type II functional response. The polynomial logistic regression analysis indicated significant negative values for linear coefficient which confirmed the type II response of various growth stages of the two predators on various prey species used. The 4th instar larvae of both the predators consumed highest number of aphids, irrespective of the species, closely followed by the adult females. Among the two coccinellid predators used in the study, the predatory stages of *H. variegata* consistently consumed more number of prey individuals as compared to *A. tetraspilota*. The study revealed the estimates of maximum number of aphids attacked per day as 33.5 for 4th instar larvae and 32.8 for adult females of *H. variegata* when *A. craccivora* was used as prey. The lowest handling times were regularly noted for 4th instar larvae and adult females of both the predators. Among the three prey species, lowest handling time was exhibited by the 4th instar larvae of *H. variegata* on *A. craccivora* (0.668 h) followed by *B. brassicae* (0.734 h) and *A. pomi* (0,953 h). Among the two predator species, *H. variegata* is better as a bioagent as per the laboratory studies and among the prey species tested, the predators may respond best to the patches of *A. craccivora*.

Key words: *Adalia tetraspilota*, Aphids, Biodiversity, Biology, Coccinellids, Functional response, *Hippodamia variegata*,

Signature of student　　　　　　　　Signature of Major Advisor

Dated: ……………….　　　　　　　　Dated: …………………….

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"Facts without theory is chaos, theory without facts is fantasy"

(A. F. G. Dixon)

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Mohd Abas Shah

Place : Shalimar, Srinagar

Dated : ……………………

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CHAPTER - 1

INTRODUCTION

Ladybird beetles (Coccinellidae: Coleoptera) are important predators in natural and agricultural habitats (Hodek and Honek, 1996). In agricultural habitats, coccinellids prey upon many economically important pests, including aphids, mealy bugs, scale insects, thrips, leaf hoppers, mites and other soft bodied insects (Dixon, 2000; Khan *et al*., 2009). The predator species mostly feed on either aphids or coccids, with a few feeding on both types of prey (Weber and Lundgren, 2009). Owing to their seasonal synchrony with specific preys, high foraging performance and high reproductive efficiency, the coccinellids possess the potential to be effectively employed in integrated pest management programmes (Lanzoni *et al*., 2004). This is particularly important owing to the growing concern on various hazards to human and environmental health besides the problems like pesticide resistance, pest resurgence and secondary pest outbreaks resulting from the indiscriminate use of pesticides (Huffakar and Dahlsten, 1999)

A perusal of the history of biological control reveals that the importation of ladybeetle, *Coccinella undecimpunctata* Linneaus, to New Zealand from Britain in the year 1874 for the control of aphid pests was the first use of a ladybeetle for classical biological control (Dixon, 2000). But the introduction of the vedalia beetle, *Rodolia cardinalis* Mulsant, from Australia to California in 1888 to control the cottony cushion scale, *Icerya purchase* Maskel, which threatened the citrus industry, is widely regarded the most successful case of biological pest control (Majerus, 1994). Ladybeetles are also being used extensively to control aphids and coccids through augmentation by translocation or mass rearing and release. The translocation of *Coccinella septempunctata* L. from wheat to cotton is a strategy widely used to control the cotton aphid, *Aphis gossypii* Glover in central and southern China (Pu, 1976). In India, augmentative releases of ladybeetles like *Chilocorus nigrita* F., *Cryptolaemus montrouzieri*

Mulsant, *R. Cardinalis* etc. are recommended for the management of different crop and fruit pests (Singh, 2004).

The word biodiversity is a contraction of biological diversity. It refers to the variety within the living world. Thus, the term encompasses different ecosystems, species, genes and their relative abundance (OTA, 1987). The exploration of biodiversity of the biocontrol agents is the fundamental step in any biological control programme (Kidd and Jervis, 2005).

The effectiveness of particular biocontrol ptogramme depends on various innate characteristics (biology, ecology, reproduction, predation potential etc.) of the bioagent used besides the prevailing environmental conditions and the management tactics adopted (Dixon *et al.*, 1997). The success of biological control agents is largely dependent on their high searching efficiency, host specificity and the low generation time ratio between the bioagent and the target pest species (De Bach and Rosen, 1991; Dixon, 2000). Biology plays an important role in mass rearing of bioagents and their utilization in pest management programmes as both classical and augmentative biocontrol necessitate the mass production of the natural enemies. The success or failure of a biological pest control programme is dependent on biological peculiarities of the bioagent to a large extent. Besides, biology can also aid in correlating the probable phylogeny of the groups (Hajek, 2004).

Life parameters such as rate of development, reproductive output etc. are at the beck and call of various biotic and abiotic environmental factors. What is seen is the outcome of the interplay between the genetic makeup and the prevailing environment. Among the biotic factors, food (quality and abundance) is perhaps the most influential factor (Jervis *et al.*, 2005). As far as the predaceous coccinellids are concerned, the effect of prey species on various life parameters has thoroughly been investigated. As such, preys are categorized into essential, alternative and rejected prey, on the basis of quantitative data on developmental parameters viz. rate of development, survival and reproductive capacity (Hodek and Honek, 1996).

One of the fundamental aspects of predator-prey interaction is the relationship between prey density and consumption rate of the predator, referred to as functional response. It describes the rate at which a predator kills its prey at different prey densities and can thus determine the efficiency of a predator in regulating prey populations (Murdoch and Oaten, 1975). It is recognized that functional responses derived from laboratory studies may bear little resemblance to those that could be measured in the field (Wang *et al*., 2004). Fan and Zhao (1988) pointed out that the relation between functional responses observed in the laboratory and field performance of natural enemies is not clear. However, they pointed out that studies of functional response in the laboratory could be used to infer basic mechanisms underlying natural enemy-prey interactions. Such studies provide valuable information for biological control programs. ElHag and Zaitoon (1996) observed that during biological control evaluation processes, comparisons of parameter values of two or more predators may be more meaningful and convenient.

The functional response curves may represent an increasing linear relationship (Type I), a decelerating curve (Type II), or a sigmoidal relationship (Type III). Coccinellid predators show all the three types of functional responses (Hodek and Honek, 1996). The type of response varies with prey and predator species as well as the predatory stage of the coccinellid being evaluated (Koch *et al*., 2003)

In Kashmir division of Jammu and Kashmir State, the biodiversity of predaceous coccinellids has earlier been worked out for Srinagar district only (Khan *et al*., 2009). This and earlier studies indicate that *Hippodamia (Adonia) variegata (*Goeze) and *Adalia tetraspilota* (Hope) are most abundant species of predaceous coccinellids in agro-ecosystems of Kashmir valley. However no such studies have been carried out in other districts of the valley. Similarly no studies have been carried out towards the study of relative suitability of different prey species for these predators as well as their relative predation potential.

Keeping in view the aforementioned facts, present investigation was carried out with the following objectives:

1. To study the biodiversity of predaceous coccinellids in horticulture ecosystem.
2. To study the biology and functional response of *Hippodamia variegata* (Goeze) and *Adalia tetraspilota* (Hope) on different aphid species.

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 Biodiversity 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, Micraspis, 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* (Hope) 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 septumpunctata*, *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 *Cheilomenes 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 *Hippodamia variegata* (Goeze)

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 pisum* 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. pisum* 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^{o}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* (Tajahashi). 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 10ºC 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 ºC for the *H. variegata* life cycle, whereas the life cycle decreased to 7.8 days at 30 ºC.

Jafari and Shoushtari (2010) studied the effect of different temperatures, 20, 25 and 30^{0}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^{o}C, respectively.

The threshold temperatures ranged from 2.47^{o}C for the first instar larvae to 14.63^{o}C for the pupae. However, the threshold temperatures and thermal constant for whole generation from egg to adult were 7.93 ^{o}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^{o}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 in-star) 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 Jafari (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.

2.3 Predation potential of *Hippodamia variegata*

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 1st, 2nd, 3rd and 4th 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 4th 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 4th 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.

2.4 Biology of *Adalia tetraspilota* (Hope)

Adalia tetraspilota is most abundant predatory coccinellid in Kashmir and has been observed feeding on *Aphis pomi* De Geer, *Myzus persicae, Lipaphis erysimi, Brevicoryne brassicae, Aphis fabae, Aphis craccivora* Koch, etc. (Khan *et* *al*., 2009). In Pakistan, it has been reported in Chitral Town and Drasan (Khan *et al*., 2007a). This species has also been reported from Murree (Pakistan) feeding on *Adelges* spp. and *Quadruspidiotus perniciosus* by Irshad (2001) and from Nepal by Canepari (1997).

No reports were found about the studies on biology or ecology of *A. tetraspilota*. Hence the literature concerning the representative member of *Adalia* genus i.e. *Adalia bipunctata* Linnaeus has been referred to.

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, *Acyrthosiphon 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^{o}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^{o}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^{0}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).

2.5 Predation potential of *Adalia tetraspilota* (Hope)

As with biology and ecology, no reports were found on functional response of *Adalia tetraspilota* except those of Khan and Mir (2008) and Khan (2009). 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).

CHAPTER - 3

MATERIALS AND METHODS

The materials used and methods adopted for carrying out the proposed studies on coccinellids are described parameter-wise as follows.

3.1 Biodiversity of predaceous coccinellids in horticulture ecosystem

The biodiversity of predaceous coccinellids was studied in two types of horticultural ecosystems namely, fruit and vegetable ecosystems. Field sampling was conducted to collect the predaceous coccinellid fauna from the economically important crops in the Kashmir valley. The crops covered were: apple, pear and cherry among the fruit crops and kale, knolkhol, cabbage and cauliflower among the vegetable crops. To appreciate the effect of pesticide application on biodiversity, both pesticide-treated (sprayed) and pesticide free (unsprayed) orchards/ vegetable gardens were selected for each crop. Only the adult coccinellids were collected for the study.

3.1.1 Study sites

The study covered the major fruit and vegetable growing areas of the valley namely, district Baramulla for fruit ecosystems and district Budgam for the vegetable ecosystems. Two locations from each district were selected to reduce the spatial heterogeneity existing in the distribution of coccinellid fauna. The locations were Sopore (74^{o}24′ E and 34^{o}20 ′ N, altitude; 1587 metre above mean sea level (amsl)) and Pattan (74^{o}34′ E and 34^{o}8′ N, altitude; 1587 metre amsl) from district Baramulla, and Chadoora (74^{o}47′ E and 34^{o}5′ N, altitude; 1591 metre amsl) Narkara (74^{o}45′ E and 34^{o}2′ N, altitude; 1585.56 metre amsl) and from district Budgam. Two orchards/vegetable gardens; one receiving the pesticides and the other pesticide free (at least for the last 5 years) were sampled for coccinellid fauna from each location per crop. Only the commercial cultivars/varieties of the selected crops were sampled.

3.1.2 Sampling scheme

The sampling was carried out from the first week of April till September, 2011 (for 7 months) for the fruit crops and April to July (5 months) for the vegetables. The sampling was done at fortnightly interval. Ten fruit trees from each fruit orchard and five quadrates (1 square meter, each) from each vegetable garden, selected randomly, were sampled. Each sampling unit was searched for predaceous coccinellids for 10 minutes. The coccinellids were collected by vial tapping or hand picking method from the foliage. Empty plastic vials (5x3 cm) were placed beneath the leaf blades or inflorescences and the coccinellids tapped loose with the cap. Smaller species were picked up with a moist finger or by small camel hair brush. The coccinellid specimen were killed in cyanide bottles and carried in duly labelled plastic vials (labels containing all pertinent information, viz. date of collection, location, crop etc.) to the laboratory. The samples were dried in oven at 60^{o}C, pinned with entomological pins for biodiversity count and stored in collection boxes. The specimens were got identified from National Bureau of Agriculturally Important Insects (NBAII), Bangalore.

3.1.3 Parameters of biodiversity

The data collected from the field sampling of predaceous coccinellid fauna was analysed to work out the various parameters of biodiversity as follows.

3.1.3.1 Diversity of predaceous coccinellids

Species diversity for each crop, location and type of ecosystem was worked out by adding up the total number of species found in each community.

3.1.3.2 Relative abundance

Relative abundance of different ladybeetle species for each crop, location and type of ecosystem was worked out by dividing the number of individuals of a species to the total number of individuals of all species for each community, expressed in percentage.

3.1.3.3 Species diversity index

In order to study the proportion of each species within the local community, species diversity index was computed based on Shannon-Wiener formula, also called the Shannon index or Shannon-Wiener index (Shannon, 1948).

$$\text{Species diversity Index (H)} = -\sum_{i=1}^{S}(P_i \log_e P_i)$$

Where,

H = Shannon-Wiener biodiversity index

P_i = Proportion of each species in the community

$\log_e P_i$ = Natural log of P_i

S = Number of species in the community.

3.1.3.4 Species richness index

In order to assess how the diversity of the population is distributed or organised among the particular species, species richness index (M_a) was calculated (Pielou, 1975).

Species richness index (M_a) = $S\text{-}1/ \log_e N$

Where,

S = Total number of species collected

N = Total number of individuals in all the species.

3.1.3.5 Species evenness index

With a view to understand the measure of how similar the abundance of different species is, species evenness index (J) was calculated to estimate the equitability component of diversity (Pielou, 1969).

Species evenness index (J) = $H/\log_e S$

Where,

H = Shannon-Wiener biodiversity index

S = Number of species in the community.

3.2 Biology and functional response of *Adalia tetraspilota* (Hope) and *Hippodamia variegata* (Goeze) on different aphid species.

The studies on biology and functional response of *Adali tetraspilota* (Hope) and *Hippodamia variegata* (Goeze) were carried out in the laboratory of the Division of Entomology, SKUAST-K, Shalimar, during 2011-2012. A detailed account of the materials used and methods adopted for carrying out the proposed investigations is described as follows.

3.2.1 Insect rearing

Three aphid species viz. *Aphis pomi* De Geer, *Aphis craccivora* Koch and *Brevicoryne brassicae* Linnaeus were used as diet for the studies on biology and functional response of two ladybeetle species namely, *Adalia tetraspilota* and *Hippodamia variegata*. To rear the predator coccinellids, aphid colonies were maintained in the laboratory on fresh twigs of apple (for *Aphis pomi*) / potted seedlings (*Aphis craccivora* on cowpea and *Brevicoryne brassicae* on kale seedlings), maintained in cages (18x18x18 cm), separately. The aphid colonies were collected from pesticide free apple orchard/ vegetable gardens in the University Campus.

The ladybeetle cultures were initiated by collecting the newly emerged overwintering adults of the respective coccinellid species. The adults of the two coccinellid species were maintained in plastic jars (height 20 cm and diameter 15 cm) with abundant supply of prey from the aphid colonies till oviposition. The rearing jars were provided with crumpled paper to act as ovipositing sites for the females. The eggs laid on the crumpled paper were collected every 24 hours and transferred to petri dishes for the proposed studies on the biology of the coccinellids. Coccinellid cultures were maintained on the three aphid species separately and different growth stages were harvested from time to time for the studies on functional response of the coccinellids.

All the cultures were maintained at a temperature of 25±2^{o}C and 65±5% relative humidity with a photoperiod of 14:10 light and dark hours in controlled environment rooms.

3.2.2 Effect of prey species and prey abundance on the biology of *Adalia tetraspilota* and *Hippodamia variegata*.

The effect of two aphid prey species namely, *Aphis pomi* and *Brevicoryne brassicae* at five abundance levels i.e. 10, 20, 40 , 80 and 160 aphids per individual of the predator, on some biological parameters of two coccinellid species viz. *Adalia tetraspilota* and *Hippodamia variegata* was studied under laboratory conditions. Newly emerged larvae of both the predators were taken from the stock cultures and fed separately with 3rd or 4th instar nymphs of the two aphid species, each at five abundance levels i.e. 10, 20, 40 , 80 and 160 aphids per predator per day. The aphids were fed on leaves of respective host plants in petri dishes. Each treatment was replicated 10 times for all parameters except larval survival and adult emergence which were replicated three times with 4 to 10 larvae or pupae in each replication. The studies were carried out at a temperature of 25±2^{0}C and 65±5% relative humidity with a photoperiod of 14:10 light and dark hours in controlled environment rooms.

The detailed methodology adopted for studying various parameters of biology of the two predator species is described as follows.

3.2.2.1 Larval period

To record the duration of each larval instar and total larval duration of both the predators fed on all the combinations of prey species and abundance levels, observations were made after every 24 hours. The presence of exuviae marked the transformation to the next instar.

3.2.2.2 Prepupal period

The 4th instar larvae in the later part of their life become sluggish, suspend feeding and stop movements before ecdysis to pupae. The larvae use the anal organ to fix themselves to the substratum with their head downwards. The time period between inactivation and ecdysis to pupal stage was recorded as prepupal period.

3.2.2.3 Pupal period

At the ecdysis to pupa, the exuvium was sloughed off from the pupa right up to the point where the cauda is attached to the substratum. The duration between pupation and emergence of adults was recorded as the pupal period.

3.2.2.4 Larval survival (%)

Per cent larval survival was worked out using the following formula:

$$\text{Larval survival (\%)} = \frac{\text{Number of pupae formed}}{\text{Number of 1st instars used}} \times 100$$

3.2.2.5 Adult emergence (%)

Percent adult emergence was worked out using the following formula:

$$\text{Adult emergence (\%)} = \frac{\text{Number of adults emerged}}{\text{Number of pupae used}} \times 100$$

3.2.2.6 Adult longevity

Adult longevity was recorded as the time period from the emergence of adults from the pupae till their death. Longevity of both male and female adults was recorded.

3.2.2.8 Pre-oviposition period

The pre-oviposition period worked out using 10 mated females of both the predators for each of the 10 treatment combinations, as the time period from adult emergence to initiation of egg-laying.

3.2.2.9 Oviposition period

The egg-laying by the mated females under consideration was observed daily and the duration in days from initiation of egg-laying till its termination was recorded as oviposition period.

3.2.2.10 Post-oviposition period

The time period from termination of egg-laying till the death of the mated females was recorded as the post-oviposition period.

3.2.2.11 Fecundity

The cumulative number of eggs laid by a single female throughout its oviposition period was recorded as the fecundity. During oviposition period, crumpled paper was added to the petri dishes containing the mated females to provide oviposition sites. The paper was replaced daily and the number of eggs laid was counted. The same eggs were used to work out the incubation period and hatchability percentage.

3.2.2.12 Incubation period

Incubation period of the eggs i.e. the time period elapsed from laying to hatching, was recorded for 100 eggs in each replication of all 10 treatment combinations for both the predators. The number of eggs hatching was recorded daily till no more eggs hatched and the weighted mean of eggs hatching every day and time period elapsed was calculated to work out the incubation period.

3.2.2.13 Hatchability (%)

The hatchability of eggs was determined as the percentage of eggs hatched successfully out of the total number of eggs kept under observation (100 eggs per replication). The eggs were observed daily and the total number of eggs hatching was counted till no more eggs hatched.

3.2.2.14 Statistical analysis

The data on the duration of various growth and developmental stages, fecundity and hatchability was subjected to analysis of variance in factorial completely randomized design (CRD) and least significant difference (LSD) test for the comparison of means. The analysis was done using R-software (R Development Core Team, 2008).

3.2.3 Functional response of *Adalia tetraspilota* and *Hippodamia variegata* to different aphid species

The functional response of 1st, 2nd, 3rd and 4th larval instars and adult male and female of *Adalia tetraspilota* and *Hippodamia variegata* to three aphid species namely, *Aphis pomi*, *Aphis craccivora* and *Brevicoryne brassicae* was determined under laboratory conditions. The different larval instars and adults of both the predators under consideration were taken from the stock cultures for the investigations. The larvae and adults were starved for 24 hours in vials individually before the experiments to minimize individual hunger levels as suggested by Nakamura (1977). Five aphid densities were used to work out the functional response i.e. 10, 20, 40, 80 and 160 for all the three species of aphids. The predators were introduced individually into the petri plates containing definite number of aphids per petri dish on excised leaves of respective host plants stuck to agar medium. The aphids were introduced before the predators so that they could disperse and the predators may have to search for the aphids

The aphid densities 10 and 20 were replicated 15 times for each instar of both the predators while as the aphid densities 40, 80 and 160 were replicated only 10 times. Greater number of replications was allocated to lowest two densities to obtain more precise information about the initial part of the functional response curve. One treatment was also designed for natural mortality of the aphids. After 24 hours, the number of aphids consumed by the various instars of the predators was recorded by counting the remaining number of aphids present in each petri dish. The functional response of each instar of the two predator species to all the three aphid species was analysed for two aspects i.e. nature of functional response and the parameters of functional response (attack rate and handling time).

3.2.3.1 Nature of functional response

Prior to fitting the data to a particular Hollings' equation (Holling, 1959 and 1966), it's important to know the type of functional response exhibited by a particular instar of a predator to a particular prey species. Logistic regression model is such a tool that is used to determine the shape (type) of functional response by taking into consideration the proportion of prey eaten (N_a/N_0) as a function of prey offered (N_0) (Juliano, 2001). Hence the data was fitted to the following polynomial function that describes the relationship between N_a / N_0 and N_0:

$$\frac{N_a}{N_0} = \frac{\exp\left(P_0 + P_1 N_0 + P_2 {N_0}^2 + P_2 {N_0}^3\right)}{1 + \exp\left(P_0 + P_1 N_0 + P_2 {N_0}^2 + P_2 {N_0}^3\right)}$$

Where,

P_0 = Intercept

P_1 = Linear coefficient

P_2 = Quadratic coefficient

P_3 = Cubic coefficient

N_a = Number of prey eaten

N_o = Number of prey offered.

The coefficients are estimated using the method of maximum likelihood. If $P_1 > 0$ and $P_2 < 0$, the proportion of prey consumed is positively density dependent, thus describing a type III functional response. If $P_1 < 0$, the proportion of prey consumed declines monotonically with the initial number of prey offered, thus describing a type II functional response (Juliano, 2001). The coefficients of polynomial logistic regression were determined using the function “glm” in R-software (R Development Core Team, 2008).

3.2.3.2 Parameters of functional response

After the determination of type of functional response, the data i.e. the number of aphids preyed upon by different stages of coccinellids at different densities was analysed by fitting Rogers’ Type II Random Predator Equation (Rogers, 1972) with the help of non-linear least square regression to determine the parameters of functional response.

Rogers type II Random Predator Equation is given by

$$N_a = N_o (1 - \exp [a (T_h N_a - T)])$$

Where,

N_a = Number of prey eaten

N_o = Number of prey offered

a = attack rate

T_h = handling time

T = time of confinement (24 hours)

To determine the coefficients of attack rate and handling time using non-linear least square regression as suggested by Rogers (1972), the function “nls” provided by the R-software was used (R Development Core Team, 2008).

CHAPTER - 4

EXPERIMENTAL FINDINGS

The findings of the studies on biodiversity, biology and predation of coccinellids are presented as follows.

4.1 Biodiversity of predaceous coccinellids in horticulture ecosystem

The field sampling of coccinellids in various fruit and vegetable ecosystems under pesticide treated (sprayed) and pesticide free (unsprayed) conditions at the four locations of two districts revealed the following information.

4.1.1 Species diversity of predaceous coccinellids in horticulture ecosystem

The fruit ecosystems were found to support higher number of coccinellid species as compared to the short lived vegetable ecosystems. In all, 17 species of predaceous coccinellids were found in the fruit ecosystem (Table 1) and 12 in the vegetable ecosystem (Table 2). The 17 species belong to 15 genera and three subfamilies viz. Coccinellinae, Chilocorinae and Platynaspinae. Species namely, *Adalia tetraspilota* (Hope), *Calvia punctata* (Mulsant), *Cheilomenes sexmaculata* (Fabricius), *Coccinella septempunctata* Linnaeus, *Coccinella transversalis* Fabricius, *Harmonia dimidiata* (Fabricius), *Harmonia eucharis* (Mulsant), *Hippodamia variegata (*Goeze), *Illeis indica* Timberlake, *Oenopia conglobata* Linnaeus (subfamily Coccinellinae), *Priscibrumus uropygialis* (Mulsant) (subfamily Chilocorinae) and *Platynaspis saundersi* Crotch (subfamily Platynaspinae) were present in both fruit and vegetable ecosystems. *Aiolocaria hexaspilota* (Hope), *Callicaria superba* (Mulsant), *Propylaea luteopustulata* (Mulsant) (subfamily Coccinellinae), *Chilocorus infernalis* Mulsant and *Chilocorus rubidus* (Hope) (subfamily Chilocorinae) were found in the fruit ecosystem only. All the species are presented in Plate 1 to 3.

Table 1. Species diversity of predaceous coccinellids in fruit ecosystem of district Baramulla.

S. No	**Coccinellid species**	**Apple**				**Pear**				**Cherry**			
		Sopore		**Pattan**		**Sopore**		**Pattan**		**Sopore**		**Pattan**	
		US	**S**	**US**	**S**	**US**	**S**	**US**	**S**	**US**	**S**	**US**	**S**
A.	**Subfamily Coccinellinae**												
1.	*Adalia tetraspilota* (Hope)	+	+	+	+	+	+	+	+	+	+	+	+
2.	*Aiolocaria hexaspilota* (Hope)	+	–	–	–	–	–	+	–	–	–	–	–
3.	*Callicaria superba* (Mulsant)	+	–	+	–	+	+	+	+	–	–	–	–
4.	*Calvia punctata* (Mulsant)	+	+	+	+	+	+	+	+	+	+	+	+
5.	*Cheilomenes sexmaculata* (Fabricius)	+	–	+	–	+	+	+	–	+	+	+	+
6.	*Coccinella septempunctata* Linnaeus	+	+	+	+	+	+	+	+	+	+	+	+
7.	*Coccinella transversalis* Fabricius	+	–	+	–	+	+	+	–	+	+	+	+
8.	*Harmonia dimidiata* (Fabricius)	+	–	+	–	+	+	+	+	–	–	–	–
9.	*Harmonia eucharis* (Mulsant)	+	+	+	+	+	+	+	+	+	+	+	+
10.	*Hippodamia variegata* Goeze	+	+	+	+	+	+	+	+	+	+	+	+
11	*Illeis indica* Timberlake	+	–	+	–	+	–	+	–	+	–	–	–
12.	*Oenopia conglobata* Linnaeus	+	+	+	+	+	+	+	+	+	+	+	+
13.	*Propylea luteopustulata* (Mulsant)	+	–	–	–	+	–	+	–	–	–	–	–
B.	**Subfamily Chilocorinae**												
14.	*Chilocorus infernalis* Mulsant	+	+	+	+	+	+	+	+	+	+	+	+
15.	*Chilocorus rubidus* (Hope)	+		+		+	+	+	+	–	–	–	–
16.	*Priscibrumus uropygialis* (Mulsant)	+	+	+	+	+	+	+	+	–	–	–	–
C.	**Subfamily Platynaspinae**												
17.	*Platynaspis saundersi* (Crotch)	+	+	+	+	+	+	+	+	+	–	+	–
	Total number of species	**17**	**9**	**15**	**9**	**16**	**14**	**17**	**12**	**11**	**9**	**10**	**9**

US and S refer to unsprayed and sprayed orchards, respectively.
+ = present, – = absent.

Table 2. Species diversity of predaceous coccinellids in vegetable ecosystem of district Budgam

S. No.	Coccinellid Species	Kale				Knolkhol				Cabbage				Cauliflower			
		Narkara		Chadoora		Narkara		Chadoora		Narkara		Chadoora		Narkara		Chadoora	
		US	S	US	S	US	S	US	S	US	S	US	S	US	S	US	S
A.	**Subfamily Coccinellinae**																
1.	*Adalia tetraspilota* (Hope)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.	*Calvia punctata* (Mulsant)	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–
3.	*Cheilomenes sexmaculata* (Fabricius)	+	+	+	+	+	+	+	+	+	–	+	–	+	–	+	–
4.	*Coccinella septempunctata* Linnaeus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.	*Coccinella transversalis* Fabricius	+	–	+	–	+	–	+	–	+	+	+	+	+	+	+	+
6.	*Harmonia dimidiata* (Fabricius)	+	–	+	–	+	–	+	–	–	–	–	–	–	–	–	–
7.	*Harmonia eucharis* (Mulsant)	+	+	+	–	+	–	+	–	+	–	+	–	+	–	+	–
8.	*Hippodamia variegata* Goeze	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
9.	*Illeis indica* Timberlake	+	+	+	–	+	–	+	–	+	–	+	–	+	–	+	–
10.	*Oenopia conglobata* Linnaeus	+	+	+	+	+	–	+	–	–	–	–	–	–	–	–	–
B.	**Subfamily Chilocorinae**																
11.	*Priscibrumus uropygialis* (Mulsant)	+	+	+	+	+	+	+	+	+	–	+	–	+	–	+	–
C.	**Subfamily Platynaspinae**																
12.	*Platynaspis saundersi* (Crotch)	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–
	Total number of species	**11**	**9**	**11**	**7**	**12**	**6**	**12**	**6**	**8**	**4**	**8**	**4**	**8**	**4**	**8**	**4**

US and S refer to unsprayed and sprayed vegetable gardens, respectively.
+ = present, – = absent.

Adalia tetraspilota *Aiolocaria hexaspilota* *Callicaria superba*

Calvia punctata *C. punctata* *Cheilomenes sexmaculata*

Coccinella septempunctata *C. septempunctata*

Plate 1. Species diversity of predaceous coccinellids in horticulture ecosystem of Kashmir- I

C. transversalis

Harmonia dimidiata

Harmonia eucharis

H. eucharis

Illeis indica

Oenopia conglobata

Propylea uteopustulata

Plate 2. Species diversity of predaceous coccinellids in horticulture ecosystem of Kashmir-II

Hippodamia variegata

H. variegata

H. variegata

Chilocorus infernalis

Chilocorus rubidus

Priscibrumus uropygialis

Platynaspis saundersi

Plate 3. Species diversity of predaceous coccinellids in horticulture ecosystem of Kashmir-III

Among the fruit orchards, pear supported the maximum number of ladybeetles species i.e. 16 and 17, respectively in the unsprayed orchards at Sopore and Pattan. It was followed by apple with 17 and 15 species at the two locations, respectively. The lowest number of species among the unsprayed orchards was found in cherry i.e. 11 and 10 species at the two locations, respectively. The number of predaceous coccinellid species collected from sprayed orchards was lower for all the three fruit ecosystems at both the locations. Sprayed pear orchards supported higher number of coccinellid species i.e. 14 and 12 from Sopore and Pattan, respectively. The sprayed orchards of both apple and cherry were found to support 9 species of predaceous coccinellids from both the locations. *Aiolocaria hexaspilota*, *Illeis indica* and *Propylaea luteopustulata* were absent from all sprayed fruit orchards.

Among the vegetable crops, maximum number of species was found in unsprayed gardens of knolkhol i.e. 12, both at Narkara and Chadoora. It was followed by kale with 11 species at both the locations. Least number of species was found associated with cabbage and cauliflower with 8 species each at both the locations. Among the sprayed vegetable gardens, kale supported the maximum number of species i.e. 9 and 7, respectively at Narkara and Chadoora followed by knolkhol with 6 species from both the locations. Both cabbage and cauliflower supported the least i.e. 4 species of coccinellids under pesticide treated conditions. *Calvia punctata* and *Harmonia dimidiata* were absent from all the sprayed vegetable gardens.

4.1.2 Relative abundance of predaceous coccinellids in horticulture ecosystem

Of all the 2961 adult ladybeetle specimens, 1906 were collected from the fruit ecosystems while the rest 1055 were collected from the vegetable ecosystems. Overall, *Coccinella septempunctata* was the most dominant species (27.54 %) of ladybeetles in fruit ecosystem followed by *Hippodamia variegata* (12.91 %) and *Adalia tetraspilota* (11.02 %) as depicted in Table 3. Other predominant species were *Chilocorus infernalis* (9.81 %), *Calvia punctata* (9.39 %)

Table 3. Relative abundance (%) of predaceous coccinellids in fruit ecosystems of district Baramulla.

Coccinellid Species	Apple				Pear			
	Sopore		Pattan		Sopore		Pattan	
	US	S	US	S	US	S	US	S
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Subfamily Coccinellinae								
Adalia tetraspilota	11.45	12.5	9.71	8.97	12.65	9.48	10.90	10.00
Aiolocaria hexaspilota	5.57	-	-	-	-	-	3.38	-
Callicaria superba	0.93	-	0.81	-	1.54	1.45	2.25	2.50
Calvia punctata	8.05	15.5	12.55	8.97	9.56	7.29	12.4	6.25
Cheilomenes sexmaculata	1.24	-	1.21	-	1.85	2.18	1.50	-
Coccinella septempunctata	27.24	25.0	34.4	34.61	22.53	32.84	20.68	35.00
Coccinella transversalis	0.93	-	0.81	-	1.54	-	0.75	-
Harmonia dimidiata	3.71	-	2.43		4.32	4.37	4.13	5.00
Harmonia eucharis	8.66	6.81	7.69	11.53	11.42	16.05	12.78	8.75
Hippodamia variegata	9.59	23.86	11.74	11.53	11.42	16.05	12.78	8.75
Illeis indica	0.62	-	1.21	-	1.23	-	0.75	-
Oenopia conglobata	4.95	5.68	2.83	5.12	4.63	4.37	4.13	6.25
Propylea luteopustulata	1.54	-	-	-	1.85	-	1.13	-
Subfamily Chilocorinae								
Chilocorus infernalis	8.66	9.09	8.50	15.38	9.56	8.02	1.44	8.75
Chilocorus rubidus	1.24	-	1.24	-	1.85	1.45	1.88	2.50
Priscibrumus uropygialis	3.40	3.40	3.64	2.56	3.70	3.64	4.13	5.00
Subfamily Platynaspinae								
Platynaspis saundersi	2.17	1.13	1.21	1.28	4.32	2.18	1.50	2.50
Total number of individuals collected (N)	**323**	**88**	**247**	**78**	**324**	**137**	**266**	**80**
Total number of species collected (S)	**17**	**9**	**15**	**9**	**16**	**13**	**17**	**12**

Cont…

Table 3 cont…

Cherry				Mean		
Sopore		Pattan				
US	S	US	S	US	S	Overall
10	**11**	**12**	**13**	**14**	**15**	**16**
10.86	14.81	10.74	8.00	11.20^{3}	10.47^{3}	11.02^{3}
-	-	-	-	1.90^{8}	-	1.42^{12}
-	-	-	-	1.13^{11}	0.82^{11}	1.05^{15}
6.52	9.26	6.61	6.00	9.72^{4}	8.42^{5}	9.39^{5}
1.45	1.85	3.30	2.00	1.62^{9}	1.03^{10}	1.46^{11}
25.36	24.07	28.09	40.00	26.01^{1}	31.82^{1}	27.54^{1}
2.89	3.70	4.13	6.00	1.48^{10}	1.03^{10}	1.36^{13}
-	-	-	-	3.03^{7}	2.05^{8}	2.78^{9}
13.70	11.11	9.92	10.00	8.81^{5}	8.42^{5}	8.71^{6}
15.20	18.52	14.87	14.00	11.98^{2}	15.60^{2}	12.91^{2}
2.17	-	-	-	0.98^{12}	-	0.73^{17}
5.79	3.70	4.13	6.00	4.37^{6}	5.13^{6}	4.56^{7}
-	-	-	-	0.98^{13}	-	0.73^{16}
11.59	12.96	14.87	8.00	9.72^{4}	10.06^{4}	9.81^{4}
-	-	-	-	1.27^{10}	0.82^{11}	1.15^{14}
-	-	-	-	3.03^{7}	2.87^{7}	2.99^{8}
4.35	-	3.30	-	2.67^{8}	1.44^{9}	2.36^{10}
138	**54**	**121**	**50**	**1419**	**487**	**1906**
11	**9**	**10**	**9**	**17**	**14**	**17**

US and S refer to unsprayed and sprayed orchards, respectively.

Numbers in superscript indicate abundance ranking.

and *Harmonia eucharis* (8.71 %). *Illeis indica* and *Propylaea luteopustulata* were the least abundant (0.73 %, both) preceded by *Callicaria superba* (1.05 %) and *Chilocorus rubidus* (1.15 %). The trend was similar for both sprayed and unsprayed orchards.

In the vegetable ecosystem, *Adalia tetraspilota* was the most abundant species of ladybeetles (31.18 %) followed by *Hippodamia variegata* (20.76 %), *Coccinella septempunctata* (15.54 %) and *Harmonia eucharis* (7.49 %) (Table 4). The abundance of *Calvia punctata* and *Harmonia dimidiata* was noted as lowest i.e. 0.67 and 1.52 %, respectively.

4.1.3 Biodiversity indices

The various indices of biodiversity of predaceous coccinellids viz. species diversity index (H), species evenness index (J) and species richness index (M_a) in various horticulture ecosystems are presented in Table 5. In general, the species diversity index was higher for unsprayed communities then the sprayed ones. The average value of species diversity index for unsprayed fruit ecosystems was 2.420 and for sprayed ones, it was noted as 2.032. The corresponding figures for unsprayed and sprayed vegetable ecosystems were noted as 1.903 and 1.567, respectively. The trend is same for all fruit and vegetable ecosystems.

The species diversity index was consistently higher for fruit ecosystems as compared to vegetable ecosystems. Among the unsprayed fruit crops, maximum H value was noted for apple followed by pear and the least for cherry while the trend was in favour of pear for sprayed orchards. Among the vegetables, maximum H value was noted for knolkhol closely followed by kale.

Species evenness index (J), that measures the equitability component of diversity in various habitats under different management strategies was found higher for unsprayed communities of both fruit and vegetable crops. The average value of J for unsprayed fruit ecosystems was noted as 0.902, and 0.876 for sprayed orchards. The corresponding figures for unsprayed and sprayed vegetable ecosystems were noted as 0.841 and 0.391, respectively. The trend is similar for all fruit and vegetable crops except kale, cabbage and cauliflower in which case the value of J was found to be higher for sprayed gardens than sprayed ones. The evenness index assumed

Table 4. Relative abundance (%) of predaceous coccinellids in vegetable ecosystems of district Budgam.

Coccinellid Species	**Kale**				**Knolkhol**			
	Narkara		**Chadoora**		**Narkara**		**Chadoora**	
	US	**S**	**US**	**S**	**US**	**S**	**US**	**S**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Subfamily Coccinellinae								
Adalia tetraspilota	29.16	13.89	26.95	11.54	28.24	37.93	32.54	38.70
Calvia punctata	-	-	-	-	3.05	-	2.34	-
Cheilomenes sexmaculata	5.55	8.33	4.96	7.69	2.29	3.45	3.12	6.45
Coccinella septempunctata	14.58	16.66	15.60	19.23	14.50	20.68	12.50	12.90
Coccinella transversalis	6.25	-	4.96	-	8.39	-	7.03	9.67
Harmonia dimidiata	2.77	-	2.13	-	3.05	-	3.90	-
Harmonia eucharis	6.25	8.33	4.96	-	8.39	-	7.03	-
Hippodamia variegata	19.44	19.44	21.98	23.07	18.32	29.59	17.96	22.58
Illeis indica	5.55	8.33	4.96	-	6.87	-	6.25	-
Oenopia conglobata	3.47	11.11	5.67	19.23	2.29	-	1.56	-
Subfamily Chilocorinae								
Priscibrumus uropygialis	4.17	5.55	3.54	11.54	3.05	6.89	3.90	3.22
Subfamily Platynaspinae								
Platynaspis saundersi	2.77	8.33	4.25	7.29	1.52	3.45	2.34	6.45
Total number of individuals (N)	**144**	**36**	**141**	**26**	**131**	**29**	**128**	**31**
Total number of species (S)	**11**	**9**	**11**	**7**	**12**	**6**	**12**	**7**

Cont…

Table 4 cont…

Cabbage				**Cauliflower**				**Mean**		
Narkara		**Chadoora**		**Narkara**		**Chadoora**		**US**	**S**	**Overall**
US	**S**	**S**	**US**	**US**	**S**	**US**	**S**			
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
36.05	29.41	37.66	46.15	35.00	40.00	33.33	38.89	31.44^{1}	30.00^{1}	31.18^{1}
-	-	-	-	-	-	-	-	0.81^{11}	-	0.67^{11}
2.32	-	1.29	-	1.25	-	1.28	-	3.12^{7}	4.21^{6}	3.32^{7}
15.12	23.52	14.28	23.07	15.00	25.00	16.66	22.22	14.68^{3}	19.47^{3}	15.54^{3}
8.14	11.76	7.79	15.38	3.75	15.00	10.26	22.22	7.51^{4}	7.36^{4}	7.49^{4}
-	-	-	-	-	-	-	-	1.84^{9}	-	1.52^{10}
8.14	-	9.09	-	7.50	-	6.41	-	7.05^{5}	1.58^{7}	6.07^{5}
22.09	35.29	22.08	15.38	20.00	20.00	23.07	16.67	20.35^{2}	22.63^{2}	20.76^{2}
6.97	-	6.49	-	-	-	6.41	-	6.24^{6}	1.58^{7}	5.40^{6}
-	-	-	-	-	-	-	-	2.08^{8}	4.73^{5}	2.56^{8}
1.16	-	1.29	-	3.75	-	2.56	-	3.12^{7}	4.21^{6}	3.32^{7}
-	-	-	-	-	-	-	-	1.73^{10}	4.21^{6}	2.18^{9}
86	**17**	**77**	**13**	**80**	**20**	**78**	**18**	**865**	**190**	**1055**
8	**4**	**8**	**4**	**8**	**4**	**8**	**4**	**12**	**10**	**12**

US and S refer to unsprayed and sprayed vegetable gardens, respectively.

Numbers in superscript indicate the abundance ranking.

consistently lower value for vegetable crops as compared to fruit crops. Evenness index tends to be close to 1 in case of pear followed by cherry. Among the vegetables, maximum value of evenness index was noted for kale.

The species richness index values (M_a) for sprayed and unsprayed communities of fruits and vegetables indicated that the average value was higher for unsprayed communities as compared to sprayed ones and followed the same trend for individual crops except kale. For fruit ecosystems, the average richness index assumed the value of 2.275 for unsprayed orchards and 1.839 for sprayed ones. Corresponding figures for vegetables were worked out as 1.626 and 1.275, respectively.

Overall the richness index was noted as maximum for unsprayed apple (2.521) followed by sprayed pear orchard (2.230) and sprayed gardens of kale (1.938). In general, the richness index was found to be lower for vegetable crops as compared to fruit crops.

Table 5. Biodiversity indices of ladybeetles for various fruit and vegetable ecosystems.

Ecosystem	N		S		H		J		M_a	
	US	S	US	S	US	S	US	S	US	S
Fruit ecosystem										
Apple	570	166	17	9	2.545	1.935	0.898	0.881	2.521	1.565
Pear	590	217	17	13	2.447	2.218	0.963	0.864	2.507	2.230
Cherry	259	104	11	9	2.268	1.945	0.945	0.885	1.799	1.722
Mean					**2.420**	**2.032**	**0.902**	**0.876**	**2.275**	**1.839**
Vegetable ecosystem										
Kale	285	62	11	9	2.075	2.007	0.865	0.913	1.769	1.938
Knolkhol	259	60	12	7	2.085	1.606	0.839	0.825	1.979	1.465
Cabbage	163	30	8	4	1.700	1.326	0.817	0.958	1.382	0.825
Cauliflower	158	38	8	4	1.752	1.329	0.842	0.958	1.382	0.825
Mean					**1.903**	**1.567**	**0.841**	**0.391**	**1.626**	**1.275**

N is the total number of individuals collected
S is total number of species
H is Shannon-Weiner diversity index
J is evenness index
M_a is the richness index.

4.2 Effect of prey species and prey abundance on the biology of *Adalia tetraspilota* and *Hippodamia variegata*

Studies on the biology of *Adalia tetraspilota* and *Hippodamia variegata* were carried out to assess the effect of prey species and prey abundance on various biological attributes of the two coccinellid predators. The effect of two prey species namely *Aphis pomi* and *Brevicoryne brassicae*, on the biological parameters of the two predators, provided at five abundance levels i.e. 10, 20, 40, 80 and 160 aphids per day per predatory stage, are presented as follows. The generalised life cycle of *Adalia tetraspilota* is diagrammatically represented in Plate 4 and that of *Hippodamia variegata* in Plate 5.

(A) Developmental parameters

4.2.1 Larval duration

Both prey species and prey abundance were found to have significant effect (F = 101.20; d.f. = 1, 80; P<0.0001 and F = 113.75; d.f. = 1, 80; P<0.0001) on the total larval period of *A. tetraspilota* as well as *H. variegata* (F = 209.3; d.f. = 1, 80; P<0.0001 and F = 286.34; d.f. = 1, 80; P<0.0001), as shown in Table 6 and 7. The total larval period was found to increase significantly when *A. pomi* was used as prey as compared to *B. brassicae* for both the predator species. *A. tetraspilota* larvae completed the larval period in 17.38 days and 14.70 days when *A. pomi* and *B. brassicae* were used as prey, respectively. For *H. variegata,* the corresponding figures were noted as 20.91 and 16.07 days, respectively. The total larval period got extended significantly as prey density decreased from 160 to 10 aphids per day per predator. *A. tetraspilota* larvae were found to complete the larval period in 13.04 days at the highest prey abundance level i.e. 160 aphids per day which got extended to 21.00 days at the lowest prey abundance level i.e. 10 aphids per day. More appreciable effect of varying prey density was found on *H. variegata* as the total larval period was noted as 13.27 days and 28.00 days at maximum and minimum prey density tested. The variation in total larval period for *A. tetraspilota* was found to be significant over various prey abundance levels for a particular prey species as well as over the two prey species at each abundance level tested (F = 6.16;

Table 6. Developmental period (days) and survival of *Adalia tetraspilota* immatures on two prey species and five prey densities.

Parameters	**Prey (P)***	**Density (D)****					**Mean (P)**	**CD** ***(P= 0.05)***
		10	**20**	**40**	**80**	**160**		
Incubation period	Ap	4.50 ± 0.06	4.36 ± 0.04	4.04 ± 0.07	3.69 ± 0.20	3.49 ± 0.18	**4.02**	P= 0.044
	Bb	3.94 ± 0.11	3.77 ± 0.07	3.67± 0.05	3.49 ± 0.06	3.49 ± 0.11	**3.67**	D= 0.073
	Mean (D)	**4.22**	**4.06**	**3.85**	**3.59**	**3.49**		P x D= 0.111
1st instar	Ap	4.00 ± 0.71	4.00 ± 0.5	3.75 ± 0.43	3.88 ± 0.60	3.44 ± 0.52	**3.81**	P= NS***
	Bb	3.75 ± 0.82	3.62 ± 0.99	3.55 ± 1.33	3.55 ± 0.88	3.55 ± 0.52	**3.60**	D= NS
	Mean (D)	**3.87**	**3.81**	**3.65**	**3.72**	**3.50**		P x D=NS
2nd instar	Ap	3.85 ± 0.59	3.50 ± 0.5	3.25 ± 0.43	2.77 ± 0.66	2.55 ± 0.52	**3.18**	P= 0.246
	Bb	3.00 ± 0.71	2.75 ± 0.66	2.77 ± 0.44	2.77 ± 0.66	2.44 ± 0.52	**2.75**	D= 0.406
	Mean (D)	**3.42**	**3.12**	**3.01**	**2.77**	**2.50**		P x D=NS
3rd instar	Ap	5.50 ± 0.43	4.14 ± 0.59	3.71 ± 0.42	3.25 ± 0.43	3.00 ± 0.50	**3.92**	P=0.219
	Bb	3.14 ± 0.59	2.76 ± 0.66	2.75 ± 0.43	2.55 ± 0.52	2.33 ± 0.50	**2.70**	D=0.361
	Mean (D)	**4.32**	**3.45**	**3.23**	**2.90**	**2.66**		P x D= NS
4th instar	Ap	0.25 ± 0.58	6.80 ± 0.31	5.50 ± 0.43	5.00 ± 0.70	4.75 ± 0.43	**6.46**	P= 0.297
	Bb	8.50 ± 1.47	6.85 ± 0.59	4.71 ± 0.65	4.12 ± 0.33	4.00± 0.70	**5.63**	D= 0.490
	Mean (D)	**9.37**	**6.82**	**5.10**	**4.56**	**4.37**		P x D= 0.746
Larval period	Ap	23.60 ± 2.32	18.44 ± 0.95	16.21 ± 0.60	14.91 ± 1.45	13.75 ± 0.93	**17.38**	P=0.536
	Bb	18.39 ± 1.47	15.99 ± 1.12	13.79 ± 1.73	13.01 ± 1.01	12.33 ± 1.65	**14.70**	D= 0.884
	Mean (D)	**21.00**	**17.21**	**15.00**	**13.96**	**13.04**		P x D=1.347

Cont...

Table 6 cont…

Parameters	**Prey (P)**	**Density (D)**					**Mean (P)**	**CD** *(P= 0.05)*
		10	**20**	**40**	**80**	**160**		
Larval survival (%)	Ap	40.00 ± 10.00 (39.15)	50.00 ± 10.00 (45.00)	60.00 ± 10.00 (50.85)	70.00 ± 0.00 (56.79)	80.00 ± 10.00 (63.93)	**60.00 (51.14)**	P=4.20 D= 7.57 P x D= NS
	Bb	60.00 ± 10.00 (50.85)	70.00 ± 10.00 (57.00)	70.00 ± 0.00 (56.79)	80.00 ± 10.00 (63.93)	90.00 ± 0.00 (71.57)	**74.00 (60.03)**	
	Mean (D)	**50.00 (45.00)**	**60.00 (51.00)**	**65.00 (53.82)**	**75.00 (60.36)**	**85.00 (67.75)**		
Prepupal period	Ap	2.00 ± 0.00	1.66 ± 0.28	1.50 ± 0.35	1.66 ± 0.40	1.42 ± 0.46	**1.65**	P= 0.175 D= 0.268 P x D=NS
	Bb	1.75 ± 0.30	1.40 ± 0.38	1.50 ± 0.43	1.50 ± 0.50	1.22 ± 0.44	**1.47**	
	Mean (D)	**1.87**	**1.53**	**1.50**	**1.58**	**1.32**		
Pupal period	Ap	6.50 ± 0.25	6.33 ± 0.28	5.75 ± 0.58	5.66 ± 0.40	5.42 ± 0.46	**5.93**	P= 0.195 D= 0.321 P x D=NS
	Bb	6.25 ± 0.30	5.80 ± 0.31	5.33 ± 0.40	5.25 ± 0.66	4.77 ± 0.66	**5.48**	
	Mean (D)	**6.37**	**6.06**	**5.54**	**5.45**	**5.10**		
Adult emergence (%)	Ap	52.22 ± 13.47 (46.32)	58.89 ± 8.38 (50.17)	66.03 ± 5.73 (54.39)	85.71 ± 14.29 (71.82)	87.36 ± 10.00 (69.20)	**70.04 (58.38)**	P=6.34 D= 11.52 P x D=NS
	Bb	65.81 ± 5.71 (54.26)	71.03 ± 4.18 (57.47)	85.71 ± 14.29 (71.82)	100.0 ± 0.00 (90.00)	100.0 ± 0.00 (90.00)	**84.51 (72.71)**	
	Mean (D)	**59.01 (50.29)**	**64.96 (53.82)**	**75.87 (63.11)**	**92.85 (80.91)**	**93.68 (79.60)**		

Values are Mean ± S.E. Values in parenthesis are arcsine transformed values.

* Ap = *Aphis pomi*, Bb = *Brevicoryne brassicae*

** Number of aphids per day per predator*** NS = Non-significant

Table 7. Developmental period (days) and survival of *Hippodamia variegata* immatures on two prey species and five prey densities.

Parameters	**Prey (P)***	**Density (D)****					**Mean (P)**	**CD (*P = 0.05*)**
		10	**20**	**40**	**80**	**160**		
Incubation period	Ap	3.64 ± 0.22	3.50 ± 0.21	3.24 ± 0.14	3.10 ± 0.03	3.03 ± 014	**3.30**	P= 0.082
	Bb	3.79 ± 027	3.19 ± 026	2.99 ± 0.18	2.89 ± 0.16	2.79 ± 0.27	**3.13**	D= 0.135
	Mean (D)	**3.71**	**3.34**	**3.12**	**3.00**	**2.91**		P x D= 0.203
1st instar	Ap	4.00 ± 0.70	3.87 ± 0.59	3.75 ± 0.43	3.37 ± 0.48	3.11 ± 0.60	**3.62**	P= 0.256
	Bb	3.12 ± 0.33	3.00 ± 0.70	2.77 ± 0.66	2.77 ± 0.66	2.66 ± 0.71	**2.86**	D= 0.422
	Mean (D)	**3.56**	**3.43**	**3.26**	**3.07**	**2.88**		P x D=NS
2nd instar	Ap	5.25 ± 0.43	4.12 ± 0.59	3.25 ± 0.43	2.87 ± 0.59	2.88 ± 0.33	**3.67**	P= 0.205
	Bb	4.25 ± 0.43	3.88 ± 0.60	3.11 ± 0.33	2.44 ± 0.52	2.22 ± 0.44	**3.18**	D= 0.338
	Mean (D)	**4.75**	**4.00**	**3.18**	**2.65**	**2.55**		P x D=NS***
3rd instar	Ap	6.14 ± 0.77	5.00 ± 0.50	4.25 ± 0.43	3.75 ± 0.43	3.66 ± 0.50	**4.56**	P=0.264
	Bb	5.42 ± 0.68	4.55 ± 0.72	3.44 ± 0.72	2.88 ± 0.60	2.55 ± 0.72	**3.77**	D=0.436
	Mean (D)	**5.78**	**4.77**	**3.84**	**3.31**	**3.11**		P x D= NS
4th instar	Ap	16.00 ± 1.32	11.00 ± 1.11	6.50 ± 0.43	5.88 ± 0.60	5.87 ± 0.59	**9.05**	P= 0.512
	Bb	11.81± 1.98	8.27 ± 2.38	4.16± 0.71	3.44 ± 0.52	3.55 ± 0.52	**6.25**	D= 0.845
	Mean (D)	**13.90**	**9.63**	**5.33**	**4.66**	**4.71**		P x D= NS
Larval period	Ap	31.39 ± 1.21	24.00 ± 1.80	17.75 ± 0.61	15.88 ± 1.05	15.54 ± 1.21	**20.91**	P=0.673
	Bb	24.61 ± 2.31	19.72 ± 2.94	13.49 ± 1.17	11.55 ± 1.01	11.00 ± 1.00	**16.07**	D= 1.11
	Mean (D)	**28.00**	**21.86**	**15.62**	**13.72**	**13.27**		P x D=NS

Cont…

Table 7 cont...

Parameters	**Prey (P)***	**Density (D)****					**Mean (P)**	**CD (*P = 0.05*)**
		10	**20**	**40**	**80**	**160**		
Larval survival (%)	Ap	30.00 ± 0.00 (33.21)	50.00 ± 10.00 (45.00)	50.00 ± 17.32 (44.92)	70.00 ± 10.00 57.0)	80.00 ± 10.00 (63.93)	**56.00** **(48.81)**	P=5.742 D= 10.42 P x D=NS
	Bb	50.00 ± 10.00 (45.00)	70.00 ± 10.00 (57.00)	80.00 ± 10.00 (63.93)	90.00 ± 10.00 (75.00)	90.00 ± 0.00 (71.57)	**76.00** **(62.50)**	
	Mean (D)	**40.00** **(39.11)**	**60.00** **(51.00)**	**65.00 ±** **(54.42)**	**80.00** **(66.00)**	**85.00** **(67.75)**		
Prepupal period	Ap	2.00 ± 0.00	1.66 ± 0.28	1.50 ± 0.35	1.40 ± 0.38	1.50 ± 0.43	**1.61**	P= 0.156 D= 0.258 P x D=NS
	Bb	1.50 ± 0.25	1.50 ± 0.35	1.48 ± 0.43	1.33 ± 0.50	1.22 ± 0.44	**1.40**	
	Mean (D)	**1.75**	**1.58**	**1.49**	**1.36**	**1.36**		
Pupal period	Ap	8.00 ± 0.50	6.31 ± 0.29	6.00 ± 0.50	5.46 ± 0.44	5.66 ± 0.41	**6.28**	P= 0.187 D= 0.309 P x D=NS
	Bb	7.50 ± 0.25	6.00 ± 0.50	5.33 ± 0.40	4.33 ± 0.50	4.55 ± 0.52	**5.54**	
	Mean (D)	**7.75**	**6.15**	**5.66**	**4.90**	**5.11**		
Adult emergence (%)	Ap	55.55 ± 38.49 (53.51)	58.89 ± 8.35 (50.17)	66.66 ± 0.00 (54.73)	71.03 ± 4.08 (57.47)	74.73 ± 3.18 (59.85)	**65.37** **(55.15)**	P=8.07 D= 14.65 P x D=26.94
	Bb	41.11 ± 8.39 (39.83)	56.55 ± 6.27 (48.78)	74.73 ± 3.18 (59.85)	100.0 ± 0.00 (90.00)	100.0 ± 0.00 (90.00)	**74.48** **(65.69)**	
	Mean (D)	**48.33** **(46.67)**	**57.72** **(49.47)**	**70.69** **(57.29)**	**85.51** **(73.74)**	**87.36** **(74.93)**		

Values are Mean ± S.E. Values in parenthesis are arcsine transformed values.
* Ap = *Aphis pomi*, Bb = *Brevicoryne brassicae*
** Number of aphids per day per predator
*** NS = Non-significant

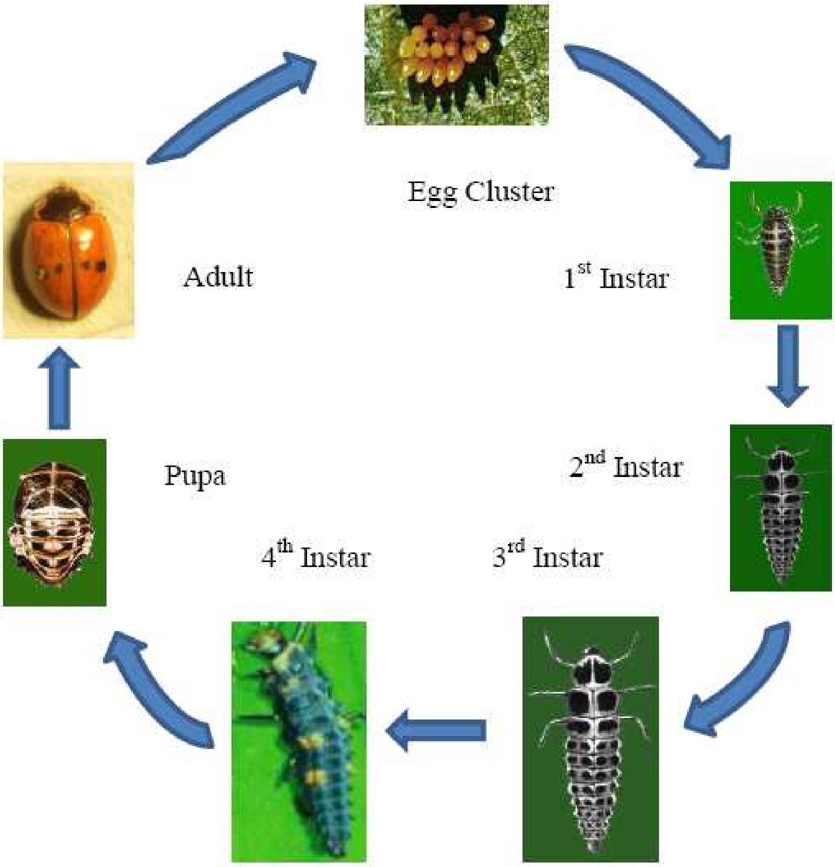

Plate 4. Diagrammatic representation of the life cycle of *Adalia tetraspilota* (Hope)

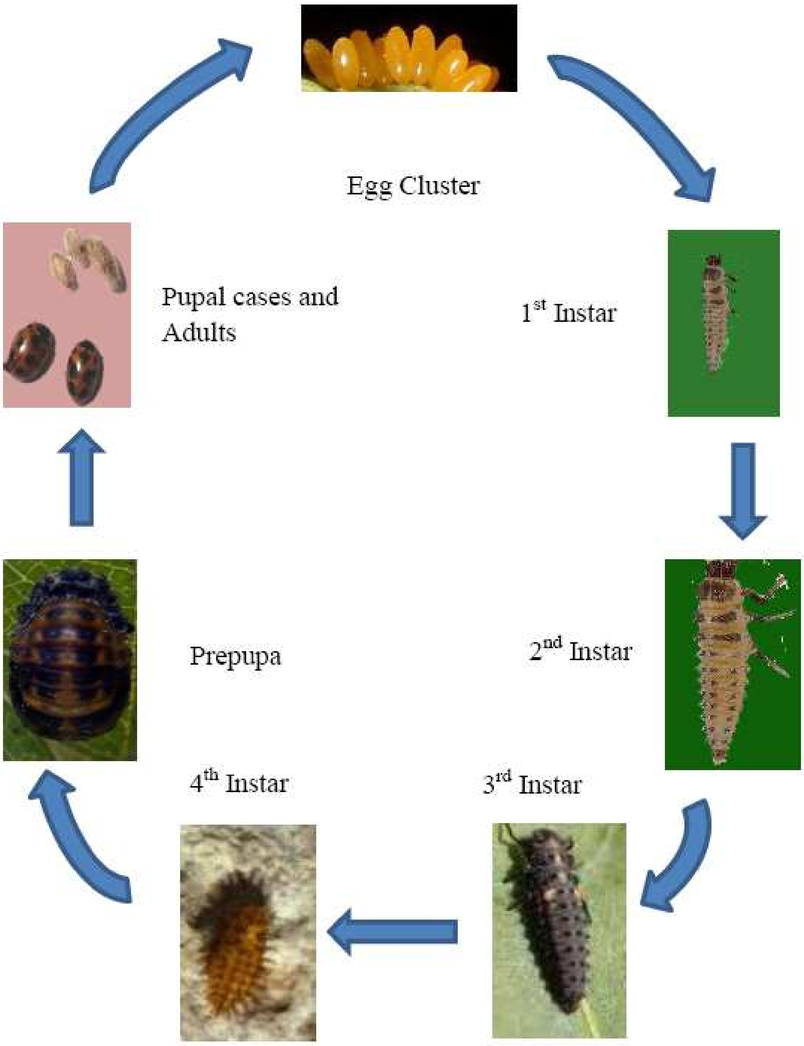

Plate 5. Diagrammatic representation of the life cycle of *Hippodamia variegata* Goeze

d.f. = 1, 80; P = 0.0002). However, the interaction effect was found to be insignificant for *H. variegata* (F = 2.13; d.f. = 1, 80; P = 0.084).

For *A. tetraspilota*, the effect of prey species was found to be significant for 2nd (F = 12.1; d.f. = 1, 80; P = 0.0005), 3rd (F = 123.72; d.f. = 1, 80; P<0.0001) and 4th instar larval duration (F = 30.93; d.f. = 1, 80; P<0.0001). However, its effect was insignificant for 1st instar duration (F = 1.607; d.f. = 1, 80; P = 0.2058). For *H. variegata*, the effect of prey species was significant for all the four larval instars. In all the cases, larval duration was longer on *A. pomi* as compared to *B. brassicae*. The effect of prey abundance followed the same trend for both the ladybird species as duration of each larval instar was recorded to increase with decrease in prey density. The variation in duration was found to be insignificant at prey density of 80 and 160 for all the larval instars of both the predators in question. For *A. tetraspilota*, the interaction effect of prey species and prey abundance was found to be significant for 4th instar larvae only (F = 3.77; d.f. = 4, 80; P = 0.0072). For *H. variegata*, the interaction effect was not found to be significant for any larval instar.

4.2.2 Incubation period

Table 6 and 7 revealed that incubation period of the eggs of *A. tetraspilota* and *H. variegata* varied significantly with different prey species (F = 237.25; d.f.= 1, 90; P<0.0001 and F = 18.06; d.f.= 1, 90; P<0.0001, respectively). For *A. tetraspilota*, the incubation period was noted as 3.67 days and 4.02 days when *B. brassicae* and *A. pomi* were used as prey, respectively. The corresponding figures for *H. variegata* were noted as 3.13 and 3.30 days, respectively. The effect of varying prey abundance was also significant for both *A. tetraspilota* (F = 153.02; d.f. = 4, 90; P<0.0001) and *H. variegata* (F = 49.53; d.f. = 4, 90; P<0.0001) eggs. The incubation period of *A. tetraspilota* eggs increased by 21 % and those of *H. variegata* by 27 % as the prey abundance decreased from 160 to 10 aphids per day. The interaction effects were noted as significant for both the predators (F = 24.77; d.f. = 4, 90; P<0.0001 for *A. tetraspilota*, and F=4.02; d.f. = 4, 90; P=0.0047 for *H. variegata*).

4.2.3 Larval survival

Significant variation in larval survival (%) on exposure to different prey species was noted for both *A. tetraspilota* (F = 20.60; d.f. = 1, 20; P=0.00019) and *H. variegata* (F = 25.81; d.f. = 1, 20; P<0.0001). The per cent larval survival increased significantly when *B. brassicae* was used as prey as compared to *A. pomi* for both the predators. The effect of prey abundance levels was also noted a significant for both *A. tetraspilota* (F = 16.02; d.f. = 4, 20; P<0.0001) and *H. variegata* (F = 15.16; d.f. = 4, 20; P<0.0001). The larval survival was highest (85.00 %) at the maximum prey density tested and lowest (50.00 %) at the minimum prey density tested for *A. tetraspilota* larvae. The corresponding figures for *H. variegata* were noted as 85.00 and 40.00 %, respectively. The variation in larval survival was statistically insignificant when the prey density decreased from 160 to 80 for both the predators. The interaction effect of prey species and prey abundance was noted as insignificant for both *A. tetraspilota* (F = 0.404; d.f. = 4, 20; P = 0.8035) and *H. variegata* (F = 0.620; d.f. = 4, 20; P = 0.653) .

4.2.4 Prepupal and pupal period

The effect of prey species was noted as significant on the duration of prepupal (F = 4.87; d.f. = 1, 80; P = 0.030) and pupal stages (F = 21.90; d.f. = 1, 80; P<0.0001) for *A. tetraspilota*. Same trend was noted for *H. variegata* (F = 70.34; d.f. = 1, 80; P = 0.0096 for prepupal period and F = 63.78; d.f. = 1, 80; P<0.0001 for pupal period). In both the cases, the respective periods got extended appreciably when *A. pomi* was used as prey as compared to the individuals fed on *B. brassicae*.

For *A. tetraspilota*, the effect of varying the prey density was found to be significant on both the prepupal (F = 4.89; d.f. = 4, 80; P = 0.0013) and pupal period (F = 21.89; d.f. = 4, 80; P<0.0001). The prepupal period got extended from 1.32 to 1.87 days and the pupal period from 5.10 to 6.37 days as the prey abundance decreased from 160 to 10. Similarly, for *H. variegata* the effect of prey abundance fed to the larvae was found to significantly affect the duration of prepupae (F = 3.49; d.f. = 4, 80; P = 0.010) as well as the pupae (F = 118.69; d.f. = 4, 80; P<0.0001). The pupal period increased from 5.11 to 7.75 days as the prey abundance decreased from 160 to 10 aphids per day per individual. For both the predator species, the variation of pupal period over the prey density of 160 and 80 was found to be insignificant.

4.2.5 Adult emergence (%)

The per cent adult emergence was found to be affected significantly by the prey species for both *A. tetraspilota* (F = 23.16; d.f. = 1, 20; P = 0.0001) and *H. variegata* (F = 7.75; d.f. = 1, 20; P = 0.011). For *A. tetraspilota,* adult emergence percentage was significantly higher (84.51 %) for individuals fed on *B. brassicae* as compared to those fed on *A. pomi* (70.04 %). The same trend was noted for *H. variegata* and the corresponding figures were registered as 74.48 % and 65.37 %, respectively. The variation in prey density also affected the adult emergence (%) significantly (F = 18.27; d.f. = 4, 20; P<0.0001 for *A. tetraspilota* and F = 9.85; d.f. = 4, 20; P=0.00014 for *H. variegata*). For *A. tetraspilota,* the adult emergence (%) decreased from 93.68 % to 59.01 % as the prey density decreased from 160 to 10 aphids per day. Corresponding figures for *H. variegata* were noted as 87.36 % and 48.33 %, respectively.

(B) Reproductive parameters

The data presented in Table 8 and 9 on the effect of prey species and prey density on various reproductive parameters and adult longevity of the two predator species under consideration revealed the following information.

4.2.6 Pre-oviposition period

Both prey species and prey abundance influenced the pre-oviposition period of the females of both the predator species. Analysis of variance revealed significant effect of prey species (F = 77.12; d.f. = 1, 90; P<0.0001), prey abundance (F = 398.9; d.f. = 4, 90; P<0.0001) as well as the interaction of prey species and prey abundance levels (F = 4.44; d.f. = 4, 90; P=0.0025) for *A. tetraspilota* females. For *H. variegata* too, all the three factors had a significant effect (F = 277.40; d.f. = 1, 90; P<0.0001 for prey species, F = 2866.23; d.f. = 4, 90; P<0.0001 for prey abundance and F = 52.65; d.f. = 4, 90; P=0.0047 for the interaction effect). For *A. tetraspilota* females, the pre-oviposition period was noted as 12.16 and 9.96 days when the predators were fed upon *A. pomi* and *B. brassicae*, respectively. The corresponding figures for *H. variegata* females were recorded as 17.30 and 14.18 days, respectively. The shortest pre-oviposition period noted for *A. tetraspilota* was 5 days when fed on *B. brassicae* at the maximum prey density and the longest period noted was 21 days for females fed on *A. pomi* at the minimum prey density tested. For *H. variegata,* shortest and longest pre-oviposition periods were noted as 5.30 and 28 days, respectively for the females which were fed under the same conditions as for those of *A. tetraspilota*. The variation in periods was found to be insignificant at the prey abundance levels of 80 and 160 for both the predators.

4.2.7 Oviposition period

Significant variation was noted in the oviposition period by varying the prey species as well as the prey abundance levels. For *A. tetraspilota*, a significant effect of prey species (F = 1230.0; d.f. = 1, 90; P<0.0001), prey abundance (F = 1075.65; d.f. = 4, 90; P<0.0001) as well as significant interaction of the two factors (F = 97.19; d.f.= 4, 90; P<0.0001). The oviposition period was positively affected by when *B. brassicae* was used as prey. The oviposition period increased from 22.92 to 31.1 days when *A. pomi* was replaced by *B. brassicae* as the prey. By decreasing the prey abundance, the oviposition period decreased from 35.5 to 15.75 days.

For *H. variegata*, significant effect of prey species (F = 1777.6; d.f. = 1, 90; P<0.0001), prey abundance (F = 708.87; d.f. = 4, 90; P<0.0001) and interaction of the two factors (F = 36.35; d.f. = 4, 90; P<0.0001) was noted on the oviposition period of the females. Longer oviposition period was noted on *B. brassicae* (33.42 days) as compared to *A. pomi* (20.90 days). The oviposition period decreased from 34.5 to 15.0 days as the prey density was decreased from 160 to 10 aphids per day.

4.2.8 Post-oviposition period

Significant variation was noted in the post-oviposition period by varying prey species and prey abundance for both the predators. For *A. tetraspilota*, by varying the prey species (F = 74.70; d.f. = 1, 90; P<0.0001), the post-oviposition period decreased from 13.42 to 10.82 days as *A. pomi* was replaced by *B. brassicae* as the prey. The post-oviposition period was found to be prey density dependent (F = 352.48; d.f. = 4, 90; P<0.0001) and increased from 5.65 to 20.25 days as the prey density decreased from 160 to 10 aphids per day per predator. For *H. variegata* also, significant effect of prey species (F = 95.92; d.f. = 1, 90; P<0.0001) and prey density (F = 353.48; d.f. = 4, 90; P<0.0001) was noted on post-oviposition period. The period increased from 8.2 to

Table 8. Reproductive parameters and adult longevity of *Adalia tetraspilota* on two prey species and five aphid densities.

Parameters	Prey (P)	Density (D)					Mean (P)	CD $_{(P = 0.05)}$
		10	**20**	**40**	**80**	**160**		
Pre-Oviposition period (days)	Ap	22.00 ± 2.21	16.00 ± 1.15	12.00 ± 1.24	6.50 ± 0.62	6.30 ± 1.05	**12.56**	P= NS D=0.763 P x D= 1.153
	Bb	25.00 ± 0.94	19.00 ± 1.05	9.80 ± 1.23	5.50 ± 0.41	5.00 ± 0.67	**12.86**	
	Mean (D)	**23.50**	**17.50**	**10.90**	**6.00**	**5.65**		
Oviposition period (days)	Ap	14.50 ± 1.54	19.50 ± 0.78	23.60 ± 0.81	28.00 ± 1.24	29.00 ± 1.63	**22.92**	P= 0.468 D= 0.769 P x D= 1.161
	Bb	17.00 ± 0.94	23.00 ± 1.24	32.00 ± 1.05	41.50 ± 1.39	42.00 ± 0.47	**31.10**	
	Mean (D)	**15.75**	**21.25**	**27.80**	**34.75**	**35.50**		
Post-Oviposition period (days)	Ap	18.5.0 ± 0.62	15.50 ± 0.78	11.30 ± 1.06	7.50 ± 1.13	6.80 ± 0.78	**11.92**	P= 0.355 D= 0.584 P x D= 0.882
	Bb	22.00 ± 1.05	18.00± 1.05	14.10 ± 0.99	5.00 ± 0.67	4.50 ± 0.41	**12.72**	
	Mean (D)	**20.25**	**16.75±**	**12.70**	**6.25**	**5.65**		
Adult longevity (Female) (days)	Ap	55.00 ± 2.35	51.00 ± 1.94	46.90 ± 1.96	42.00 ± 1.05	42.10 ± 3.17	**47.40**	P= 0.774 D= 1.271 P x D=NS
	Bb	64.00 ± 1.15	60.00 ± 0.66	55.90 ± 2.60	52.00 ± 1.94	51.50 ± 0.62	**56.68**	
	Mean (D)	**59.50**	**55.50**	**51.40**	**47.00**	**46.80**		
Adult longevity (Male) (days)	Ap	52.40 ± 2.75	48.10 ± 2.60	45.30 ± 2.62	43.30 ± 2.21	43.00 ± 2.49	**46.42**	P=1.01 D= 1.658 P x D= NS
	Bb	46.30 ± 2.40	44.00 ± 2.49	41.20 ± 2.39	39.00 ± 2.71	38.00 ± 2.40	**41.70**	
	Mean (D)	**49.35**	**46.05**	**43.25**	**41.15**	**40.50**		

Cont…

Table 8 cont…

Parameters	**Prey (P)**	**Density (D)**					**Mean (P)**	**CD** ***(P = 0.05)***
		10	**20**	**40**	**80**	**160**		
Fecundity	Ap	104.0 ± 8.98	154.8 ± 15.38	221.0 ± 17.61	295.0 ± 5.81	312.0 ± 14.77	**217.4**	P= 5.38 D= 8.83 P x D=NS
	Bb	307.7 ± 18.91	377.3 ± 10.88	442.0 ± 16.05	520.0 ± 7.24	532.0 ± 11.32	**435.8**	
	Mean (D)	**205.9**	**266.1**	**331.5**	**407.5**	**422.0**		
Hatchability (%)	Ap	43.00 ± 4.10 (40.97)	51.00 ± 3.52 (45.57)	60.00 ± 2.94 (50.78)	72.00 ± 4.18 (58.11)	73.00 ± 4.49 (58.77)	**59.8** **(50.84)**	P= 0.886 D= 1.454 P x D=2.198
	Bb	49.00 ± 3.34 (44.43)	60.00 ± 2.82 (50.78)	76.00 ± 3.12 (60.71)	80.00 ± 3.68 (63.52)	82.00 ± 2.11 (64.93)	**69.4** **(56.87)**	
	Mean (D)	**46.00** **(42.70)**	**55.50** **(48.17)**	**68.00** **(55.74)**	**76.00** **(60.81)**	**77.50** **(61.85)**		

Values are Mean ± S.E. Values in parenthesis are arcsine transformed values.
* Ap = *Aphis pomi*, Bb = *Brevicoryne brassicae*
** Number of aphids per day per predator
*** NS = Non-significant

Table 9. Reproductive parameters and adult longevity of *Hippodamia variegata* on two prey species and five aphid densities.

Parameters	**Prey (P)**	**Density (D)**					**Mean (P)**	**CD** (***P = 0.05***)
		10	**20**	**40**	**80**	**160**		
Pre-Oviposition period	Ap	28.00 ± 0.94	27.50 ± 0.78	17.00 ± 0.47	7.00 ± 0.66	7.00 ± 0.67	**17.30**	P= 0.340
	Bb	28.00 ± 0.94	22.00 ± 1.15	11.00 ± 1.15	6.10 ± 0.87	5.30 ± 0.48	**14.48**	D=0.558
	Mean (D)	**28.00**	**24.75**	**14.00**	**6.55**	**6.15**		P x D= 0.843
Oviposition period	Ap	12.00 ± 0.81	14.50 ± 1.02	21.00 ± 1.76	29.00 ± 1.24	28.00 ± 2.40	**20.90**	P= 0.596
	Bb	18.00 ± 1.05	28.00 ± 0.94	38.00 ± 1.05	42.10 ± 0.37	41.00 ± 2.21	**33.42**	D= 0.979
	Mean (D)	**1500**	**21.25**	**29.50**	**35.55**	**34.50**		P x D= 1.47
Post-Oviposition period	Ap	16.00 ± 1.41	13.00 ± 0.94	9.00 ± 0.66	7.00 ± 0.94	5.00 ± 0.66	**10.0**	P= 0.369
	Bb	13.00 ± 0.81	10.00 ± 1.05	7.00 ± 1.05	6.00 ± 0.47	5.00 ± 0.81	**8.20**	D= 0.606
	Mean (D)	**14.50**	**11.50**	**8.00**	**6.50**	**5.00**		P x D= 0.915
Adult longevity (Female)	Ap	56.00 ± 1.94	55.00 ± 1.76	47.00 ± 1.24	43.00 ± 1.56	40.00 ± 1.05	**48.20**	P= 0.959
	Bb	59.00 ± 1.05	60.00 ± 2.10	56.00 ± 2.66	53.90 ± 2.02	51.30 ± 5.31	**56.04**	D= 1.57
	Mean (D)	**57.50**	**57.50**	**51.50**	**48.45**	**45.65**		P x D=2.37
Adult longevity (Male)	Ap	54.20 ± 3.98	51.00 ± 2.10	49.10 ± 2.84	44.30 ± 2.98	42.00 ± 2.35	**48.12**	P=1.21
	Bb	53.10 ± 2.96	49.00 ± 3.80	44.20 ± 3.79	41.10 ± 2.33	40.00 ± 2.49	**45.48**	D= 1.99
	Mean (D)	**53.65**	**50.00**	**46.65**	**42.70**	**41.00**		P x D= NS

Cont…

Table 9 cont…

Parameters	**Prey (P)**	**Density (D)**					**Mean (P)**	**CD** ***(P = 0.05)***
		10	**20**	**40**	**80**	**160**		
Fecundity	Ap	110.0 ± 8.05	180.0 ± 11.95	235.0 ± 6.66	335.0 ± 20.22	346.0 ± 15.83	**241.2**	P= 8.70 D= 14.29 P x D=21.59
	Bb	188.0 ± 9.00	390.0 ± 15.94	470.0 ± 28.28	580.0 ± 41.83	570.0 ± 29.98	**439.6**	
	Mean (D)	**149.0**	**285.0**	**352.5**	**457.5**	**458.0**		
Hatchability (%)	Ap	57.00 ± 1.94 (58.73)	60.00 ± 2.10 (49.03)	65.0 ± 1.33 (50.77)	71.00 ± 1.49 (53.73)	73.00 ± 3.23 (57.42)	**65.20** **(53.94)**	P= 0.601 D= 0.987 P x D=1.49
	Bb	62.00 ± 2.49 (51.9)	72.00 ± 2.90 (58.08)	82.0 ± 2.40 (64.9)	84.00 ± 1.94 (66.46)	85.00 ± 1.88 (67.2)	**77.00** **(61.74)**	
	Mean (D)	**59.50** **(50.49)**	**66.00** **(54.43)**	**73.50** **(59.34)**	**77.50** **(61.94)**	**79.00** **(62.99)**		

Values are Mean ± S.E. Values in parenthesis are arcsine transformed values.
* Ap = *Aphis pomi*, Bb = *Brevicoryne brassicae*
** Number of aphids per day per predator
*** NS = Non-significant

10 days as *B. brassicae* was replaced by *A. pomi* as prey. The period got extended from 5 to 14.5 days as the prey abundance decreased from 160 to 10. The interaction of prey species and prey abundance was significant for *H. variegata* (F = 10.06; d.f. = 4, 90; P<0.0001) but insignificant for *A. tetraspilota* (F = 0.59; d.f. = 4, 90; P=0.665). For both the predators, the variation in the period was insignificant as the prey density decreased from 160 to 80 aphids per day per predator.

4.2.9 Adult longevity

Adult longevity of both *A. tetraspilota* and *H. variegata* male and female individuals was found to be prey species and prey abundance dependent. For *A. tetraspilota*, the analysis of variance revealed significant effect of prey species on longevity of adult males (F = 62.74; d.f. = 1, 90; P<0.0001) and females (F = 88.06; d.f. = 4, 90; P<0.0001). The adult females lived for 51.88 and 48.50 days when fed on *B. brassicae* and *A. pomi*, respectively. In contrast, longevity of males was found to be lower for individuals fed upon *B. brassicae* (41.70 days) as compared to those that preyed upon *A. pomi* (46.42 days). Also, there was significant effect of prey abundance on the longevity of male (F = 42.46; d.f. = 4, 90; P<0.0001) and female (F = 50.99; d.f. = 4, 90; P<0.0001) individuals of *A. tetraspilota*. The longevity of both adult males and females increased with decreasing prey abundance levels. The interaction of prey species and prey abundance was insignificant for longevity of male (F = 0.578; d.f. = 4, 90; P=0.678) but significant for female individuals (F = 47.91; d.f. = 4, 90; P<0.0001).

For *H. variegata*, prey species had a significant effect on the longevity of both adult females (F = 269.58; d.f. = 1, 90; P<0.0001) and males (F = 18.98; d.f. = 1, 90; P<0.0001). The longevity of male adults was noted lower (45.48 days) on *B. brassicae* and comparatively higher (48.12 days) on *A. pomi*. In contrast, female adults lived longer when fed on *B. brassicae* (56.04 days) than when fed upon *A. pomi* (48.20 days). Similarly prey abundance also affected the longevity of adult females (F = 99.65; d.f. = 4, 90; P<0.0001) and males (F = 58.63; d.f. = 4, 90; P<0.0001) significantly. The longevity of both adult females and males increased with decreasing prey density. The adult males lived for a maximum of 54.2 days while the females lived for a maximum of 60.00 days. The longevity of adult females of both the predators was found to be at par at the prey density of 80 and 160 aphids per day. Same trend was noted for the longevity of adult males of both the predator species.

4.2.10 Fecundity

For both the predators, the fecundity was found to be strongly influenced by quality and quantity of prey. For *A. tetraspilota*, analysis of variance revealed significant effects of prey species (F = 6647.8; d.f. = 1, 90; P<0.0001) and prey abundance (F = 945.06; d.f. = 4, 90; P<0.0001) on the fecundity of the females. The females were found to lay more eggs when fed on *B. brassicae* (435.8 eggs per female) as compared to *A. pomi* (217.4 eggs per female). The fecundity decreased from 422 to 205.9 eggs as the prey abundance decreased from 160 to 10 aphids per day, however the interaction effect was insignificant on fecundity (F = 1.99; d.f. = 4, 90; P=0.1026).

For *H. variegata*, the analysis of variance revealed a significant effect of prey species (F = 2095.34; d.f. = 1, 90; P<0.0001) and prey abundance (F = 717.48; d.f. = 4, 90; P<0.0001) besides a significant interaction effect (F = 50.03; d.f. = 4, 90; P<0.0001) on the fecundity of females. As with *A. tetraspilota*, the fecundity of *H. variegata* females was significantly higher on *B. brassicae* (439.6 eggs per female) as compared to *A. pomi* (241.2 eggs per female). Maximum fecundity (458.0) was noted on highest prey density and the minimum (149.0) on lowest prey abundance level. The variation in fecundity was found to be statistically insignificant between the prey density of 80 and 160 aphids per day.

4.2.11 Hatchability (%)

Just like most other characters, the hatchability of eggs of both the predators was found to be dependent on prey species and prey abundance. For *A. tetraspilota*, hatchability (%) varied from 43.00 % to 82.00%. The maximum hatchability was noted for the eggs laid by females fed upon *B. brassicae* at the abundance level of 160 aphids per day and the lowest for the eggs laid by females fed upon *A. pomi* at the lowest prey abundance level i.e.10 aphids per day.

For *H. variegata*, hatchability (%) was found to vary from 57.00 to 85.00 %. The lowest hatchability was noted for the eggs laid by females fed upon *A. pomi* at abundance level of 10 aphids per day (lowest prey density) and highest on the eggs laid by the females fed upon *B. brassicae* with highest abundance (160 aphids per day). The hatchability was found to be better for eggs of *H. variegata* as compared to those of *A. tetraspilota* under same prey species and prey abundance conditions.

4.3 Functional response of *Adalia tetraspilota* and *Hippodamia variegata* to three aphid species

4.3.1 Prey consumption rates and nature of functional response

The prey consumption rates and per cent prey consumed by 1st, 2nd, 3rd and 4th instar larvae and adult male and female individuals of the coccinellids predators, *Adalia tetraspilota* and *Hippodamia variegata* on three aphid species viz. *Aphis pomi*, *Aphis craccivora*, and *Brevicoryne brassicae* are presented in Table 10 to 15. A perusal of the data indicates that the predatory growth stages of both the predators consume *A. craccivora* nymphs the most, followed by *B. brassicae* and *A. pomi*. The 1st instar larvae of *A. tetraspilota* consumed a maximum of 19.3 ± 1.344 *A. craccivora* nymphs per day followed by those of *B. brassicae* (12.5 ± 1.377) and *A. pomi* (1.3 ± 0.677). The prey consumption rates increased from 4.53 ± 0.409 to 11.30 ± 0.677 as the offered prey density increased from 10 to 160 per predator for *A. pomi* and from 7.46 ± 0.400 to 19.3 ± 1.344 for *A. craccivora*. For *B. brassicae*, the prey consumption rates increased from 7 ± 0.428 to 12.5 ± 1.18 as the offered prey density increased from 10 to 80; however, it declined slightly thereafter. Comparatively, the 1st instar larvae of *H. variegata* consumed slightly higher number of aphids per day: 12.7 ± 1.111 for *A. pomi*, 20.3±1.344 for *A. craccivora* and 17.7 ± 0.722 for *B. brassicae.*

The 2nd instar larvae of *A. tetraspilota* consumed a maximum of 15.0 ± 0.544, 23.2 ± 0.622 and 20.0 ± 1.111 aphids per day of *A. pomi*, *A. craccivora* and *B. brassicae*, respectively in 24 hours. The corresponding figures for 2nd instar larvae of *H. variegata* were recorded as 16.7 ± 0.6778, 25.70 ± 0.622 and 22.0 ± 0.444, respectively. Maximum consumption rate for 3rd instar larvae of *A. tetraspilota* was recorded on *A. craccivora* as 26.2 ± 0.844 aphids per day. The maximum consumption on aphids per day for 3rd instar larvae of *H. variegata* was 29.5 ± 0.722 when *A.*

craccivora was used as prey. The trend was similar for 4th instar larvae of both the predators as well as the adult male and female ladybeetles.

Among the various predatory growth stages of *A. tetraspilota* used, the aphid consumption was recorded as maximum by the 4th instar larvae followed by the adult female on all the three prey species used. Same trend was noted for *H. variegata*. Among all the growth stages, the predatory individuals of *H. variegata* consumed more number of aphids per day as compared to those of *A. tetraspilota*.

Percentage of prey consumed by all predatory stages decreased as the offered prey density increased on all the prey species used for both the predators. The percentage of prey consumed by each predatory stage of both the predatory species on all the three species used, declined monotonically with increasing prey density as depicted in Figure 1 and 2. The graphical analysis of percentage of prey consumed versus offered prey density suggested type II functional response for all the predatory stages of both the predators on all the three prey species used. It was further confirmed by the estimates of logistic regression model. The linear coefficient of logistic regression model consistently assumed significant negative (<0) values for all the growth stages of both the predators on all the three prey species (Table 16 to 21).

4.3.2 Parameters of functional response

The handling time (T_h) and attack rate (a) are the parameters that reflect the significance of functional response. As the polynomial logistic regression model suggested the type II functional response for all the predatory stages of both the predators, *A. tetraspilota* and *H. variegata* on all three prey species namely, *A. pomi*, *A. craccivora* and *B. brassicae*, the data on predation rates was fitted to the random predator equation to estimate the handling time (T_h) and attack rate (a). The estimates are presented in Table 22 to 27.

The maximum handling time was noted for 1st larvae of *A. tetraspilota* when *A. pomi* was used as prey (1.942 ± 0.129) followed by 2nd instar larvae and adult male with T_h noted as 1.430 ± 0.039 and 1.235 ± 0.066, respectively (Table 22). The lowest handling time was noted for 4th instar larvae (1.020 ± 0.008) followed by adult female

Table 10. Predation rates (Mean ± S.E.) and per cent prey consumption for first instar larvae of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replica-tions**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed
Adalia tetraspilota	10	15	4.53 ± 0.63	45.30	7.46 ± 0.59	74.60	7.0 ± 0.65	70.00
	20	15	6.0 ± 0.82	30.00	11.26 ± 0.88	56.30	10.0 ± 1.55	50.00
	40	10	10.80 ± 1.47	27.00	15.2 ± 0.63	38.00	11.8 ± 1.10	29.50
	80	10	11.0 ± 0.87	13.75	17.8 ± 0.91	21.25	12.5 ± 1.18	15.62
	160	10	11.30 ± 0.82	7.06	19.3 ± 1.15	12.06	12.4 ± 1.17	7.75
Hippodamia variegata	10	15	4.46 ± 0.73	44.60	8.00 ± 0.96	80.00	6.46 ± 1.06	64.60
	20	15	6.46 ± 0.74	32.30	11.46 ± 1.06	57.30	10.46 ± 0.99	52.30
	40	10	10.7 ± 1.05	26.75	15.2 ± 0.78	38.00	12.20 ± 0.92	30.50
	80	10	11.5 ± 0.96	14.37	18.0 ± 1.41	22.50	14.20 ± 0.67	17.75
	160	10	12.7 ± 1.05	7.93	20.30 ± 1.16	12.68	17.7 ± 0.84	11.06

Table 11. Predation rates (Mean ± S.E.) and per cent prey consumption by second instar larvae of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replications**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed
Adalia tetraspilota	10	15	4.76 ± 0.79	47.5	8.26 ± 0.59	82.6	7.2 ± 0.74	72.00
	20	15	7.73 ± 0.70	38.65	12.73 ± 1.03	63.65	12.53 ± 0.74	62.65
	40	10	11.0 ± 1.05	27.5	16.5 ± 0.70	41.25	15.3 ± 0.82	38.25
	80	10	14.2 ± 0.63	17.75	20.2 ± 1.03	25.25	19.2 ± 0.63	24.00
	160	10	15.0 ± 0.73	9.37	23.2 ± 0.78	14.50	20.0 ± 1.05	12.50
Hippodamia variegata	10	15	4.46 ± 0.77	44.60	8.46 ± 0.64	84.60	6.73 ± 0.59	67.30
	20	15	8.26 ± 0.88	41.30	13.0 ± 1.07	65.00	12.73 ± 0.59	63.65
	40	10	11.7 ± 0.63	29.25	16.70 ± 0.82	41.75	16.0 ± 0.67	40.00
	80	10	15.0 ± 0.66	18.75	21.70 ± 0.82	27.12	18.70 ± 0.94	23.37
	160	10	16.7 ± 0.83	10.44	25.70 ± 0.78	16.06	22.0 ± 0.67	13.75

Table 12. Predation rates (Mean ± S.E.) and per cent prey consumption for third instar larvae of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replica-tions**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed
Adalia tetraspilota	10	15	4.53 ± 0.63	45.30	9.46 ± 0.64	94.60	7.26 ± 0.74	72.60
	20	15	8.0 ± 0.75	40.00	15.0 ± 0.92	75.00	14.53 ± 0.64	72.65
	40	10	11.8 ± 0.63	29.50	20.2 ± 0.63	50.50	15.5 ± 0.71	38.75
	80	10	17.0 ± 0.66	21.25	22.8 ± 0.92	28.50	20.5 ± 0.53	25.62
	160	10	16.70 ± 1.15	10.44	26.2 ± 0.91	16.37	21.4 ± 0.96	13.37
Hippodamia variegata	10	15	5.46 ± 0.52	54.60	9.46 ± 0.63	94.60	7.26 ± 0.80	72.60
	20	15	9.0 ± 1.000	45.00	15.26 ± 0.70	76.30	13.26 ± 0.72	66.30
	40	10	14.2 ± 0.63	35.50	21.2 ± 0.92	53.00	18.0 ± 0.67	45.00
	80	10	19.0 ± 1.05	23.75	24.3 ± 0.67	30.37	22.0 ± 0.82	27.5
	160	10	21.0 ± 1.13	13.12	29.5 ± 0.85	18.44	24.2 ± 0.63	15.12

Table 13. Predation rates (Mean ± S.E.) and per cent prey consumption for fourth instar larvae of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replications**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed
Adalia tetraspilota	10	15	7.0 ± 0.65	70.00	9.37 ± 0.59	97.30	7.53 ± 0.83	75.30
	20	15	11 ± 0.65	55.00	16.26 ± 0.88	81.30	15.73 ± 0.79	78.65
	40	10	15.5 ± 0.70	38.75	22.5 ± 0.96	56.26	17.0 ± 0.81	42.50
	80	10	19.5 ± 0.97	24.37	27.7 ± 0.67	36.62	24.7 ± 0.78	30.87
	160	10	21.3 ± 0.94	13.31	29.8 ± 0.63	18.62	25.3 ± 1.15	15.81
Hippodamia variegata	10	15	7.46 ± 0.74	74.60	9.73 ± 0.46	97.30	8.0 ± 0.85	80.00
	20	15	12.0 ± 2.44	60.00	17.2 ± 1.03	86.00	15.26 ± 1.34	76.30
	40	10	17.0 ± 1.05	42.50	26.3 ± 2.59	65.75	20.7 ± 2.05	51.75
	80	10	22.0 ± 1.24	27.50	30.5 ± 1.35	38.12	28.0 ± 1.49	35.00
	160	10	23.0 ± 1.56	14.37	33.5 ± 1.96	20.93	29.8 ± 2.48	18.62

Table 14. Predation rates (Mean ± S.E.) and per cent prey consumption for adult males of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replications**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed
Adalia tetraspilota	10	15	5.53 ± 1.50	55.30	8.53 ± 0.83	85.30	7.0 ± 0.84	70.00
	20	15	8.26 ± 1.06	41.30	14.73 ± 1.16	73.65	12.53 ± 0.74	41.76
	40	10	12.0 ± 0.94	30.00	19.20 ± 1.32	48.00	15.5 ± 1.07	38.75
	80	10	16.5 ± 1.08	20.62	22.0 ± 1.19	27.50	19.7 ± 1.06	24.62
	160	10	17.0 ± 0.91	10.62	25.0 ± 0.67	15.62	19.5 ± 0.84	12.19
Hippodamia variegata	10	15	5.46 ± 0.83	54.60	8.26 ± 0.88	82.60	7.0 ± 0.84	70.00
	20	15	9.0 ± 0.76	45.00	15.0 ± 0.65	75.00	13.46 ± 0.73	67.30
	40	10	13.7 ± 0.94	34.25	20.0 ± 0.92	50.50	17.7 ± 0.67	44.25
	80	10	18.8 ± 1.03	23.50	24.2 ± 0.82	30.25	21.2 ± 0.92	26.50
	160	10	20.5 ± 1.08	12.80	28.3 ± 1.32	17.68	24.7 ± 0.95	15.44

Table 15. Predation rates (Mean ± S.E.) and per cent prey consumption for adult females of *Adalia tetraspilota* and *Hippodamia variegata* on three prey species.

Predator	**Prey density offered (N_0)**	**Replica-tions**	**Prey species**					
			Aphis pomi		***Aphis craccivora***		***Brevicoryne brassicae***	
			Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed	Prey consumed (N)	% prey consumed
Adalia tetraspilota	10	15	5.73 ± 0.70	57.30	9.73 ± 0.59	97.30	7.33 ± 0.59	73.30
	20	15	9.53 ± 0.83	47.65	15.73 ± 0.52	78.65	15.0 ± 0.88	75.00
	40	10	14.0 ± 0.81	35.00	23.7 ± 0.82	59.25	16.5 ± 0.52	41.25
	80	10	18.0 ± 0.66	22.50	28.2 ± 1.05	35.25	24.2 ± 0.56	30.25
	160	10	19.8 ± 0.78	12.37	29.50 ± 0.85	18.43	25.0 ± 1.05	15.62
Hippodamia variegata	10	15	6.26 ± 0.59	62.60	9.46 ± 0.52	94.60	8.53 ± 0.64	85.30
	20	15	10.73 ± 0.88	53.65	16.0 ± 0.96	80.00	14.73 ± 1.28	73.65
	40	10	16.5 ± 1.35	41.25	24.5 ± 0.85	61.25	20.7 ± 0.95	51.75
	80	10	21.5 ± 1.58	26.87	29.0 ± 1.15	36.25	26.3 ± 0.92	32.87
	160	10	22.5 ± 1.43	14.06	32.8 ± 0.92	20.50	29.5 ± 1.51	18.44

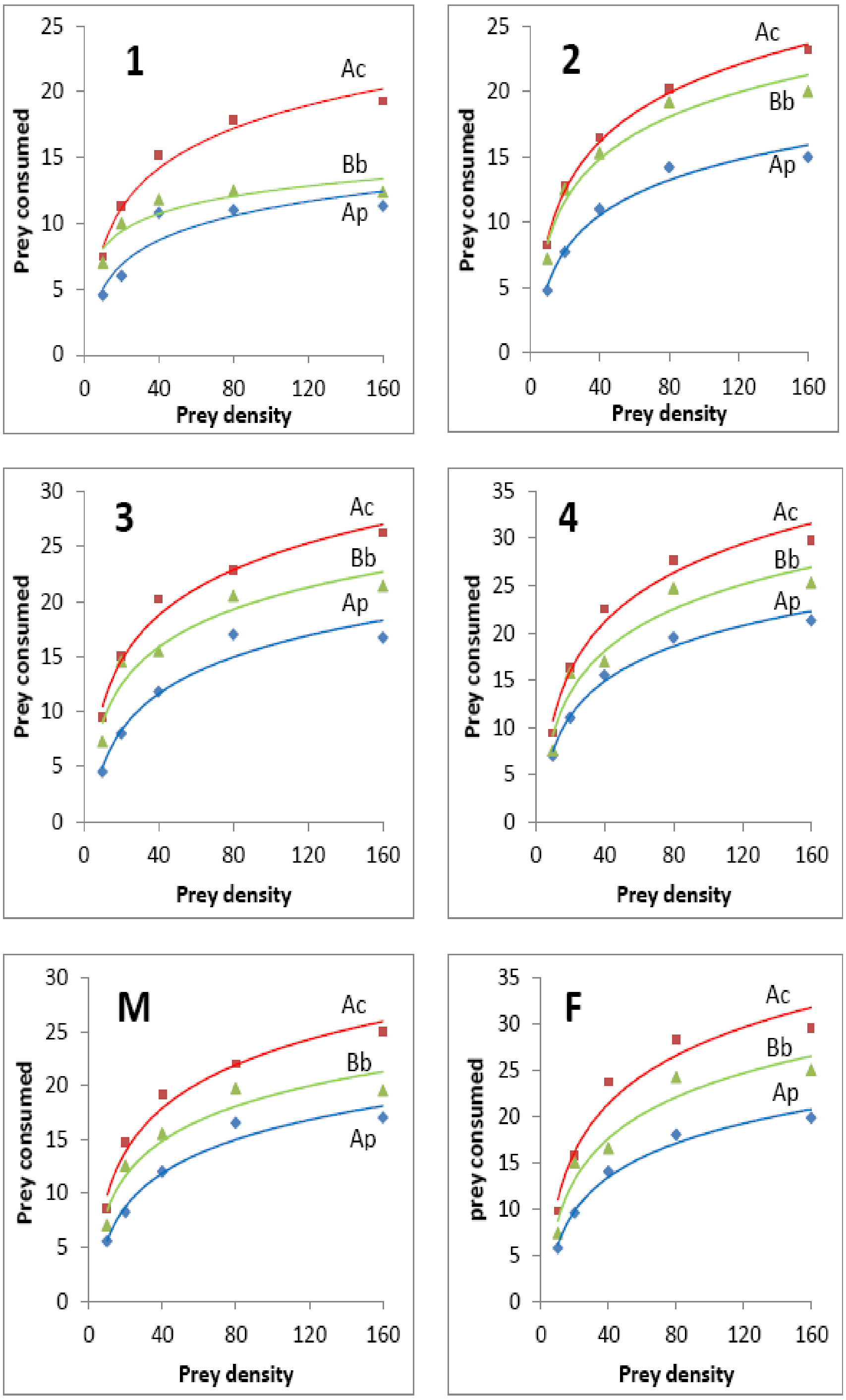

Figure 1. Prey consumption versus prey density offered for various growth stages of *Adalia tetraspilota* on three aphid species; Ac = *Aphis craccivora*, Bb = *Brevicoryne brassicae*, Ap = *A. pomi*. 1, 2, 3, 4 refer to 1st, 2nd, 3rd and 4th instar larvae and M, F for adult male and female of *A. tetraspilota*.

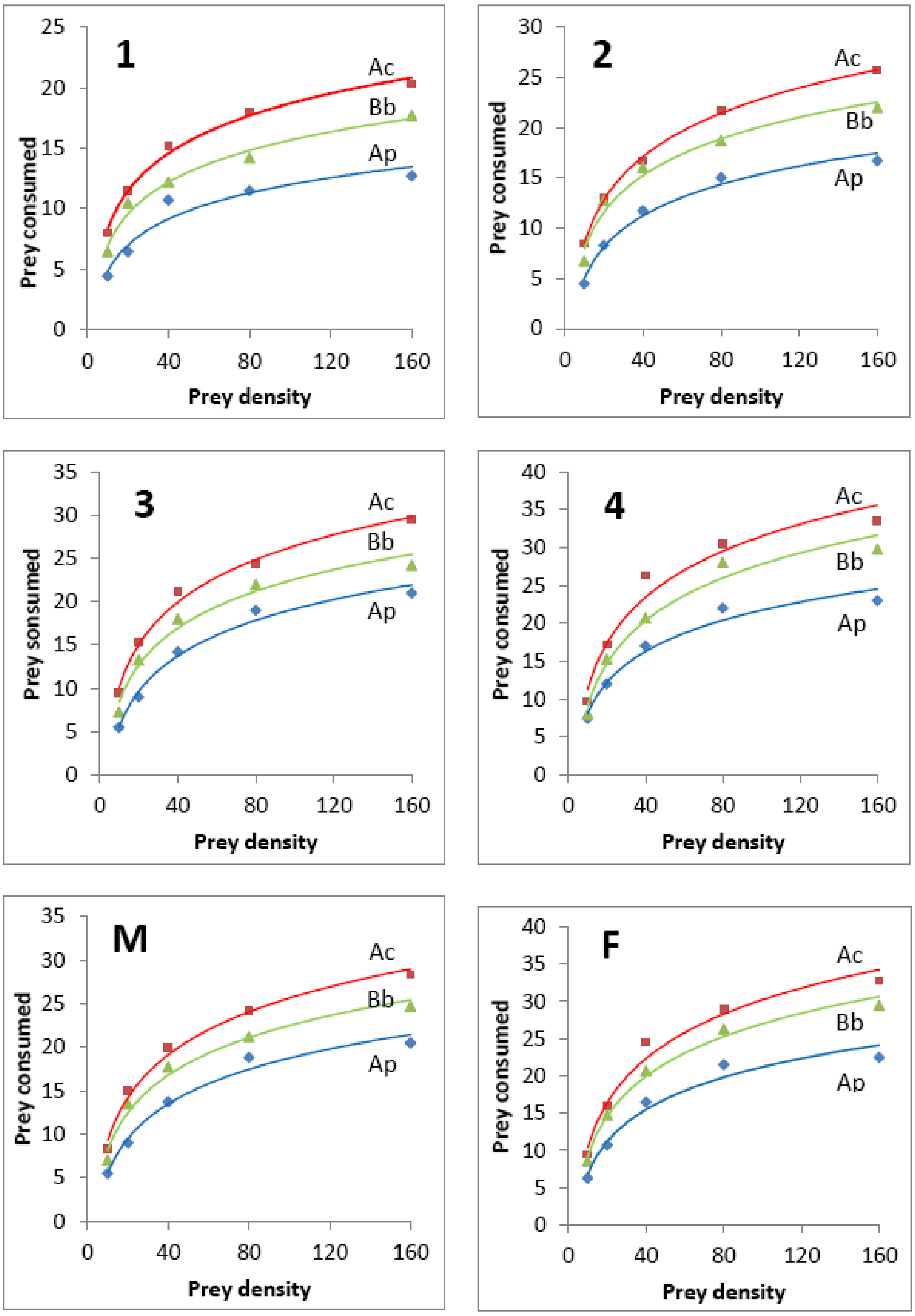

Figure 2. Prey consumption versus prey density offered for various growth stages of *Hippodamia variegata* on three aphid species; Ac = *Aphis craccivora*, Bb = *Brevicoryne brassicae*, Ap = *A. pomi*. 1, 2, 3, 4 refer to 1st, 2nd, 3rd and 4th instar larvae and M, F for adult male and female of *H. variegata*.

Table 16. Maximum likelihood estimates from logistic regression analysis of the proportion of *Aphis pomi* eaten by different stages of *Adalia tetraspilota* against initial number of aphids offered.

Growth stage	Parameters	Estimates	S.E.	Z value	*Pr* (Z)
First instar	Intercept	1.621	9.974	0.163	0.871
	Linear	-2.381e-02	5.983e-02	-0.398	0.691
	Quadratic	2.156e-05	8.999e-04	0.024	0.981
	Cubic	2.055e-07	3.552e-06	0.058	0.954
Second instar	Intercept	2.894e-01	9.769e-01	0.296	0.767
	Linear	-4.384e-02	5.842e-02	-0.751	0.453
	Quadratic	3.525e-04	8.739e-04	0.403	0.687
	Cubic	-1.115e-06	3.435e-06	-0.325	0.745
Third instar	Intercept	1.862e-01	9.713e-01	0.192	0.848
	Linear	-3.719e-02	5.761e-02	-0.646	0.519
	Quadratic	3.205e-04	8.572e-04	0.374	0.708
	Cubic	-1.121e-06	3.359e-06	-0.334	0.739
Fourth instar	Intercept	1.399	9.970e-01	1.403	0.161
	Linear	-6.861e-02	5.750e-02	-1.193	0.233
	Quadratic	6.239e-04	8.457e-04	0.738	0.461
	Cubic	-2.019e-06	3.297e-06	-0.612	0.540
Adult male	Intercept	6.656e-01	9.697e-01	0.686	0.492
	Linear	-5.800e-02	5.766e-02	- 1.006	0.314
	Quadratic	5.685e-04	8.587e-04	0.662	0.508
	Cubic	-1.970e-06	3.367e-06	-0.585	0.558
Adult female	Intercept	6.951e-01	9.627e-01	0.722	0.470
	Linear	-4.520e-02	5.651e-02	-0.800	0.424
	Quadratic	3.476e-04	8.379e-04	0.415	0.678
	Cubic	-1.054e-06	3.279e-06	-0.321	0.748

Table 17. Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by different stages of *Adalia tetraspilota* against initial number of aphids offered.

Growth stage	Parameters	Estimates	S.E.	Z value	*Pr* (Z)
First instar	Intercept	1.604	1.012	1.585	0.113
	Linear	-9.303e-02	5.977e-02	-1.557	0.120
	Quadratic	8.768e-04	8.915e-04	0.984	0.325
	Cubic	-2.843e-06	3.504e-06	-0.811	0.417
Second instar	Intercept	1.836	1.036	1.773	0.0763
	Linear	-8.568e-02	5.902e-02	-1.452	0.1466
	Quadratic	8.191e-04	8.638e-04	0.948	0.3430
	Cubic	-2.696e-06	3.360e-06	-0.802	0.4224
Third instar	Intercept	2.330	1.095	2.127	0.0334
	Linear	-1.037e-01	6.123e-02	-1.694	0.0903
	Quadratic	1.044e-03	8.877e-04	1.176	0.2398
	Cubic	-3.496e-06	3.437e-06	-1.017	0.3091
Fourth instar	Intercept	2.704	1.158	2.335	0.0196
	Linear	-1.149e-01	6.339e-02	-1.812	0.0700
	Quadratic	1.224e-03	9.086e-04	1.347	0.1779
	Cubic	-4.232e-06	3.497e-06	-1.210	0.2263
Adult male	Intercept	1.707	1.025	1.666	0.0956
	Linear	-7.904e-02	5.850e-02	- 1.351	0.1766
	Quadratic	7.414e-04	8.567e-04	0.865	0.3868
	Cubic	-2.445e-06	3.334e-06	-0.733	0.4634
Adult female	Intercept	2.430	1.112	2.185	0.0289
	Linear	-1.062e-01	6.164e-02	-1.722	0.0850
	Quadratic	1.127e-03	8.887e-04	1.269	0.2046
	Cubic	-3.904e-06	3.431e-06	-1.138	0.2551

Table 18. Maximum likelihood estimates from logistic regression analysis of the proportion of *Aphis craccivora* eaten by different stages of *Adalia tetraspilota* against initial number of aphids offered.

Growth stage	**Parameters**	**Estimates**	**S.E.**	**Z value**	***Pr* (Z)**
First instar	Intercept	1.698	1.022	1.662	0.0965
	Linear	- 8.176e-02	5.864e-02	-1.394	0.1632
	Quadratic	7.567e-04	8.616e-04	0.878	0.3798
	Cubic	-2.435e-06	3.359e-06	-0.725	0.4685
Second instar	Intercept	2.359	1.099	2.147	0.0318
	Linear	-1.051e-01	6.138e-02	- 1.712	0.0868
	Quadratic	1.057e-03	8.896e-04	1.188	0.2348
	Cubic	-3.509e-06	3.444e-06	-1.019	0.3083
Third instar	Intercept	3.500	1.343	2.607	0.00913
	Linear	-1.352e-01	7.060e-02	- 1.915	0.05554
	Quadratic	1.355e-03	9.929e-04	1.365	0.17219
	Cubic	-4.444e-06	3.788e-06	-1.173	0.24076
Fourth instar	Intercept	4.180	1.548	2.700	0.00693
	Linear	-1.557e-01	7.875e-02	- 1.978	0.04798
	Quadratic	1.637e-03	1.086e-03	1.507	0.13184
	Cubic	-5.530e-06	4.104e-06	-1.348	0.17780
Adult male	Intercept	2.726	1.192e+00	2.288	0.0222
	Linear	-1.037e-01	6.461e-02	-1.604	0.1087
	Quadratic	9.609e-04	9.234e-04	1.041	0.2981
	Cubic	-3.034e-06	3.551e-06	-0.854	0.3930
Adult female	Intercept	3.670	1.456	2.520	0.0117
	Linear	-1.272e-01	7.508e-02	-1.695	0.0902
	Quadratic	1.252e-03	1.044e-03	1.200	0.2302
	Cubic	-4.114e-06	3.956e-06	-1.040	0.2983

Table 19. Maximum likelihood estimates from logistic regression analysis of the proportion of *Aphis pomi* eaten by different stages of *Hippodamia variegata* against initial number of aphids offered.

Growth stage	Parameters	Estimates	S.E.	Z value	*Pr* (Z)
First instar	Intercept	8.865e-02	9.933e-01	0.089	0.929
	Linear	-2.709e-02	5.957e-02	-0.455	0.649
	Quadratic	7.271e-05	8.953e-04	0.081	0.935
	Cubic	2.689e-08	3.531e-06	0.008	0.994
Second instar	Intercept	1.504e-01	9.715e-01	0.155	0.877
	Linear	-3.174e-02	5.771e-02	-0.550	0.582
	Quadratic	1.788e-04	8.612e-04	0.208	0.836
	Cubic	-4.388e-07	3.382e-06	-0.130	0.897
Third instar	Intercept	4.734e-01	9.581e-01	0.494	0.621
	Linear	-3.631e-02	5.624e-02	-0.646	0.518
	Quadratic	2.614e-04	8.335e-04	0.314	0.754
	Cubic	-7.922e-07	3.260e-06	-0.243	0.808
Fourth instar	Intercept	1.683	1.026	1.641	0.101
	Linear	-7.432e-02	5.829e-02	-1.275	0.202
	Quadratic	7.007e-04	8.510e-04	0.823	0.410
	Cubic	-2.323e-06	3.305e-06	-0.703	0.482
Adult male	Intercept	5.442e-01	9.602e-01	0.567	0.571
	Linear	-4.241e-02	5.648e-02	-0.751	0.453
	Quadratic	3.529e-04	8.374e-04	0.421	0.673
	Cubic	-1.150e-06	3.276e-06	-0.351	0.726
Adult female	Intercept	8.776e-01	9.679e-01	0.907	0.365
	Linear	-4.110e-02	5.603e-02	-0.733	0.463
	Quadratic	2.887e-04	8.252e-04	0.350	0.726
	Cubic	-8.554e-07	3.218e-06	-0.266	0.790

Table 20. Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by different stages of *Hippodamia variegata* against initial number of aphids offered.

Growth stage	Parameters	Estimates	S.E.	Z value	*Pr* (Z)
First instar	Intercept	1.38	9.961e-01	1.390	0.164
	Linear	-8.049e-02	5.867e-02	-1.372	0.170
	Quadratic	7.320e-04	8.729e-04	0.839	0.402
	Cubic	-2.278e-06	3.425e-06	-0.665	0.506
Second instar	Intercept	1.491	1.012e	1.473	0.141
	Linear	-6.332e-02	5.790e-02	-1.094	0.274
	Quadratic	4.781e-04	8.497e-04	0.563	0.574
	Cubic	-1.327e-06	3.311e-06	-0.401	0.689
Third instar	Intercept	1.687	1.039	1.623	0.105
	Linear	-6.482e-02	5.861e-02	-1.106	0.269
	Quadratic	5.176e-04	8.536e-04	0.606	0.544
	Cubic	-1.536e-06	3.312e-06	-0.464	0.643
Fourth instar	Intercept	2.396	1.155	2.075	0.038
	Linear	-8.507e-02	6.300e-02	-1.350	0.177
	Quadratic	8.026e-04	9.012e-04	0.891	0.373
	Cubic	-2.638e-06	3.465e-06	-0.761	0.446
Adult male	Intercept	1.622	1.032	1.572	0.116
	Linear	-6.254e-02	5.836e-02	-1.072	0.284
	Quadratic	4.980e-04	8.514e-04	0.585	0.559
	Cubic	-1.625e-06	3.308e-06	-0.491	0.623
Adult female	Intercept	2.591	1.183	2.191	0.0285
	Linear	-9.416e-02	6.413e-02	-1.468	0.1420
	Quadratic	8.922e-04	9.151e-04	0.975	0.3296
	Cubic	-2.893e-06	3.515e-06	-0.823	0.4103

Table 21. Maximum likelihood estimates from logistic regression analysis of the proportion of *Aphis craccivora* eaten by different stages of *Hippodamia variegata* against initial number of aphids offered.

Growth stage	Parameters	Estimates	S.E.	Z value	*Pr* (Z)
First instar	Intercept	8.776e-01	9.679e-01	0.907	0.365
	Linear	-4.110e-02	5.603e-02	-0.733	0.463
	Quadratic	2.887e-04	8.252e-04	0.350	0.726
	Cubic	-8.554e-07	3.218e-06	-0.266	0.790
Second instar	Intercept	2.567	1.124	2.283	0.022
	Linear	-1.151e-01	6.235e-02	-1.846 .	0.064
	Quadratic	1.213e-03	8.997e-04	1.348	0.177
	Cubic	-4.117e-06	3.475e-06	-1.185	0.236
Third instar	Intercept	3.478	1.359	2.559	0.010
	Linear	-1.293e-01	7.118e-02	-1.817	0.069
	Quadratic	1.274e-03	9.986e-04	1.276	0.202
	Cubic	-4.123e-06	3.805e-06	-1.084	0.278
Fourth instar	Intercept	4.161	1.696e	2.453	0.014
	Linear	-1.310e-01	8.509e-02	-1.540	0.123
	Quadratic	1.221e-03	1.164e-03	1.049	0.294
	Cubic	-3.851e-06	4.377e-06	-0.880	0.378
Adult male	Intercept	2.498e	1.169e	2.136	0.032
	Linear	-8.892e-02	6.362e-02	-1.398	0.162
	Quadratic	7.826e-04	9.101e-04	0.860	0.389
	Cubic	-2.403e-06	3.501e-06	-0.686	0.492
Adult female	Intercept	3.366	1.415	2.378	0.017
	Linear	-1.079e-01	7.353e-02	-1.467	0.142
	Quadratic	9.803e-04	1.026e-03	0.955	0.339
	Cubic	-3.065e-06	3.896e-06	-0.787	0.431

Table 22. Estimates of attack rate (a) and handling time (T_h) for various growth stages of *Adalia tetraspilota* preying upon *Aphis pomi*, for random predator equation.

Growth stage	**Parameters***	**Estimate**	**S.E.**	**t - value**	***Pr* (t)**
First instar	a	0.0434	0.0259	1.675	0.1925
	T_h	1.9420	0.1293	15.020	0.0064
Second instar	a	0.0418	0.0073	5.66	0.0109
	T_h	1.4308	0.0392	36.48	4.53e-05
Third instar	a	0.0322	0.0178	1.806	0.1687
	T_h	1.1788	0.1574	7.496	0.049
Fourth instar	a	0.064	0.0036	17.34	0.0004
	T_h	1.0205	0.0083	122.29	1.21e-06
Adult male	a	0.0426	0.0132	3.233	0.0481
	T_h	1.2351	1.0668	18.488	0.00034
Adult female	a	0.0508	0.0036	13.99	0.0079
	T_h	1.0776	0.0129	83.21	3.83e-06

*a in hours^{-1} and T_h in hours

Table 23. Estimates of attack rate (*a*) and handling time (T_h) for various growth stages of *Adalia tetraspilota* preying upon *Aphis craccivora*, for random predator equation.

Growth stage	Parameters*	Estimate	S.E.	t- value	*Pr* (t)
First instar	a	0.07431	0.00223	33.32	5.94e-05
	T_h	1.15446	0.00381	302.42	7.97e-08
Second instar	a	0.06120	0.00795	7.692	0.00457
	T_h	0.92714	0.01972	47.01	2.12e-05
Third instar	a	0.08163	0.01583	5.158	0.0141
	T_h	0.83546	0.02223	37.57	4.15e-05
Fourth instar	a	0.12758	0.00849	15.01	0.00064
	T_h	0.75073	0.00480	156.20	5.79e-07
Adult male	a	0.0808	0.01325	6.09	0.00885
	T_h	0.87878	0.01902	46.21	2.23e-05
Adult female	a	0.17436	0.02259	7.71	0.00452
	T_h	0.772611	0.00680	113.58	1.50e-06

*a in hours^{-1} and T_h in hours

Table 24. Estimates of attack rate (a) and handling time (T_h) for various growth stages of *Adalia tetraspilota* preying upon *Brevicoryne brassicae*, for random predator equation.

Growth stage	Parameters*	Estimate	S.E.	t- value	Pr (t)
First instar	a	0.04342	0.02593	1.675	0.19256
	T_h	1.94207	0.12930	15.02	0.00064
Second instar	a	0.04184	0.00739	5.66	0.0109
	T_h	1.43081	0.03922	36.48	4.53e-05
Third instar	a	0.03221	0.01784	1.806	0.16871
	T_h	1.17998	0.15742	7.496	0.00492
Fourth instar	a	0.06413	0.00369	17.34	0.00041
	T_h	1.02056	0.00834	122.29	1.21e-06
Adult male	a	0.04266	0.01320	3.233	0.04811
	T_h	1.23514	0.06681	18.48	0.00034
Adult female	a	0.05082	0.00363	13.99	0.00079
	T_h	1.07765	0.01295	83.21	3.83e-06

*a in hours^{-1} and T_h in hours

Table 25. Estimates of attack rate (*a*) and handling time (T_h) for various growth stages of *Hippodamia variegata* preying upon *Aphis pomi*, for random predator equation.

Growth stage	**Parameters***	**Estimate**	**S.E.**	**t- value**	***Pr* (t)**
First instar	a	0.03304	0.00889	3.717	0.0338
	T_h	1.16433	0.07484	15.55	0.0005
Second instar	a	0.05405	0.00988	5.468	0.0120
	T_h	0.97097	0.03144	30.87	7.46e-05
Third instar	a	0.08023	0.00305	26.3	0.0001
	T_h	0.90752	0.00440	206.1	2.52e-07
Fourth instar	a	0.10279	0.02054	5.006	0.01530
	T_h	0.73441	0.01779	41.29	3.13e-05
Adult male	a	0.06186	0.00864	7.158	0.00561
	T_h	0.86497	0.02088	41.41	3.1e-05
Adult female	a	0.08592	0.00430	19.95	0.00027
	T_h	0.73356	0.00536	136.8	8.6e-07

*a in hours^{-1} and T_h in hours

Table 26. Estimates of attack rate (*a*) and handling time (T_h) for various growth stages of *Hippodamia variegata* preying upon *Aphis craccivora*, for random predator equation.

Growth stage	**Parameters**	**Estimate**	**Std. Error**	**t- value**	***Pr* (t)**
First instar	a	0.06105	0.00707	8.63	0.0032
	T_h	1.07593	0.0178	60.40	1e-05
Second instar	a	0.05391	0.00783	6.87	0.0062
	T_h	0.81036	0.02465	32.87	6.19e-05
Third instar	a	0.06700	0.01521	4.40	0.0216
	T_h	0.71392	0.03124	22.85	0.0001
Fourth instar	a	0.14429	0.01341	10.76	0.0017
	T_h	0.66856	0.00593	112.60	1.54e-06
Adult male	a	0.07237	0.01086	6.66	0.0068
	T_h	0.75567	0.01914	39.48	3.57e-05
Adult female	a	0.10670	0.01127	9.46	0.0025
	T_h	0.66733	0.00912	73.14	5.63e-06

*a in hours^{-1} and T_h in hours

Table 27. Estimates of attack rate (*a*) and handling time (T_h) for various growth stages of *Hippodamia variegata* preying upon *Brevicoryne brassicae*, for random predator equation.

Growth stage	**Parameters**	**Estimate**	**S.E.**	**t- value**	***Pr* (t)**
First instar	*a*	0.039410	0.007857	5.016	0.0153
	T_h	1.722287	0.047736	36.079	4.68e-05
Second instar	*a*	0.039024	0.002173	17.96	0.000377
	T_h	1.265181	0.013122	96.42	2.46e-06
Third instar	*a*	0.046697	0.005205	8.972	0.00292
	T_h	0.994083	0.021749	45.708	2.31e-05
Fourth instar	*a*	0.08117	0.01797	4.518	0.0203
	T_h	0.95328	0.02523	37.788	4.08e-05
Adult male	*a*	0.045798	0.006889	6.648	0.00693
	T_h	1.016929	0.029934	33.972	5.61e-05
Adult female	*a*	0.07006	0.01732	4.044	0.0272
	T_h	0.96121	0.03253	29.551	8.51e-05

**a* in hours^{-1} and T_h in hours

(1.077 ± 0.012). The highest attack rate was noted for 4th instar larvae (0.064 ± 0.003) followed by adult female (0.050 ± 0.003).

With *A. craccivora* as prey, the minimum handling time was noted for 4th instar larvae (0.750 ± 0.004) followed by adult female (0.772 ± 0.006) (Table 23). The maximum attack rate was noted for adult female (0.174 ± 0.022) followed by 4th instar larvae (0.127 ± 0.008). Same trend was noted for both handling time and attack rate when *B. brassicae* was used as prey for evaluating the functional response of various growth stages of *A. tetraspilota* (Table 24). Among the three prey species, minimum handling time was exhibited by 4th instar larvae of *A. tetraspilota* on *A. craccivora* (0.750 ± 0.004) and maximum attack rate was possessed by adult females of against *A. craccivora* (0.1743 ± 0.022).

With *H. variegata* preying upon *A. pomi*, minimum handling time was exhibited by adult female (0.733 ± 0.005) followed by 4th instar larvae (0.734 ± 0.017) and adult male (0.864 ± 0.020) (Table 25). Maximum attack rate was noted for 4th instar larvae (0.102 ± 0.020) followed by adult female (0.085 ± 0.004). With *A. craccivora* as prey, minimum handling time was noted for adult female predators (0.667 ± 0.009) followed by 4th instar larvae (0.668 ± 0.005). The maximum attack rate was noted for 4th instar larvae (0.144 ± 0.013) followed by adult female (0.106 ± 0.102), as depicted in Table 26. Same trend was noted when the functional response of various predatory stages of *H. variegata* was evaluated on *B. brassicae* as prey (Table 27). Among the predatory stages of *H. variegata* preying upon the three aphid species, minimum handling time was exhibited by adult females on *A. craccivora* (0.667 ± 0.009) and maximum attack rate was exhibited by 4th instar larvae (0.144 ± 0.013) on the same prey species. These values are respectively lower and higher than possessed by any of the predatory stages of *A. tetraspilota* on the three aphid species used as prey.

CHAPTER - 5

DISCUSSION

5.1 Biodiversity of predaceous coccinellids in horticulture ecosystem

The sampling of predaceous coccinellids in the major fruit (district Baramulla) and vegetable (district Budgam) belts of Kashmir valley during 2011-12 revealed the presence of 17 and 12 species, respectively. Bhagat *et al*. (1988) reported 12 species of ladybeetles from apple orchards of Jammu and Kashmir. Azim and Bhat (2005) published the taxonomic notes of 8 ladybeetle species from Kashmir, 2 from subfamily Chilocorinae and 6 from subfamily Coccinellinae. Later, Khan *et al*. (2007) worked out the species diversity and relative abundance of predaceous coccinellids in various fruit, vegetable and flower ecosystems from district Srinagar of Jammu and Kashmir. They reported 13 species each from apple and pear orchards, and 3 and 4 ladybeetle species, respectively from cabbage and cauliflower gardens. Tara and Feroz (2009) reported the presence of 5 coccinellid species from various altitudes of Ladakh.

The fruit orchards supported more number of ladybeetle species as compared to vegetable gardens and more adult individuals were recovered from the former. Unsprayed pear orchards were found to support maximum number of species followed by apple and cherry. Knolkhol gardens were found to support maximum number of species among the vegetable ecosystems however; more number of individuals was recovered from kale gardens. The presence of any species in a given habitat is mainly determined by the presence of essential prey, other than the physical conditions of the environment (Hodek, 1973). Most of the coccinellid species found to be absent from the vegetable gardens were found to possess prey range that is normally lacking in the vegetable crops, as per the prey range records reported by Omkar and Pervez (2000).

The high mobility of some coccinellid species is known to affect the adult assemblages in various habitats, depending on the nature of adjacent habitats (Miliczky and Horton, 2005). Apart from providing hibernation shelter, adjacent cultivated or uncultivated land may serve both as source of prey and a source of re-enforcement of active natural enemies after the pest outbreak on crops (Hodek, 1973). The idea that extra-orchard habitats or comparable habitats adjacent to other crops act as source of natural enemies, has been demonstrated for a number of crop ecosystems (Ekborn *et al*., 2000). Gut *et al*. (1988) monitored the arthropod colonisation of young pear trees that had been placed in different agricultural settings (a mixed crop assemblage versus a pear monoculture) rather than native habitats. Differences were noted in arthropod species richness on the young pears and also in kinds and abundances of arthropods on pears depending on the surrounding habitats. Miliczky and Horton (2005) studied the effect of distance from adjacent native habitats on densities of beneficial arthropods within pear and apple orchards and found that densities of beneficial arthropods declined significantly as distance from extra-orchard habitat increased. The difference in the nature of fruit and vegetable ecosystems in terms of duration and adjacent vegetation probably account for some variation in the number of ladybeetle species and adults recovered in the current study. The fruit orchards were surrounded by perennial vegetation such as other orchards and nearby forest trees whereas the vegetable cultivation was intensive in nature with large scale monoculture and clean cultivation practices adopted.

In addition to immigration of natural enemies from adjacent habitats, resource concentration through increased botanical diversity may be a factor that could affect the diversity and relative abundance of various ladybeetles in various ecosystems under consideration. Hongjiao *et al*. (2010) studied the effects of intercropping systems on diversity and composition of predatory arthropods in vegetable fields and reported higher species richness and diversity indices in intercropping systems than in monocultures. Song *et al*. (2010) reported that intercropping with aromatic plants significantly improved the diversity and various diversity indices of natural enemies in pear orchard. The cultural operations such as extent of weeding and pruning could also affect the diversity and abundance of natural enemy assemblages. Rekha *et al*. (2009) reported higher abundance of coccinellid species in partially weeded plots of rice and cowpea than weeded plots. The fruit orchards in the present study had an extensive cover of weedy grasses and other weed flora besides the regular cultivation of some vegetables and leguminous crops in parts of the orchards could provide better food and shelter to the coccinellids as compared to intensive and clean-cultivated vegetable crops. The improved figures of species richness index and species evenness index for pear orchards may be due to less intensive nature of management practices such as pruning etc. Similarly, higher diversity for unsprayed knolkhol and kale habitats may be due to their cultivation in kitchen gardens which are more diverse and less intensively cultivated.

Differences in species diversity, number of individuals recovered, species richness and equitability component of diversity of ladybeetles between the pesticide free and pesticide treated crop habitats point towards an appreciable effect of pesticides on the biodiversity of ladybeetles. The sprayed horticultural ecosystems supported less number of predaceous coccinellid species. Two ways in which pesticide treatments probably influenced the coccinellid assemblages are the direct toxic effect of pesticide applications and the indirect effect through changes in prey abundance and distribution (Lovei *et al.*, 1991). Other than direct mortality of ladybeetles, pesticides could inflict a myriad of sublethal effects resulting in reduced fitness and/or decrease in intrinsic rate of increase of the ladybeetles (Desneux *et al.*, 2007). The extent of pesticide application and nature of pesticides applied could account for the variation noted between the various crop ecosystems. In general, apple, cabbage and cauliflower were found to be grown under maximum pesticide pressure and thus experienced the worst effects. The relative abundance of various coccinellid species found in sprayed ecosystems was found to be appreciably higher than their corresponding figures in unsprayed ones because of the less number of species present.

5.2 Effect of prey species and prey abundance on the biology of *Adalia tetraspilota* and *Hippodamia variegata*

The original assumption that all aphids are suitable for all species of aphidophagous coccinellids was rejected by Hodek (1960) and Blackman (1967). Since then, it has generally been accepted that not all eaten prey are suitable food for coccinellids. It should be discriminated between the food enabling development and oviposition (essential prey) and the food that is good only for survival (alternative). Also there is a category of rejected prey that may be toxic. However, there are different levels of suitability of individual essential preys (Hodek and Honek, 1996). The current investigation indicated that both *Aphis pomi* and *Brevicoryne brassicae* are essential prey for both *A. tetraspilota* and *H. variegata*, *B. brassicae* being more suitable in comparison to *A. pomi*.

The study also revealed that the coccinellid predators in question could complete their life cycle at the least prey density of 10 aphids per day per individual. It may be ascribed to the fact that predaceous coccinellids show a pronounced ability to adjust to food scarcity as an adaptation to intermittent absence of prey. Most of the biological parameters showed no significant variation as the prey abundance was increased from 80 to 160, indicating that the prey sufficiency lies below 80 aphids per predatory stage per day. Studies on functional response of the two predators on the same prey species indicate that the satiation plateau is reached as the prey density increases from 40 to 80. Thus the zone of prey sufficiency must lie between 40 to 80 aphids per predator per day. According to Hodek and Honek (1996), the larvae of *Coccinella septumpunctata* could complete the development when food supply was artificially reduced to 55 or 40 per cent, although the immature survival is considerably reduced and reproductive output is affected. Same results were obtained from the current study. The effect of prey species and prey abundance on the various biological parameters of *A. tetraspilota* and *H. variegata* is discussed as follows.

5.2.1 Larval period

The duration of all larval instars of *H. variegata* and all but the first instar of *A. tetraspilota*, was found to vary significantly with the prey species and prey abundance. So was the effect on total larval period of both the predators. The larval duration was consistently longer for the predator individuals fed on *A. pomi* as compared to those fed on *B. brassicae*. According to Shafiei *et al.* (2001), the lengthening of the developmental period is a mechanism that allows insects to survive to inadequate nutrition during the larval stage, as it allows insects to extend their feeding activity to acquire enough food resources to complete growth. The varied palatability of the two aphid prey species towards the coccinellid predators may be attributed to the species specific alkanes present on the surface of the aphids (Liepert and Dettnere, 1996); and differences in the wax patterns of the aphids that could be used in the recognition and determination of palatability (Kosaki and Yamaoka, 1996). Higher palatability of *B. brassicae* for *A. tetraspilota* and *H. variegata* larvae may be attributed to its nutrient contents which probably ease its digestion (Pervez and Omkar, 2004). The reduced consumption of some aphids has been ascribed to certain alkaloids and other allelochemicals, not suitable for the constitution and metabolism of the ladybeetles (Okamoto, 1966). However, this aspect needs to be confirmed by chemical analysis of body contents. The reduced consumption in response to chemical constituents might maintain the unwanted chemicals below harmful levels but still ensure survival, thus it became clear that *B. brassicae* is a more suitable prey for both *A. tetraspilota* and *H. variegata* as compared to *A. pomi*.

The larval period lasted for 20.91 and 16.07 days on *A. pomi* and *B. brassicae*, respectively for *H. variegata*, and 17.38 and 14.7 days, respectively for *A. tetraspilota*. No reports were found regarding the biology of *A. tetraspilota*; however enormous quantity of literature exists regarding the various biological aspects of *H. variegata*. The larval duration has been reported as 16.5 days for *H. variegata* reared on *Aphis fabae* (Jafari, 2011), 8.83 days for *H. variegata* larvae reared on *Aphis gossypii* (Wu *et al.*, 2010), 11.8 days for *H. variegata* reared on *B. brassicae* and *Rhopalosiphum padi* (ElHag and Zaitoon, 1996), 9.4 days for *H. variegata* reared on

Myzus persicae (Lanzoni *et al.*, 2004). The variation in the presented findings may be due to factors such as prey species, host plant of prey, rearing conditions etc. that are reported to affect the various biological parameters (Lanzoni *et al.*, 2004). Besides, geographical variations in the predator-prey system may also be important (Bobzhansky, 1933).

The prey abundance levels significantly affected the larval period of both predators. For, *A. tetraspilota*, the larval period was limited to duration of 13.04 days at the highest prey density (160) and extended to a period of 21.0 days at the lowest prey density (10). For *H. variegata*, the larval period increased from 13.27 to 28 days as the prey density decreased from 160 to 10. The elongation of developmental periods with shortage of food has been reported for many ladybeetle species like *Coloeomegilla maculata* (Cividanes *et al.*, 2010); *Harmonia axyridis* (Agarwala *et al.*, 2008); *Harmonia dimidiata* (Sharmila *et al.*, 2010); *Adalia bipunctata* (Wratten, 1973); *Propylea japonica* (Kauwachi, 1979); *Coleomegilla maculata, Hippodamia convergens* and *Harmonia axyridis* (Phoofolo *et al.*, 2008). According to Schuder *et al.* (2004), ladybeetles react to shortage of food by developing more slowly, as an adaptation.

Insignificant variation in larval duration of *H. variegata* when the prey abundance decreased from 160 to 80 indicated that the zone of food sufficiency for *H. variegata* might be close to 80 aphids per day per predator. According to Dixon (2000), there is definite quantity of food that acts as threshold above which the developmental rate is optimal.

5.2.2 Incubation period

Incubation period of the eggs laid by females that were fed on different prey species in definite quantities showed significant variation. The eggs of the parents that were fed on *B. brassicae* hatched earlier as compared to those fed on *A. pomi*. Such an effect of parental diet on the embryogenesis has been reported by many workers like Pervez and Omkar (2004) for *P. dissecta*; Kaluskov and Hodek (2004) for *C. septumpunctata* and Jalali *et al.* (2009) for A. *bipunctata*, to mention a few. The incubation period of *H. variegata* eggs has been reported to last for 3.35 days

(Jafari, 2011); 2.6 days (Lanzoni *et al.*, 2004); 2.42 days (Wu *et al.*, 2010) and 2.8 days (ElHag and Zaitoon, 1996) under different rearing conditions on different preys.

5.2.3 Immature survival (%)

Appreciable variation in survivorship of larvae was noted by varying the prey species and prey abundance. For both the predators, larval survival was higher for individuals reared on *B. brassicae* as compared to those reared on *A. pomi*. Higher mortality was noted as the prey abundance decreased. Larval survival decreases as less of the prey is consumed either due to its less suitability or shortage in supply (Kaluskov and Hodek, 2004). Same effect of varying prey species and prey abundance was noted on the adult emergence percentage of both the predator species. The pupae suffered more mortality on *A. pomi* as compared to *B. brassicae*. The emergence percentage consistently increased with increasing prey abundance levels. According to Parvez and Omkar (2004), possible reasons for increased mortality of immatures on the less consumed prey include; slow starvation resulting from lower consumption and/or inability of the ladybird metabolism to detoxify or sequester the unsuitable chemicals. In general, neonate larvae and 4th instars suffered the maximal mortality. First instars suffered high mortality because of their thin cuticle making them more vulnerable to physical stresses (Ponsonby and Copland, 1996). The 4th instar larvae suffered more as the prey abundance decreased as they could not cater the high metabolic needs under food shortage (Cividanes *et al.*, 2010). Larval survival in the range of 50-75 % has been reported for *H. variegata* by different workers (Wu *et al.*, 2010; Lanzoni *et al.*, 2004 and ElHag and Zaitoon, 1996). Wu *et al*. (2010) reported the adult emergence of *H. variegata* fed on *A. gossypii*, reared on five host plants, to vary from 87.23 to 100.00 %. The overall pre-adult survival was found to vary from 44.06 to 58.97 % depending on the host plant of prey. Lanzoni *et al*. (2004) reported the immature survival of *H. variegata* reared on *M. persicae* as 49.1 % while ElHag and Zaitoon (1996) reported 61.8% immature survival of *H. variegata* reared on *B. brassicae*.

5.2.4 Prepupal and pupal period

The prepupal and pupal periods of both the predators increased significantly as *A. pomi* was used as prey as compared to *B. brassicae*. The effect of varying prey species on prepupal and pupal period is known for many other coccinellid predators, such as *C. septumpunctata* (Omkar and Srivastava, 2003; Kalushkov and Hodek, 2004), *A. bipunctata* (Jalali *et al*., 2009), *C. sexmaculata* (Omkar and Bind, 2004), and *P. dissecta* (Pervez and Omkar, 2004) to mention a few. The effect of varying prey abundance levels was also found to be significant on the prepupal and pupal period of both *A. tetraspilota* and *H. variegata*, increasing prey density decreased the respective developmental periods. Sharmila *et al*. (2010) reported significant effect of prey density on prepupal and pupal period of *H. dimidiata*. Similar effects have earlier been reported by Kawauchi (1979) on *P. japonica* and Hukusima and Ohwaki (1972) on *H. axyridis*. Significant effect of prey density on pupal period of *H. axyridis* has also been reported by Agarwala *et al*. (2008). The pupal period of *H. variegata* varied from 5.11 to 7.75 days under different prey species and prey abundance conditions. The values are in close proximity of earlier reported values like those of ElHag and Zaitoon (1996); Lanzoni *et al*. (2004); Wang *et al*. (2004); Rebolledo *et al*. (2007) and Jafari (2011).

5.2.5 Pre-oviposition, oviposition and post-oviposition period

Both the reproductive (oviposition) and non-reproductive (pre- and post-oviposition) periods of adult females were found to be dependent on prey species and prey abundance. The longest reproductive periods with shortest non-reproductive periods were noted for females fed upon *B. brassicae* as compared to those fed upon *A. pomi*. It confirms the relatively more suitable nature of *B. brassicae* as the prey for both *A. tetraspilota* and *H. variegata*. The non-reproductive periods increased significantly while the reproductive periods decreased with decreasing prey abundance.

Omkar and Srivastava (2003) reported that increased quantity of high quality food decreased the length of pre-oviposition period. The decreased consumption of less suitable foods, by affecting the pre-adult development, probably results in slower sexual maturation and longer pre-oviposition periods (Kauwachi, 1981). High consumption of suitable prey supports early ovariole maturation and provides energy and nutriment to sustain a longer oviposition period and *vice versa* for less suitable or unsuitable food (Honek, 1980). The females with long reproductive periods result in higher reproductive output (fecundity). Several reports suggest a tradeoff between adult longevity and fecundity (Dixon, 2000). Hence the females with long oviposition periods have relatively shorter post–oviposition periods.

The pre-oviposition, oviposition and post-oviposition period were noted as 12.6, 22.92 and 10.82 days on *A. pomi*, and 9.96, 31.10 and 13.42 days on *B. brassicae* , respectively for *A. tetraspilota* females. For *H. variegata* females, pre-oviposition period was noted as 17.3 and 14.48 days, oviposition period as 20.9 and 33.42 days, and post-oviposition period as 10.0 and 8.2 days, respectively on *A. pomi* and *B. brassicae*. For *H. variegata*, the pre-oviposition period has been reported as 6.2 days (Jafari, 2011); 6.5 days (ElHag and Zaitoon, 1996); 7 days (Lanzoni *et al.*, 2004) and 3.82 days (Wu *et al.*, 2010) for adult females reared on different prey species. Wu *et al.* (2010) reported the oviposition and post-oviposition period of 30.53 and 6.18 days, respectively for *H. variegata* females reared on *A. gossypii*. Lanzoni *et al.* (2004) reported a mean oviposition period of 32.2 days on *M. persicae* while as Jafari (2011) reported the period to vary from 37 to 48 days for *H. variegata* females reared on *A. fabae*. Discrepancies in experimental methods including different rearing conditions may help to explain these variations. Furthermore, the geographical variability produces differences in various biological attributes of the coccinellid predators (Bobzhansky, 1933).

5.2.6 Adult longevity

The variation of prey species and prey abundance significantly affected the longevity of both male and female adults. In both cases, the females lived longer than the males. The *A. tetraspilota* females lived for 48.5 and 51.88 days when reared on *A. pomi* and *B. brassicae,* respectively. The *H. variegata* females lived for 48.2 and 56.04 days, respectively when fed upon *A. pomi* and *B. brassicae*. Wu *et al*. (2010) reported longevity of 38.95 days for adult females reared on *A. gossypii*; Jafari (2011) reported an average longevity of 55.5 days for adults of *H. variegata* reared on *A. fabae* while Rebolledo *et al*. (2007) reported a mean longevity of 55.09 days for adult females of *H. variegata*. The adult males of *A. tetraspilota* were found to live for 46.42 and 41.7 days, respectively when reared on *A. pomi* and *B. brassicae* while the adult males of *H. variegata* lived for 48.12 and 45.48 days, respectively on the two prey species used in the present study. Rebolledo *et al*. (2007) reported a mean longevity of 51.45 days for adult males of *H. variergata* while as Wu *et al*. (2010) reported the male longevity as 36.21 days. ElHag and Zatoon (1996) reported a mean adult longevity of 71.8 days for *H. variegata*. Elhabi *et al*. (2000) found that the longevity of male and female adults was 44.0 and 61.0 days for *H. variegata*.

The adult females of both the predators lived longer when fed upon the more suitable prey (*B. brassicae*). It is because of the elongated oviposition period, as reported for many other ladybeetles like *C. septempuncata* (Kalushkov and Hodek, 2004); *A. bipunctata* (Jalali *et al*., 2009); *P. dissecta* (Pervez and Omakar, 2004) and others. The longevity of both male and female adults increased with decreasing prey availability. It can be explained as an adaptation to food shortage and reproduction-longevity trade-off for females. Ohgushi (1996) reported that the trade-off becomes more apparent when the organisms are food limited. Decreasing the prey abundance reduced the fecundity, hence the longevity increased.

5.2.7 Fecundity

Reproductive output was appreciably higher for females fed on *B. brassicae* (more suitable prey) and the fecundity drastically decreased under food shortage conditions. Higher fecundity for females reared on more suitable and abundant aphid species has been reported to be due to increased prey consumption leading to higher conversion of food to eggs (Baumgartner *et al*., 1987; Rhamahalinghan, 1987; Pervez and Omkar. 2004). Kalushkov and Hodek (2004) reported that essential aphid foods affected adult weight at eclosion and hence fecundity of ladybeetles.

A. tetraspilota females laid 217 and 435.8 eggs on the average when reared on *A. pomi* and *B. brassicae*, respectively. The females of *H. variegata* were found to lay an average of 241.2 and 439.6 eggs, respectively on *A. pomi* and *B. brassicae*.

Lanzoni *et al*. (2004) reported a mean fecundity of 841.7 eggs for *H. variegata* females reared on *M. persicae*. Kontodimas and Stathas (2005) reported the fecundity as 276.3 eggs; Wu *et al*. (2010) reported the fecundity as 647.58 eggs while Jafari (2011) reported a mean fecundity of 943.9 eggs for *H. variegata* females. The variation in reported figures of fecundity may be due to variation in prey species used, variation in nutritional quality of prey or the rearing conditions (Kaluskov and Hodek, 2004).

5.2.8 Hatchability

Hatchability of eggs was found to be strongly dependent on the feeding history of the parents as per cent hatchability varied significantly with prey species and prey abundance. Again, egg hatchability was significantly higher on the aphid prey *B. brassicae* as compared to *A. pomi*. The hatchability declined as the prey abundance reduced. Simmons (1988) reported high consumption of suitable prey to increase the weight of eggs, which contained a large quantity of yolk and consequently increased egg viability.

The hatching percentage noted for *A. tetraspilota* was 59.8 and 69.4 % on *A. pomi* and *B. brassicae*, respectively. For *H. variegata* eggs, the corresponding figures were noted as 65.2 and 77.0 %, respectively. Wu *et al*. (2010) reported the hatchability as 85.9 % for the eggs of *H. variegata* reared on *A. gossypii*. Jafari (2010) reported that 82.86 % of eggs hatched while Elhabi *et al*. (2000) reported mean hatchability of 79 %. Lanzoni *et al*. (2004) reported that 70 % of the laid eggs hatched successfully. The reports still confirm that egg hatchability is dependent on the prey used and rearing methodology adopted.

5.3 Functional response of *Adalia tetraspilota* and *Hippodamia variegata* to three aphid species

5.3.1 Prey consumption rates and nature of functional response

A perusal of the data on prey consumption rates of various predatory stages of *Adalia tetraspilota* and *Hippodamia variegata* indicated that the 4th instar larvae of both the predators consumed highest number of aphids, irrespective of the prey species, closely followed by the adult females. The observation that 4th instar larvae consumed greatest proportion of prey over 24 hours, consuming over 60% of total prey consumed by all the larval stages, is consistent with the observations of many other workers on the same and other coccinellids like those of Farhadi *et al*. (2010) for *H. variegata* preying upon *Aphis fabae*; Khan (2009) for *A. tetraspilota* preying upon *Brevicoryne brassicae*; Khan (2010) for *Harmonia eucharis* preying upon *Aphis pomi*; Lee and Kang (2004) for *Harmonia axyridis* preying upon *Aphis gossypii*, to mention a few. As pointed out by Jervis *et al* (2006), final instar larva accounts for more than 75 % of total growth that occurs in predaceous coccinellids, cumulative increase in prey biomass consumed reaches its peak in 4th instar larvae for coccinellids. The higher prey consumption rates of adult females may be due to a higher nutrient requirement for special purposes such as egg production, or due to delayed satiation (Mills, 1982) or due to possible faster digestive rate of adult females (Pervez and Omkar, 2005). Bedddington *et al*. (1976) pointed out that variation in prey consumption rates could be expected from the between-instar differences that exist with respect to attack rate and handling time (parameters of functional response), and metabolic rate, which increases with development.

Among the two coccinellid predators used in the study, the predatory stages of *H. variegata* consistently consumed more number of prey individuals as compared to *A. tetraspilota*. The elevated prey consumption curves for *H. variegata* over that of *A. tetraspilota* indicated a possible delayed satiation and/or a possible faster digestive rate in case of the former. Pervez and Omkar (2005) speculated that the elevated functional response curve of *Cheilomenes sexmaculata* over *Coccinella transversalis* may be a result of such differences. Isikber (2004) found that large sized aphidophagous predators consumed comparatively more aphids than small sized species.

The variation in prey consumption rates of a predator on various prey species is attributed to various factors such as prey mobility (Dixon, 2000), nutritional status (Thompson, 1999), suitability of the prey for the growth and reproduction of the predator (Hodek and Honek, 1996), prey size (Isikber, 2004), effect of host plant of prey (Wu *et al*., 2010), etc. As *A. craccivora* was reared on a legume host, it is expected to possess a higher percentage of protein nitrogen which could possibly make it a comparatively more preferred prey (Atwal and Sethi, 1963). Some or all the mentioned factors could probably account for observed variation in prey consumption rates of *H. variegata* and *A. tetraspilota*.

The current study revealed the estimates of maximum number of aphids attacked per day as 33.5 for 4th instar larvae and 32.8 for adult females of *H. variegata* when *A. craccivora* was used as prey. Rest of the predatory stages of both the predator species consumed lower numbers of prey individuals in the speculated period of time on any of the three aphid prey species used. The results are consistent with those of Khan and Mir (2008) who reported the maximum prey consumption in the range of 15-30 aphids per day for adult females of coccinellid species *A. tetraspilota*, *Coccinella septumpunctata*, *Calvia punctata* and *H. variegata* preying upon *B. brassicae*, and Khan (2010) with all predaceous stages of *Harmonia eucharis* preying upon *A. pomi*. However, all these estimates are considerably lower than those reported by other workers from other parts of the world working with same coccinellid species. Jafari *et al* (2010) reported maximum consumption by 4th instar larvae of *H. variegata* as 52.78 preying upon *A. fabae*. Saleh *et al*. (2010) reported a maximum consumption of 147.06 aphids per day for the adult females of *H. variegata* upon *Brcahycaudus helichrysi*. Jafari and Goldasteh (2009) reported the estimate of maximum prey consumption for *H. variegata* as 135.29 preying upon *A. fabae*. Similar results were found for *Adalia bipunctata* preying upon various aphid species (Omkar and Pervez, 2005). Other than the effects of prey species in terms of its nutritional status and possible tritrophic interactions of prey host plant on the predator, another very important factor that may be responsible for the variation in various biological and predation parameters is the geographical variation in the populations of the coccinellid predators (Kontodimas and Stathas, 2005). As suggested by Dobzhansky (1933), the geographical variability produces differences in the populations of coccinellid predators with respect to various biological and ecological parameters.

The graphical analysis of per cent prey consumption (trend-line analysis) and the results of polynomial logistic regression revealed that a type II asymptotic curve described the data well. The logistic regression model increases the credibility of the correctness of the curves, as in such studies ecologists normally face difficulties in curve-fitting when the data set of type II responses shows inclination towards type III response which can lead to drawing of misleading of misleading inferences (Pervez and Omkar, 2005). Higher number of replications for the lowest two offered prey densities in the first instance and subsequent curve-fitting using the polynomial logistic regression were hence used to take care of such apprehensions.

Out of the three types of functional responses identified by Holling (1959), only type III produces density dependent mortality that is thought to regulate target populations. The only possibility of exhibiting type III functional response in the present study is the concentration of predator hunting in high-density patches (Farhadi *et al*., 2010). The mechanism may have operated in the current study, however no evidence of type III functional response was found for the predator-prey complexes under study. The other mechanisms of type III response i.e. switching behaviour and predator learning could not have operated as the experiments were short term and single prey based.

5.3.2 Parameters of functional response

The coefficient of attack rate (a) and handling time (T_h) were the parameters used to find out the magnitude of the functional responses exhibited by the predatory stages of *A. tetraspilota* and *H. variegata* on the three prey species, namely *A. pomi*, *A. craccivora* and *B. brassicae*. Their values differed for various growth stages of each predator and for the three prey species tested. So did the parameter values for the two predators. It indicates that various predatory stages of a predator have different abilities to respond to increasing prey densities, so do the various predators for a particular prey species and a particular predator towards various prey species. These results are in conformation with those of Pervez and Omkar (2005) who investigated the functional responses of *Cheilomenes sexmacvulta* (F.), *Propylea dissecta* (M.) and *Cocccinella transversalis* F. adults on *Myzus persicae* (Sulzer) and

Aphis craccivora. The differences in the parametric values might be due to variation in size, voracity, satiation time, digestion ability, walking speed, etc. (Mills, 1982; Pervez and Omkar. 2005).

In general, attack rate coefficients obtained in the various treatments don't differ as much as those of the handling time. This observation is consistent with that of Atthan *et al*. (2010) and Pervez and Omkar (2005). The handling time is a good indicator of consumption rate and effectiveness of a predator because it reflects the cumulative effect of time taken during capturing, killing, subduing and digesting the prey (Veervel and Baskaran, 1997). The lowest handling times were regularly noted for 4th instar larvae and adult females of both the predators. Among the three prey species, lowest handling time was exhibited by the 4th instar larvae of *H. variegata* on *A. craccivora* (0.668 h) followed by *B. brassicae* (0.734 h) and *A. pomi* (0.953 h). The lowest handling time figures were noted for 4th instar larvae of *A. tetraspilota* too, lowest on *A. craccivora* (0.7507 h) followed by *B. brassicae* (0.8496 h) and *A. pomi* (1.0205). Clearly, *H. variegata* larvae are better predators at devouring *A. craccivora* nymphs.

The practical implication of these studies is that 4th instar larvae and females are the stages that are most effective as predators. It may be suggested that mass release of the predators in question may be most effective if releases are done primarily as last stage individuals (4th instars and adult females). Such releases would facilitate rapid killing of prey immediately after release. The sex ratio of mass produced ladybeetles if made to favour female individuals may be advantageous for biological control as adult females and 4th instar larvae are better in devouring of aphid prey.

Among the two predator species, *H. variegata* is better as a bioagent as per the laboratory studies and among the prey species tested, the predators may respond best to the patches of *A. craccivora*. However, the prey consumption rates are comparatively lower besides the uncontrolled and highly variable field conditions could radically change functional response of the predators (Farhadi *et al*., 2010). Other factors such as intrinsic growth rates, host patchiness, predation and competition, host traits, etc. also have a major influence on the efficiency of predator in managing prey population. Hence, functional response although an important tool, cannot alone be attributed to success and failure in biocontrol programs. However, the laboratory data provide information as to how these predators will respond to increasing prey density under simplified experimental conditions. For conclusive estimation of their biocontrol potential, further field based studies are needed.

CHAPTER - 6

SUMMARY AND CONCLUSION

The biodiversity of predaceous coccinellids was worked out in major fruit (district Baramulla) and vegetable (district Budgam) growing belts of Kashmir valley during the cropping season of 2011. Two locations from each district, with both pesticide-treated and pesticide-free orchards of fruit crops including apple, pear and cherry and vegetable fields including kale, knolkhol, cabbage and cauliflower were sampled for adult coccinellids. The study revealed the presence of 17 and 12 species of predaceous coccinellids in fruit and vegetable ecosystems, respectively. The fruit orchards supported more number of ladybeetle species as compared to vegetable gardens and more adult individuals were recovered from the former. Less intensively cultivated crops like pear, kale and knolkhol were found to be comparatively rich in ladybeetle diversity. Higher values of biodiversity indices were noted for fruit orchards as compared to those of vegetable gardens. The extra orchard vegetation, botanical diversity within the crop fields and extant of weeding and pruning probably affected the ladybeetle assemblages significantly. Extra-orchard vegetation and higher botanical diversity within the crop ecosystems were found to be associated with rich species diversity while the clean cultivation practices were probably detrimental to biodiversity. *Coccinella septempunctata*, *Hippodamia variegata* and *Adalia tetraspilota* turned out to be the predominant ladybeetle species in fruit orchards in decreasing order while as *A. tetraspilota* was noted as the predominant species in vegetable ecosystems followed by *H. variegata* and *C. septempunctata*. Pesticide treated ecosystems were found to support less number of ladybeetle species. The sprayed orchards were found to have 14 species of ladybeetle as compared to 17 in unsprayed ones. Similarly, only 10 species were recovered from the sprayed vegetable gardens as compared to 12 from unsprayed gardens. The biodiversity indices indicated appreciable effect of pesticide application on the coccinellids assemblages. The species diversity index and equitability index consistently assumed higher values for unsprayed crop ecosystems as compared to those of sprayed ones.

The studies on the biology of *Adalia tetraspilota* and *Hippodamia variegata* revealed that both *Aphis pomi* and *Brevicoryne brassicae* were suitable preys for the two predators in question however, the predators performed better when fed upon *B. brassicae*. The prey densities also affected the developmental parameters of the two predators appreciably and the optimal growth and development was noted in the prey density range of 40-80 aphids per day per predator. The larval period lasted for 20.91 and 16.07 days on *A. pomi* and *B. brassicae*, respectively for *H. variegata*, and 17.38 and 14.7 days, respectively for *A. tetraspilota*. The prey abundance levels significantly affected the larval period of both predators. For *A. tetraspilota*, the larval period was limited to duration of 13.04 days at the highest prey density (160) and extended to a period of 21.0 days at the lowest prey density (10). For *H. variegata*, the larval period increased from 13.27 to 28 days as the prey density decreased from 160 to 10. The eggs of the parents that were fed on *B. brassicae* hatched earlier as compared to those fed on *A. pomi*. Appreciable variation in survivorship of larvae was noted by varying the prey species and prey abundance. The prepupal and pupal periods of both the predators increased significantly as *A. pomi* was used as prey as compared to *B. brassicae*. The pupal period of *H. variegata* varied from 5.11 to 7.75 days under different prey species and prey abundance conditions. Both the reproductive (oviposition) and non-reproductive (pre- and post-oviposition) periods of adult females were found to be dependent on prey species and prey abundance. The longest reproductive periods with shortest non-reproductive were noted for females fed upon *B. brassicae* as compared to those fed upon *A. pomi*. The pre-oviposition, oviposition and post-oviposition period were noted as 12.6 and 9.96, 22.92 and 31.10, and 13.42 and 10.82 days, respectively on *A. pomi* and *B. brassicae* for *A. tetraspilota* females. For *H. variegata* females, pre-oviposition period was noted as 17.3 and 14.48 days, oviposition period as 20.9 and 33.42 days, and post-oviposition period as 10.0 and 8.2 days, respectively on *A. pomi* and *B. brassicae*. The *A. tetraspilota* females lived for 48.5 and 51.88 days when reared on *A. pomi* and *B. brassicae*, respectively. The *H. variegata* females lived for 48.2 and 56.04 days, respectively when fed upon *A. pomi* and *B. brassicae*. In both cases, the females lived longer than the males. Reproductive output was appreciably higher for females fed on

B. brassicae (more suitable prey) and the fecundity drastically decreased under food shortage conditions. *A. tetraspilota* females laid 217 and 435.8 eggs on the average when reared on *A. pomi* and *B. brassicae*, respectively. The females of *H. variegata* were found to lay an average of 241.2 and 439.6 eggs, respectively on *A. pomi* and *B. brassicae*. Hatchability of eggs was found to be strongly dependent on the feeding history of the parents as per cent hatchability varied significantly with prey species and prey abundance. The hatching percentage noted for *A. tetraspilota* was 59.8 and 69.4 % on *A. pomi* and *B. brassicae*, respectively. For *H. variegata* eggs, the corresponding figures were noted as 65.2 and 77.0 %, respectively.

Studies on functional response of various predatory stages of *A. tetraspilota* and *H. variegata* on three different prey species *Aphis pomi*, *Aphis craccivora* and *Brevicoryne brassicae* using different prey densities revealed that with increase in prey density the predation rates increased and the response curves rose curvilinearly reaching a plateau, characteristic of type II functional response. The polynomial logistic regression analysis indicated significant negative values for linear coefficient which confirmed the type II response of various growth stages of the two predators on various prey species used.

The 4th instar larvae of both the predators consumed highest number of aphids, irrespective of the species, closely followed by the adult females. Among the two coccinellid predators used in the study, the predatory stages of *H. variegata* consistently consumed more number of prey individuals as compared to *A. tetraspilota*. The current study revealed the estimates of maximum number of aphids attacked per day as 33.5 for 4th instar larvae and 32.8 for adult females of *H. variegata* when *A. craccivora* was used as prey. Rest of the predatory stages of both the predator species consumed lower numbers of prey individuals in the speculated period of time on any of the three aphid prey species used. However, all these estimates are considerably lower than those reported by other workers from other parts of the world working with same coccinellid species. The coefficient of attack rate (a) and handling time (T_h) were the parameters used to find out the magnitude of the functional responses exhibited by the predatory stages of *A. tetraspilota* and *H.*

variegata on the three prey species using the Roger's Random Predation equation. Their values differed for various growth stages of each predator and for the three prey species tested. So did the parameter values for the two predators. It indicates that various predatory stages of a predator have different abilities to respond to increasing prey densities, so do the various predators for a particular prey species and a particular predator towards various prey species. In general, attack rate coefficients obtained in the various treatments don't differ as much as those of the handling time. The lowest handling times were regularly noted for 4th instar larvae and adult females of both the predators. Among the three prey species, lowest handling time was exhibited by the 4th instar larvae of *H. variegata* on *A. craccivora* (0.668 h) followed by *B. brassicae* (0.734 h) and *A. pomi* (0.953 h). The lowest handling time figures were noted for 4th instar larvae of *A. tetraspilota* too, lowest on *A. craccivora* (0.7507 h) followed by *B. brassicae* (0.8496 h) and *A. pomi* (1.0205). Clearly, *H. variegata* larvae are better predators at devouring *A. craccivora* nymphs. Among the two predator species, *H. variegata* is better as a bioagent as per the laboratory studies and among the prey species tested, the predators may respond best to the patches of *A. craccivora*.

Based on the findings of the present study, the following conclusions are drawn:

- The fruit and vegetable ecosystems support 17 and 12 species of predaceous coccinellids, respectively.
- The biodiversity indices are consistently higher for fruit orchards as compared to vegetable fields.
- *Adalia tetraspilota*, *Coccinella septempunctata Hippodamia variegata* and *Chilocorus infernalis* are predominant species of predaceous coccinellids in horticulture ecosystems of Kashmir.
- Pesticide application affects the biodiversity of coccinellids appreciably.
- Both *Aphis pomi* and *Brevicoryne brassicae* are essential preys for *A. tetraspilota* and *H. variegata*, the latter being more suitable.

- Prey species and prey abundance has significant effect on the biological parameters of the aphidophagous coccinellid predators.
- The optimum biological performance of the predators lies in the prey density range of 40-80 nymps per day per predator.
- All the predatory stages of the two predators exhibit type II functional response to various densities of *A. pomi*, *B. brassicae* and *A. craccivora*.
- The 4th instar larvae and adult females exhibit the maximum predation rates.
- The predatory stages of *H. variegata* perform better than those of *A. tetraspilota*.

  Fourth instar larvae and adult females of *H. variegata* are best at devouring *A. craccivora* patches

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. D.P Abrol, Professor and Head, Division of Entomology, SKUAST-J, Chatha, Jammu during viva-voce examination held on 28-05-2012 have been incorporated in the manuscript entitled **"Biodiversity, Biology and Predation of coccinellids in Horticulture Ecosystem"** submitted by **Mr. Mohd Abas Shah (Regd. No. 2010-A-844-M).**

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