

**Population dynamics and predatory activities of
marmalade syrphid fly *Episyrphus balteatus* De Geer in
vegetable ecosystem of Kashmir**

Rasikh Ahmad Parray
(MSH-2020-296)



Division of Entomology
Faculty of Horticulture

**Sher-e-Kashmir University of Agricultural Sciences and
Technology of Kashmir**

2022

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Thesis

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(Entomology)

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Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Entomology, Faculty of Horticulture

Certificate – I

This is to certify that the thesis entitled “**Population dynamics and predatory activities of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science in Horticulture (Entomology)**, to the **Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Rasikh Ahmad Parray (Regd. No. MSH-2020-296)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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This is to certify that the thesis entitled, “**Population dynamics and predatory activities of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir**” submitted by **Mr. Rasikh Ahmad Parray (Regd. No. MSH-2020-296)** to the **Faculty of Horticulture, 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 Horticulture (Entomology)** was examined and approved by the Advisory Committee and External Examiner on

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Title of the Thesis : **“Population dynamics and predatory activities of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir”**

ABSTRACT

The population density of both adults and larvae of marmalade syrphid fly *Episyrphus balteatus* De Geer was worked out in the vegetable growing belts of Srinagar and Budgam districts of Kashmir valley during the cropping season of 2021. Three locations from each district were selected, and the sampling was done on four vegetable crops : tomato & brinjal from Solaneaceae family and cabbage & kale from Cruciferae family at each location. The study revealed that the highest population density of both the adults and larvae of marmalade syrphid fly was found at Harwan area of Srinagar district, followed by Chadoora area of Budgam district in all the crops and among all the selected locations. The lowest population density of both the adults and larvae of marmalade syrphid fly was found at proper Budgam of Budgam district in all the crops. Pesticide treated ecosystems were found to support less populations of marmalade syrphid fly as compared to no and less sprayed ecosystems. The population density of both the adult and larvae of marmalade syrphid fly demonstrated a positive and significant correlation with mean temperature whereas, a positive but insignificant correlation was found between the population density of both the adult and larvae of marmalade syrphid fly with mean relative humidity.

Studies on functional response of 2nd and 3rd instar larvae of *Episyrphus balteatus* De Geer on two different prey species: *Brevicoryne brassicae* and *Myzus persicae* using different prey densities at four different temperatures of

20⁰C, 25⁰C, 30⁰C and 35⁰C revealed type II functional response. The polynomial logistic regression analysis indicated significant negative values for linear coefficient at all the four different temperatures of 20⁰C, 25⁰C, 30⁰C and 35⁰C which confirmed the type II response of 2nd and 3rd instar larvae of *E. balteatus* on the two different prey species used. Among the two larval instars used in the study, the 3rd instar larvae of *E. balteatus* consumed more number of prey individuals irrespective of the species at all the temperatures as compared to 2nd instar larvae. The study revealed the estimates of maximum number of aphids attacked per day as 53.7 for 3rd instar larvae and 39.6 for 2nd instar at 30⁰C when *B. brassicae* was used as prey. Among the two larval instars, lowest Handling time (*Th*) and highest Attack rate (*a*) was exhibited by the 3rd instar larvae of *E. balteatus* at 30⁰C on *B. brassicae* (0.394 h & 0.232 h⁻¹). According to laboratory research, among the two larval instars, the third instar larvae is better as a bioagent, and among the tested prey species, the predators may react best to the patches of *B. brassicae*.

Key words: Marmalade syrphid fly, Population density, Functional response, Attack rate & Handling time.

Signature of Student

Dated : _____

Signature of Major Advisor

Dated: _____

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Place: Shalimar, Srinagar

Dated:

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Chapter-1

INTRODUCTION

Syrphids (Diptera: Syrphidae) are one of the most important predators of aphids and are known to regulate the prey population effectively (Ssymank *et al.*, 2008). Due to their unusual behaviour of hovering in the sun over flowers to feed on pollen and nectar, they are also known as hover flies, flower flies, or sun flies (Kevan, 2002).

Three sub-families, 180 genera and roughly 6,000 known species make up the family Syrphidae worldwide and is one of the largest families of diptera (Pape and Evenhuis, 2013). According to Ghorpade (1981), 312 species of predatory syrphidae are found in India and 169 species of syrphid flies have been recorded in Western Himalaya (Shah *et al.*, 2014) and in Kashmir valley, 23 species of syrphid flies have been reported among which 20 species have been observed in the vegetable ecosystem of Kashmir (Khan, 2017).

Syrphinae and Eristalinae are the two most important sub-families of the family Syrphidae. The larvae of sub family Eristalinae are non-predatory in nature whereas the larvae of sub-family Syrphinae are predatory in nature (Ghorpade, 1981).

Syrphid flies have been reported all over the world (Khan 2015; Khan and Riyaz, 2017). Adult syrphid flies resemble bees and wasps. Eggs are usually laid on the leaves infested with aphids. Syrphid flies are economically very important as they act as pollinators of crops and also as bio-agents feeding usually on aphids such as *Brevicoryne brassicae*, *Myzus persicae*, *Lipaphis erysimi*, *Aphis gossypii* etc. (Khan *et al.*, 2020).

The marmalade syrphid fly *Episyrphus balteatus* De Geer (Diptera: Syrphidae) belongs to the subfamily Syrphinae (Stubbs and Falk, 1983). The larvae of this species are predators on more than 100 species of aphids worldwide

(Sadeghi and Gilbert, 2000b). Marmalade syrphid fly *E. balteatus* is the most common hoverfly in central Europe (Tenhumberg and Poehling, 1991) and in the UK (Stubbs and Falk, 1983; Gilbert, 1993). Predominance of marmalade syrphid fly *E. balteatus* in the natural habitat (Tenhumberg and Poehling, 1995) is due to the female oviposition behavior. Eggs are always laid near aphid colonies (Chandler, 1968a and 1968 b; Scholz and Poehling, 2000) and the emerging young larvae locate immediately the food sources. In order to effectively control aphids in natural agro-ecosystems, the marmalade syrphid fly *E. balteatus* has the potential to be an effective predator (Scholz and Poehling, 2000).

Marmalade syrphid fly *Episyrphus balteatus* can be found throughout the year in various habitats, including urban gardens, visiting flowers for pollen and nectar. The larva is terrestrial and feeds on aphids. The adults feed properly on pollen and nectar, or honeydew produced by aphids. Syrphid flies along with other aphidophagous insects play a key role in the reduction of aphid populations (Sobota and Twardowski, 2004).

Biological control of insect pests often depends on the activity of predatory arthropods (Symondson *et al.*, 2002). However, the sheer presence of predators does not always result in a decrease in the population of prey and successful biological control in the field does not necessarily follow a laboratory demonstration of prey suppression. This discrepancy may result from a variety of ecological factors that can weaken or disrupt prey suppression in the field, where predators may be constrained by the presence of natural enemies, alternative prey, or floral resources (Kindlmann and Dixon, 2010). Likewise, field experiments do not necessarily predict dynamics observed at spatial and temporal scales that are relevant to the ecosystem. In field studies, predators are frequently manipulated in small areas or for brief times. Although useful, these conclusions might not apply to broad areas or extended time periods (Harwood and Obrycki, 2005).

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 quantifies how quickly a predator kills its prey at various prey concentrations and may therefore be used to assess how effective a predator is at controlling prey populations (Murdoch and Oaten, 1975). Recognized is the possibility that functional responses obtained from laboratory investigations may not closely resemble those that could be assessed in the field (Wang *et al.*, 2004). The relationship between functional responses seen in the lab and natural enemy performance in the field is unclear, according to Fan and Zhao (1988). They did, however, note that laboratory investigations of functional response could be utilised to deduce fundamental mechanisms underpinning natural enemy-prey interactions. Such research offers useful data for biological control efforts. During biological control evaluation processes, comparisons of parameter values of two or more predators may be more meaningful and convenient (El Hag and Zaitoon, 1996).

One important element controlling the population dynamics of predator-prey systems is the functional response of a predator. It depicts the rate at which a predator decimates its prey populations, allowing one to assess the effectiveness of a predator in controlling prey populations (Murdoch and Oaten 1975). The functional response may represent an increasing linear relationship (Type I), a decelerating curve (Type II), or a sigmoidal relationship (Type III). The type of response varies with prey and predator species as well as the predatory stage of the syrphid fly being evaluated. A single predator can respond differentially to various prey-types and it seems likely that a predators response to a single prey type differs within and between species (Koch *et al.*, 2003).

Although a considerable amount of research has been conducted on the biodiversity, biology and predatory potential of the syrphid flies in fruit and flower ecosystems of Kashmir (Khan *et al.*, 2015; Khan 2017a; Khan and Riyaz, 2017; Khan 2017b and Khan and Shah, 2017). However, no work on syrphid flies

has been done in vegetable ecosystem of Kashmir. Keeping in view the aforementioned facts, the present investigation was carried out with the following objectives:

1. To study the population dynamics of marmalade syrphid fly *Episyrphus balteatus* in vegetable ecosystem of Kashmir.
2. To record the prey of marmalade syrphid fly *Episyrphus balteatus* and evaluate the predation against predominant aphids.

Chapter-2

REVIEW OF LITERATURE

Workdone in India and abroad on the proposed aspects of marmalade syrphid fly *Episyrphus balteatus* De Geer has been reviewed and summarized as follows;

2.1 Population dynamics of marmalade syrphid fly *Episyrphus balteatus* De Geer

The family Syrphidae comprises of three sub-families, 180 genera and about 6,000 described species worldwide and is one of the largest families of diptera (Pape and Evenhuis, 2013).

Kumar *et al.* (1988) conducted a study on the the population build up and dispersion of immature stages of aphidophagus syrphids (Syrphidae; Diptera) on ray, *Brassicae juncea* Coss and they reported egg and larval populations of aphidophagus syrphids, *Ischiodon scutellasis*, *Sphaeropharia Indiana*, *Episyrphus balteatus*, *Metasysphus confrater*, *Metasyrphus latilunulatus*, *Scaeva latimaculata* and *Sphaeropharia Indiana* in *Brassica juncea* fields in Punjab (India) in December-March 1984-85 and 1985-86 at weekly intervals. At low and high aphid densities, egg and larval population dispersion was non-aggregated where as, at intermediate densities, it was aggregated.

Kotwal *et al.* (1989) conducted a study on the incidence, population build up, relative abundance and predation of syrphid flies and the workers were of the opinion that syrphid flies are the most important predators of aphids.

Rehman (2009) conducted a study on the population dynamics of *Myzus persicae* (Sulzer) and its associated natural enemies in spring potato crop, Peshawar-Pakistan and reported that *Coccinella septempunctata*, *Episyrphus balteatus* and *Chrysoperla carnea* were the predominant natural enemies of *Myzus persicae*. The population density of all the natural enemies was found to be

highest in the 3rd week of March and declined thereafter with the decrease in *Myzus persicae* population.

Sajjad *et al.* (2010) reported 14 species of syrphid flies while carrying out a study on the seasonal variation in abundance and composition of Hoverfly (Diptera: Syrphidae) communities in Multan Pakistan. Among sub-family Syrphinae, *Ischiodon scutellaris*, *Episyrphus balteatus* and *Sphaerophoria bengalensis* were the most abundant. *Eristalinus areneus* and *Eristalinus laetuss* were the most frequent floral visitors.

Naderloo *et al.* (2013) found 31 species of syrphid flies from four different habitat types in Iran's Zanzan province: riverside, woodland, fruit orchard, and rice field. In the province of Zanzan, adult hoverflies were gathered from several habitats. The three that were discovered to be the most prevalent were *Sphaerophoria scripta* (Linnaeus), *Eristalis arbustorum* (Linnaeus), and *Eristalis tenax* (Linnaeus). The highest and lowest levels of species richness and diversity, respectively, were found in the rice field and along the river.

Mitra *et al.* (2015) reported 357 species of syrphid flies belonging to three subfamilies from different types of ecosystems in India. The sub-family Syrphinae shares the maximum number of species. The maximum number of species were reported from West Bengal and the least number of species were reported from Tripura.

Sengupta *et al.* (2016) reported 355 species of syrphid flies belonging to 69 genera, while carrying out a study on the updated distributional account of Indian hover flies (Diptera: Syrphidae). However, some species which were reported in earlier studies but due to lack of proper literature documentation they have not been documented in this current and updated checklist namely, *Syrphus agraensis* (Nayar and Nayar 1965) and *Scavea lunata* (Wiedemann, 1830).

Khan and Riyaz (2017) conducted a study on the diversity and distribution of syrphid family communities in temperate fruit orchards of Kashmir and

reported 19 species of syrphid flies from the Apple, Pear, Peach and Plum orchards of Kashmir valley. Among these *Eristalis tenax* was found relatively most dominant followed by *Eoseristalis cerealis*, *Eristalis interruptus* and *Episyrphus balteatus*. The highest relative abundance and distribution of syrphid flies was recorded in apple orchards followed by pear orchards and lowest in peach orchards. Species diversity was greater in fruit orchards of Harwan and species richness was greater in fruit orchards of Warpora of district Baramulla.

Khan *et al.* (2017) reported 21 species of syrphid flies from the floriculture ecosystem of Kashmir including daffodil, rose, chrysanthemum and wild flowers: dandelion, fennel and black berry. Among these *Eristalis tenax* was found most abundant and distributed followed by *Eoseristalis cerealis* and *Eupeodus corolla* were as *Syritta sp.* followed by *Palpada sp.* where found least distributed and abundant in all the locations of Kashmir valley. The highest species richness was observed in Mamoosa area of district Baramulla followed by Shalimar area of district Srinagar.

Kumar *et al.* (2017) carried out a research on the isolation, identification and occurrence of major syrphid fly species of various agricultural, horticultural, medicinal and oil seed crops in western Uttar Pradesh and reported 18 species of predatory syrphid flies, out of them 12 species belonging to three families were identified. *Episyrphus balteatus* was the most abundant among the reported species followed by *Ischiodon scutellaris* and *Eristalis taphicus*.

Thangjam *et al.* (2019) reported 23 species belonging to 16 genera and 2 subfamilies *viz* *Eristalinae* and *Syrphinae* from Assam Agriculture University, Assam. Among the reported species, *Episyrphus viridaureus* and *Lathyrophthalmus avorum* were found to be most abundant.

Ahmed *et al.* (2020) reported 15 species of syrphid flies belonging to 9 genera and 2 subfamilies (*Eristalinae* and *Syrphinae*) in Faisalabad, Pakistan while

carrying a research on the taxonomic study of family Syrphidae of Faisalabad, Pakistan.

2.2 Prey and Predation potential of marmalade syrphid fly *Episyrphus balteatus* De Geer

Sundby (1966) conducted a study on the predation capacity of syrphid species and found that, in comparison to the spring season, only a tiny number of aphids are devoured by several syrphid fly species during the winter season.

Tawfix *et al.* (1974) carried out a study on the predation potential of several syrphid species, including *Syrphus corollae*, *Metasysphus corollae*, *Ischiodon scutellaris*, *Episyrphus balteatus*, *Syrphus confrater* and *Macrosysphus confrater* and concluded that the predation potential of various syrphid species is dependent on the concerned species and prevailing environmental conditions.

Roy and Basu (1977) carried out a study on the predation potential of *Episyrphus balteatus* and reported that *E. balteatus* consumed 22.5, 91.7 and 395.8 aphids of *Lipaphis erysimi* per larva in 1st, 2nd and 3rd instar, respectively. The total consumption being 510 aphids per larva during the total life span at a mean temperature of 27±2°C and relative humidity of 89±5 percent.

Gorpada (1981) analysed the existing work on aphidophagous syrphidae from India and neighbouring countries and identified 47 bug species that preyed on a total of 542 insect species. Only syrphid fly species were found to prey on the mustard aphid in this collection.

Sharma (1983) conducted a study on the various syrphid species of India and reported two species of syrphid flies *Metasyrphus corolla* and *Syrphus Indiana*, that prey on *Brevicoryne brassicae* (Lin.). Similarly, *Episyrphus balteatus* and *Metasyrphus sp.* were found to prey on the cabbage aphid *Brevicoryne brassicae* by Kotwal *et al.* (1984).

Bhagat and Lone (1984) did a study on the distribution of syrphid flies in Kashmir valley and found that three species of syrphids, *Episyrphus balteatus*,

Syrphus Indiana and *Syrphus spp.*, preyed on different types of aphids in Kashmir valley.

Laska (1984) conducted a study on the predation potential of *Episyrphus balteatus* and reported the daily aphid requirement of *Episyrphus balteatus* varies between 0.5 and 15.0 mg depending on the size and instar of the larva.

While reviewing the published studies on aphidophagus syrphidae from India, Agarwal *et al.* (1984) discovered *Episyrphus balteatus*, *Ischiodon scutellaris* and *Metanostoma orientale* preying on the mustard aphid.

Ankersmit *et al.* (1986) conducted a research on the *Episyrphus balteatus* as a predator of aphid *Sitobion avenae* on winter wheat and reported that the high rate of reproduction and the short feeding period make *E. balteatus* an excellent exploiter of a temporary habitat: a cereal aphid colony. The 3rd instar larvae of *E. balteatus* were found to be possessing maximum predatory activity among all the three larval instars.

Makhmoor and Verma (1987) reported that *Episyrphus balteatus* consumed 218 individuals of Cabbage aphid *Brevicoryne brassicae* per 3rd larval instar during December-February at maximum and minimum temperatures of 14.5 and 9.1°C with a relative humidity of 75 per cent and 202 individuals of cabbage aphid *B. brassicae* during March-April with a corresponding maximum and minimum temperature of 19.4°C and 13.6°C with a relative humidity of 65 per cent. Similar observations for more consumption of aphids during winter season in comparison to spring season in case of *Syrphus rebessi* have also been reported (Sundby, 1966).

Bhagat *et al.* (1988) reported four species of syrphid flies viz., *Episyrphus balteatus*, *Macrosyrphus confrater*, *Metasyrphus corollae* and *Syrphus pyrasteri* preying upon *Aphis pomi* infesting apple trees in Kashmir valley.

Tenhumberg (1995) conducted a study on the effect of predation by *Episyrphus balteatus* larvae on aphid populations in fields of winter wheat and

recorded lower consumption rates the field as compared to the laboratory experiments. The lower consumption rates in the field may be attributed to the additional time required by the predators to find the prey.

Bargen *et al.* (1998) reported the first instar larvae of the *Episyrphus balteatus* showed focused search over short distances, guided by olfactory signals from aphids but not honeydew, while carrying a study on the prey discovery by larvae and adult females. In a 4-arm olfactometer, however, second and third instars did not react to aphid-plant-complex odors. The larvae's ability to feed was found to be stimulated by aphid extracts, honeydew, and sucrose. The females were able to evaluate the aphid numbers and adjust oviposition rates accordingly, with higher prey numbers eliciting increased oviposition.

Patro and Behera (2002) studied the biology and feeding potential of *Sphaerophoria javana* (Weid) on the bean aphid *Aphis craccivora* (Koch) under laboratory conditions at $27.9 \pm 1.1^\circ\text{C}$ and 85.7 ± 5.2 percent relative humidity and they discovered that the corresponding durations of the egg, larval, and pupal stages were 1.96 ± 0.07 , 6.30 ± 0.22 , and 5.38 ± 0.04 days respectively. The total life cycle was completed in 14.02 ± 0.2 days. The per day consumption of 1st, 2nd and 3rd instar larvae was 12.7 ± 2.2 , 69.4 ± 7.4 and 112.2 ± 7.7 aphids, respectively.

Samuel *et al.* (2005) conducted a study on feeding potential and its effect on development of *Episyrphus balteatus* (De Geer) (Diptera: Syrphidae) by using variable prey density and reported that *E. balteatus* larvae required at least 20 aphids per day for proper growth and development; 80 aphids per day was discovered to be the optimum number at which the larvae consumed 400–500 aphids for their full development and emergence; and normal duration of adulthood. In field, it was observed that the adult females of *E. balteatus* also determine whether to deposit, based on the patch-size of the prey. They have been found to oviposit very judiciously accounting the number of preys to avoid shortage of food to their young ones. In other words, the larval instars of *E.*

balteatus demonstrated a positive density-dependent response / Holling's type I functional response to aphid colony size in terms of oviposition behaviour.

Verma *et al.* (2006) reported that the four species of syrphids *viz.*, *Episyrphus balteatus*, *Eupeodes frequens*, *Metasyrphus corollae* and *Betasyrphus serarius* were found preying upon *Aphis faba*. They reared these four species under laboratory conditions and found that the average number of aphids consumed per larvae were 416.25, 288.20, 354.40 and 288.75 for all the four predators.

Farzad (2010) conducted a study on the biology and feeding rate of *Episyrphus balteatus* De Geer on *Aphis pomi* under laboratory conditions and reported that the mean daily consumption of 1st, 2nd and 3rd instar larvae of *E. balteatus* to be 8.40 ± 0.44 , 36.82 ± 1.67 and 64.33 ± 2.63 respectively.

Jalilian *et al.* (2011) conducted a study on the functional response and mutual interference of *Episyrphus balteatus* and *Scaeva albo maculata* (Dip.: Syrphidae) fed on *Myzus persicae* (Hom.: Aphididae) under laboratory conditions and reported a type II functional response for both the predators.

Amiri-Jami and Sadeghi-Namaghi (2013) studied the functional and numerical responses of *Episyrphus balteatus* to different densities of 4th instar black bean aphid, *Aphis fabae* on broad bean *Vicia faba L.* and reported a type-II functional response.

Mushtaq *et al.* (2014) conducted a study on the predatory preference and its impact on the developmental period of *Episyrphus balteatus* on four aphid species, including *Brevicoryne brassicae*, *Schizaphis graminum*, *Myzus persicae* and *Rhopalosiphum padi*. They found that the larval growth was significantly higher when *S. graminum* was present, while the developmental duration was significantly longer when *B. brassicae*'s predatory influence on aphids was more successful because of its comparatively lower consumption and greater growth.

Regardless of the prey type, the third instar larvae of *E. balteatus* showed the highest aphid consumption.

Sedarratian-Jehromi *et al.* (2014) conducted a study on the functional response and mutual interference of *Episyrphus balteatus* and *Scaeva albomaculata* fed on *Myzus persicae* and found that the estimated values of attack rate for the first, second and third instars of *E. balteatus* were 0.0359, 0.0420 and 0.0677, respectively and the values of handling time were 2.257, 0.506 and 0.316. The calculated values of attack rate and handling time for the second and third instars of *S. albomaculata* were 0.0590, 0.0655 and 0.575, respectively. The obtained results show that there is no significant relationship between log attack rate (a) and log third instars density (P) in *E. balteatus*, but there is a significant relationship in *S. albomaculata*, as indicated by the interference coefficient for the third instars of this predator, which was -0.274 when it was fed on 100 density of *M. persicae*.

Khan *et al.* (2015) carried out a study on the functional response of four syrphid flies to green apple aphid *Aphis pomi* in laboratory conditions and reported that all predators and preying stages demonstrated type II functional response. Predator larvae in their second and third instars were placed in Petri dishes with progressively higher densities of nymphs of the same size as *A. pomi*. *E. balteatus*, *E. tenax*, *E. interruptus* and *S. scripta* were found to have the highest consumption rates. An operational Type II functional response was displayed by all predator species and stages. The coefficients of attack rate and handling time revealed negligible variation among species and preying stages, indicating that the four syrphid species had equivalent potential to control *A. pomi* colonies.

Varshney (2016) conducted a study on the feeding potential of the syrphid larvae, *Episyrphus balteatus* (De Geer) and *Ischiodon scutellaris* (Fabricius) on the mustard aphid, *Lipaphis erysimi* (Kalt.) and reported that that the larvae of *I. scutellaris* consumed more aphids than the *E. balteatus* during their entire larval period and these variations were significant during the 1st and 3rd larval instars. He

also reported that all the predators and preying stages demonstrated type II functional response.

Khan (2017) carried out a research on the functional response of four syrphid predators to mealy cabbage aphid *Brevicoryne brassicae* in laboratory conditions and reported that all the predators and preying stages demonstrated type II functional response. In petri dishes, increasing densities of *B. brassicae* nymphs of the same size were exposed to the predator larvae in their second and third instars. The *E. balteatus* third instar was observed to consume the highest number of aphids. It was discovered that there was a considerable difference between species and preying stages in the coefficients of attack rate and handling time. According to the findings, the third instar larva of the predator *E. balteatus* is the most effective at controlling *B. brassicae* colonies.

Faheem *et al.* (2019) conducted a study aiming to explore and compare the predatory potential of two syrphid fly species *Ischiodon scutellaris* (Fabricius) and *Episyrphus balteatus* (De Geer) on wheat aphid *Schizaphis graminum* (Rondani) at different temperatures under laboratory conditions and observed that during their entire life span, *I. scutellaris* larvae devoured noticeably more aphids than *E. balteatus* larvae, and this difference was particularly significant in the first and third instars. However, the *I. scutellaris* fed on substantially more aphids each day after the 10th day after hatching than did the other species' average daily prey consumption.

Meena (2019) conducted a study on the biology and feeding potential of *Episyrphus balteatus* on green apple aphid *Aphis pomi* De Geer (Hemiptera: Aphididae) in the hills of Shimla and found that larvae of this species of Syrphid flies are very effective predators of green apple aphid *A. Pomi* De Geer in Himachal Pradesh and should be reared commercially for use in biological control of this aphid pest of Apple nursery and young plants.

Khan *et al.* (2020) conducted a research on the sucking insect pests of temperate vegetable crops and reported that the temperate region's vegetable crops are particularly vulnerable to high insect pest infestation and significant post-harvest losses. Monoculture, overlapping crops, dense cropping, overuse of fertilisers and pesticides, ongoing availability of preferred host plants, etc. have all contributed to a variety of pest issues, with insect pests responsible for more than 40% of the yield loss in vegetable crops. The sucking pests of temperate vegetable crops reported were *Myzus persicae*, *Aphis gossypii*, *Macrosiphum euphorbiae*, *Brevicoryne brassicae*, *Lipaphis pseudobrassicae* & *Brachycaudus helichrysi*.

Khatua *et al.* (2020) conducted a study on the feeding potential and functional response of the syrphid fly *Eumerus albifrons* Walker to cow pea aphid, *Aphis craccivora* Koch under laboratory conditions. The results showed that the first and second instars of *E. albifrons* exhibited a Holling's type II functional response, which is characterised by a hyperbolic curve.

Li and Wu (2022) studied the bi-directional predation between larvae of the hover fly *Episyrphus balteatus* (Diptera: Syrphidae) and the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and reported. 1st and 2nd larval instars of *S. frugiperda* were eaten by *E. balteatus*, while third and higher larval instars of *S. frugiperda* preyed on all larval instars of *E. balteatus*. According to the Holling type III response in petri dishes, the 2nd and 3rd larval instars of *E. balteatus* preyed on the 1st and 2nd larval instars of *S. frugiperda*, with a theoretical maximum predation of 77 and 71 individuals in 24 hours. The 5th and 6th larval instars of *S. frugiperda* exhibited Holling type III response on larvae of *E. balteatus*, with a maximum predation of 29 and 36 individuals, of 1st instar larvae of *E. balteatus* respectively. None of the *S. frugiperda* larvae that fed on *E. balteatus* larvae developed to adulthood and only about 20% of *E. balteatus* larvae that fed on *S. frugiperda* larvae became adults.

Chapter -3

MATERIALS AND METHODS

The materials used and methods adopted for carrying out the proposed studies on marmalade syrphid fly *Episyrphus balteatus* De Geer are described parameter-wise as follows.

3.1 Population dynamics of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir

The population dynamics of marmalade syrphid fly *E. balteatus* was studied in vegetable ecosystem of Kashmir. Field sampling was conducted to collect the *E. balteatus* from the economically important vegetable crops in the Kashmir valley. The crops covered were tomato and brinjal from Solanaceae family and cabbage and kale from Cruciferae family (Plate 1). Both the adult and larvae of *E. balteatus* were collected for the study.

3.1.1 Study sites.

The study covered the two vegetable growing areas of the Kashmir valley namely, district Srinagar and district Budgam. Three locations from each district were selected to reduce the spatial heterogeneity existing in the distribution of marmalade syrphid fly fauna. The locations were Shalimar (74.880⁰E and 34.148⁰N, altitude; 1587 metre above mean sea level (amsl)), Harwan (74.890⁰E and 34.156⁰N, altitude; 1638 metre and Batpora (74.839⁰E and 34.14⁰N, altitude; 1592 metre amsl) from district Srinagar and Chadoora (74.798⁰E and 33.94⁰N, altitude; 1577 metre amsl), Narkara (74.743⁰E and 34.034⁰N, altitude; 1586 metre amsl) and proper Budgam (74.641⁰E and 33.934⁰N, altitude; 1610 metre amsl) from district Budgam. Only the commercial cultivars/varieties of the selected crops were sampled.



(a)



(b)



(c)



(d)

Plate 1: Crops under study: (a) Tomato (b) Brinjal (c) Cabbage and (d) Kale

3.1.2 Sampling Method.

Adult syrphids were collected by making double stroke sweeps using insect collection net (Diameter 32 cm and handle 92 cm) and were counted as adults caught / sweep. The larvae of *E. balteatus* were collected by hand picking and were counted as larvae collected / 5 plants (Plate 2).

3.1.3 Sampling Scheme.

The sampling was conducted from 11th June to 9th September 2021 in tomato and brinjal where as in case of cabbage and kale, the sampling was conducted from 5th March to 3rd June 2021 at weekly intervals. Population counts were made by random sampling throughout the cropping season. For adult collection, two sweeps were carried out and for larval collection, observations were taken from five randomly selected plants. The observations on population dynamics of both adults as well as larvae were replicated thrice. The marmalade syrphid fly specimen were killed in cyanide bottles and carried in duly labelled plastic bottles (labels containing all pertinent information, viz. date of collection, location, crop etc.) to the laboratory. The samples were dried in oven at 60 °C, pinned with entomological pins for density count and stored in collection boxes. The specimens were identified by Prof. Zakir Husain Khan from the Division of entomology, SKUAST-K Shalimar, Srinagar.

3.1.4 Parameters of population dynamics.

The data collected from the field sampling of *E. balteatus* was analysed to work out the various parameters of population dynamics as follows.

3.1.4.1 Population density of marmalade syrphid fly *Episyrphus balteatus* De Geer.

Population density of both the adults and larvae of *E. balteatus* was worked out by analysing the number of adults collected per sweep and number of larvae collected per 5 plants respectively in each crop and at all the locations at weekly intervals.



(a)



(b)

Plate 2: (a) Sweep-net Method for adult collection and (b) Hand-picking Method for larval collection

3.1.4.2 Correlation of population density of adult and larvae of marmalade syrphid fly with weather parameters of mean temperature mean relative humidity.

The data on population density was subjected to correlation studies with weather parameters during the experimental period like mean temperature and mean relative humidity. Meteorological data of abiotic factors were collected from Agro-meteorology Unit SKUAST-K Shalimar.

3.2 Prey and temperature dependent functional response of marmalade syrphid fly *Episyrphus balteatus* De Geer on two different aphid species

3.2.1 Prey of *Episyrphus balteatus* De Geer.

The prey of *E. balteatus* was recorded in all the crops and at all the locations based on morphological characters and was then verified in the laboratory of Division of Entomology SKUAST-K Shalimar, Srinagar.

3.2.2 Temperature dependent functional response of marmalade syrphid fly *Episyrphus balteatus* De Geer on two different aphid species.

The studies on temperature dependent functional response of *E. balteatus* on two different predominant aphid species viz., *Brevicoryne brassicae* and *Myzus persicae* were carried out in the laboratory of the Division of Entomology, SKUAST-K, Shalimar, during summer 2021. A detailed account of the materials used and methods adopted for carrying out the the proposed investigations is described as follows.

3.2.2.1 Insect rearing.

Two aphid species viz. *B. brassicae* (Linnaeus) and *M. persicae* (Sulzer) were used as diet for the studies of temperature dependent functional response of 2nd and 3rd instar larvae of *E. balteatus*. To rear the predator larvae, aphid colonies were maintained on fresh leaves of cabbage, in cages (18x18x18 cm) separately

(Plate 3a). The colonies were collected from pesticide free vegetable fields in the University Campus of SKUAST-K Shalimar, Srinagar.

Stock cultures of *E. balteatus* were established using adults captured at the Shalimar campus of SKUAST-K, Srinagar during summer 2021 (Plate 3b). The stock cultures were maintained at a room temperature of $25\pm 2^{\circ}\text{C}$ under a 14-h photoperiod. The insects were fed with flowers of *Brassica acephala* (Pollen source) placed in a conical flask and cotton pad soaked in diluted honey (10%) and sugar solution, placed at the bottom of a rearing cage. To obtain a group of larvae of the same age, females were induced to lay eggs on leaves of cabbage infested with aphids.

3.2.2.2 Temperature dependent functional response

Functional response of 2nd and 3rd instar larvae of the *Episyrphus balteatus* (Plate 4a) to various densities of different aphids was determined. The predatory larvae were deprived of prey for a period of 12 hours prior to the experiment. Individual larvae were then exposed to different densities of the test aphids in petri dishes (9 × 1.5 cm) on excised leaves of cabbage at varying temperatures of 20° C, 25°C, 30°C and 35°C. Eight different densities of similar sized (generally fourth instars) aphids were provided: 2, 4, 8, 16, 32, 64, 128 and 256 aphids to both 2nd and 3rd instar larvae respectively (Plate 4b). At the end of a 24-hour period, the larvae were removed from experimental Petri dishes and the numbers of unconsumed aphids was counted. The aphids were introduced before the predators so that they could disperse and the predators may have to search for the aphids. All the experiments were conducted in an incubator at 20° C, 25°C, 30°C and 35°C, 60–70% RH and a photoperiod of 16:8 (L:D) h (Plate 4c) and replicated 10 times for each predator larval stage at each prey density, Control experiments without predators were carried out in parallel and natural aphid mortality was accounted for. The functional response of 2nd and 3rd larval instar to both the aphid species was analysed for two aspects i.e. type of functional



Plate 3a: Stock culture of field collected aphids in cages



Plate 3b: Stock culture of adults of *Episyrrhus balteatus* in rearing cage



(a)

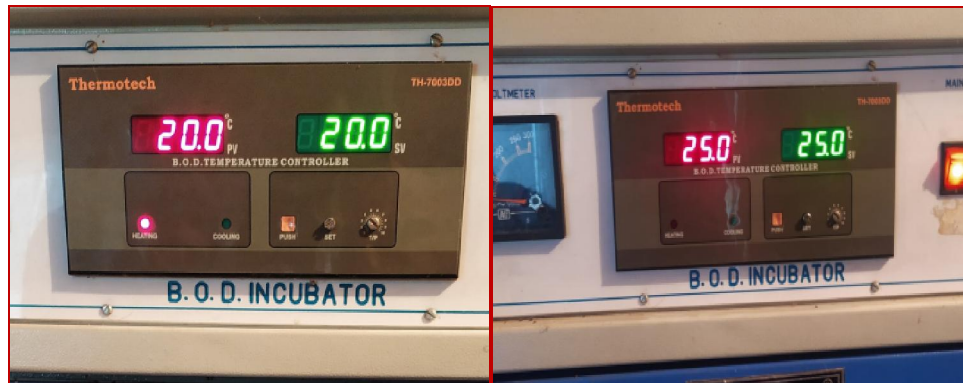


(b)

Plate 4a: 2nd (a) and 3rd instar larvae (b) of *Episyrrhus balteatus*



Plate 4b: 2nd and 3rd instar larvae of *Episyrrhus balteatus* with *Brevicoryne brassicae* in petridishes.



(a)

(b)



(c)

(d)

Plate 4c: Evaluation of predation rates of 2nd and 3rd instar larvae of *E. balteatus* against *Brevicoryne brassicae* and *Myzus persicae* in an incubator at different temperatures of 20, 25, 30 and 35°C

response and the parameters of functional response (attack rate and handling time).

3.2.2.2.1 Type of functional response

It's crucial to understand the sort of functional response displayed by a certain instar of a predator to a specific prey species before fitting the data to a specific Hollings' equation (Holling, 1959 and 1966). 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 consumed (N_a/N_0) as a function of prey offered (N_0). Hence, the data was fitted to the following polynomial function that describes the relationship between N_a /N_0 and N_0 .

$$\frac{N_a}{N_0} = \frac{\exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3)}{1 + \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3)}$$

Where,

P_0 = Intercept

P_1 = Linear coefficient

P_2 = Quadratic coefficient

P_3 = Cubic coefficient

N_a = Number of prey eaten

N_0 = 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 $P_1 < 0$, then a type II functional response will be described by a fraction of prey consumed that drops monotonically with the amount of prey initially offered. (Juliano, 2001). The coefficients of polynomial logistic regression were determined using the function “glm” in R software (R Development Core Team, 2008).

3.2.2.2.2 Parameters of functional response

After the determination of type of functional response, the data i.e., the number of aphids preyed upon by 2nd and 3rd instar larvae of *Episyrphus balteatus* 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

$$N_a = N_o [1 - \exp \{a (Th N_a - T)\}]$$

Where,

N_a = Number of prey eaten

N_o = Number of prey offered

a = attack rate

Th = 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 Population dynamics and predatory activities of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir as follows.

4.1 Population dynamics of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir

The random field sampling of *E. balteatus* in four vegetable crops at six different locations of two districts revealed the following information.

4.1.1 Population density of *Episyrphus balteatus* in vegetable ecosystem of Kashmir during 2021

Data on the population density of *E. balteatus* in four vegetable crops i.e. tomato and brinjal from Solanaceae family and cabbage and kale from Cruciferae family recorded at six different locations of Kashmir valley i.e. three in Srinagar district and three in Budgam district is presented in Tables 1-4. It is evident from the tables that the population density (i.e. numer of adults/sweep and number of larvae/5 plants respectively) of both the adults and larvae of *E. balteatus* was low in all the crops initially at the beginning of cropping season i.e. 23rd standard week in case of tomato and brinjal (second week of June) and 9th standard week in case of cabbage and kale (first week of March) which increased gradually and attained peak in the 29th standard week in case of tomato and brinjal (fourth week of July) and 19th standard week in case of cabbage and kale (2nd week of May) respectively. There-after it started decreasing again till the end of growing season. The highest population density of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district in all the four crops followed by Chadoora area of Budgam. The lowest population density of both the adults and larvae of *E. balteatus* was recorded at proper Budgam. Solanaceous crops were found supporting the

maximum number of both adults as well as larvae as compared to the cruciferous crops.

Taking into account the impact of abiotic factors (weather parameters) on the population density of adult and larvae of *E. balteatus*, a correlation analysis was performed (Table 9 and 10). It showed that there was a significant positive correlation between the mean temperature and the adult and larval population density of *E. balteatus*. In addition, there was a positive, but non-significant correlation between the mean relative humidity and the adult and larval population density of *E. balteatus*.

4.1.2 Population distribution of *Episyrphus balteatus* in vegetable ecosystem of Kashmir during 2021

Distribution of adult and larval population of *E. balteatus* in the vegetable ecosystem of Kashmir during 2021 is presented in Tables 5-8. Observations were the sum of six sweeps/week for adults and the sum of fifteen plants/week for larvae.

It is evident from the tables that the weekly population distribution (i.e. number of adults/week and number of larvae/15 plants/week respectively) of both the adults and larvae of *E. balteatus* was low in all the crops initially at the beginning of cropping season i.e. 23rd standard week in case of tomato and brinjal (second week of June) and 9th standard week in case of cabbage and kale (first week of March) which increased gradually and attained peak in the 29th standard week in case of tomato and brinjal (fourth week of July) and 19th standard week in case of cabbage and kale (2nd week of May) respectively. There-after it started decreasing again till the end of growing season. The highest distribution of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district in all the four crops followed by Chadoora area of Budgam. The lowest distribution of both the adults and larvae of *E. balteatus* was recorded at proper Budgam.

Table-1: Population density of *Episyrphus balteatus* recorded in Tomato and Brinjal in Srinagar district during Summer 2021

Standard week	Population density												Meteorological parameters	
	Tomato						Brinjal						Mean T (°C)	Mean RH (%)
	Harwan		Shalimar		Batpora		Harwan		Shalimar		Batpora			
	A	L	A	L	A	L	A	L	A	L	A	L		
23	0.17	0.33	0	0	0	0	0	0	0	0	0	0	21.2	66.5
24	0.33	0.67	0.17	0.33	0.17	0	0	0	0	0	0	0	21.62	65.35
25	0.5	1	0.33	0.67	0.17	0.67	0.17	0.67	0	0.33	0	0.33	23.14	67.68
26	0.5	1	0.17	0.67	0.17	0.33	0.17	0.33	0	0.33	0	0	23.07	52.78
27	0.5	1.33	0.33	1	0.33	0.67	0.33	0.67	0.17	0.33	0	0.33	23.85	60.21
28	0.5	1.33	0.33	0.67	0.17	0.67	0.33	0.67	0.17	0.33	0	0.33	23.5	68.57
29	1	3	0.83	2.33	0.67	2	0.83	2	0.5	1.67	0.33	1.33	25.35	68.79
30	0.83	2.67	0.66	2.33	0.5	1.67	0.5	1.67	0.5	1.33	0.33	1	25.21	71.42
31	0.5	1.33	0.33	1.33	0.17	1	0.33	1	0.17	0.67	0	0.33	23.5	63.21
32	0.33	0.67	0.17	0.67	0.17	0.67	0.17	0.67	0	0.33	0	0.33	22.21	63.14
33	0.67	2	0.5	1.67	0.5	1.33	0.33	1.33	0.33	1	0.17	0.67	24.35	57.5
34	0.5	1	0.33	0.67	0.17	0.67	0.33	0.67	0	0.33	0.17	0.33	23.3	59.35
35	0.33	0.67	0.17	0.33	0.17	0.33	0.17	0.33	0	0	0	0	21.64	60.29

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 2: Population density of *Episyrphus balteatus* recorded in Tomato and Brinjal in Budgam district during Summer 2021

Standard week	Population density												Meteorological parameters	
	Tomato						Brinjal						Mean T (°C)	Mean RH (%)
	Chadoora		Narkara		Proper Budgam		Chadoora		Narkara		Proper Budgam			
	A	L	A	L	A	L	A	L	A	L	A	L		
23	0	0	0	0	0	0	0	0	0	0	0	0	20.4	67.2
24	0.17	0.33	0.17	0	0.17	0	0	0	0	0	0	0	20.82	66.05
25	0.33	0.67	0.33	0.67	0.17	0.33	0.17	0.67	0	0.33	0	0	22.34	68.38
26	0.33	0.67	0.17	0.33	0	0	0.17	0.33	0	0	0	0	22.27	53.48
27	0.5	1	0.33	0.67	0.33	0.67	0.33	0.67	0.17	0.33	0	0.33	23.05	60.91
28	0.33	1	0.33	0.67	0.17	0.33	0.33	0.67	0.17	0.33	0	0.33	22.7	69.27
29	0.83	2.67	0.5	2.33	0.5	2	0.5	1.67	0.33	1.33	0.33	1.33	24.55	69.49
30	0.67	2.33	0.5	2	0.33	1.33	0.33	1.33	0.33	1	0.33	1	24.41	72.12
31	0.33	1	0.33	0.67	0.17	0.67	0.17	1	0.17	0.67	0	0.33	22.7	63.91
32	0.17	0.33	0.17	0.33	0	0	0.17	0.67	0	0.33	0	0	21.41	63.84
33	0.5	2	0.33	1.67	0.17	1.33	0.33	1.33	0.33	0.67	0.17	0.67	23.55	58.2
34	0.33	0.67	0.17	0.33	0.17	0.33	0.17	0.67	0	0.33	0	0.33	22.5	60.05
35	0.17	0.33	0.17	0	0	0	0	0.33	0	0	0	0	20.84	61.2

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 3: Population density of *Episyrphus balteatus* recorded in Cabbage and Kale in Srinagar district during Spring Summer 2021

Standard week	Population density												Meteorological parameters	
	Cabbage						Kale						Mean T (°C)	Mean RH (%)
	Harwan		Shalimar		Batpora		Harwan		Shalimar		Batpora			
	A	L	A	L	A	L	A	L	A	L	A	L		
9	0	0	0	0	0	0	0	0	0	0	0	0	10.19	61.57
10	0	0	0	0	0	0	0	0	0	0	0	0	10.1	66.4
11	0	0	0	0	0	0	0	0	0	0	0	0	9.59	60.14
12	0.17	0.33	0	0.33	0	0	0	0.33	0	0	0	0	13.1	57.28
13	0.17	0.33	0	0.33	0	0.33	0	0.33	0	0.33	0	0	15.7	64.5
14	0.17	0.67	0.17	0.67	0.17	0.67	0.17	0.67	0	0.33	0	0.33	17.3	62.71
15	0.17	0.67	0.17	0.33	0	0.33	0	0.33	0	0.33	0	0	16.58	65.3
16	0.17	1	0.17	1	0.17	0.67	0.33	1	0.17	0.67	0	0.33	20.44	57.4
17	0.17	0.67	0.17	0.67	0	0.33	0	0.67	0	0.33	0	0	17.01	64.75
18	0.33	1	0.17	0.67	0	0.33	0.33	0.67	0.17	0.33	0.17	0.33	19.94	58
19	0.67	1.67	0.5	1.33	0.33	1	0.5	1.33	0.33	1	0.33	0.67	21.94	69.18
20	0.33	1.33	0.33	1	0.17	0.67	0.33	1	0	0.67	0	0.67	20.42	66.85
21	0.33	1	0.33	1	0.33	0.67	0	0.67	0	0.67	0	0.33	20	68

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 4: Population density of *Episyrphus balteatus* recorded in Cabbage and Kale in Budgam district during Spring Summer 2021

Standard week	Population density												Meteorological parameters		
	Cabbage						Kale						Mean T (°C)	Mean RH (%)	
	Chadoora		Narkara		Proper Budgam		Chadoora		Narkara		Proper Budgam				
	A	L	A	L	A	L	A	L	A	L	A	L			
9	0	0	0	0	0	0	0	0	0	0	0	0	0	9.39	62.27
10	0	0	0	0	0	0	0	0	0	0	0	0	0	9.3	67.1
11	0	0	0	0	0	0	0	0	0	0	0	0	0	8.79	60.84
12	0	0.33	0	0	0	0	0	0	0	0	0	0	0	12.3	58
13	0	0.33	0	0.33	0	0	0	0.33	0	0	0	0	0	14.9	65.2
14	0.17	0.67	0.17	0.67	0	0.33	0	0.33	0	0.33	0	0	0	16.5	63.41
15	0.17	0.33	0	0.33	0	0	0	0.33	0	0	0	0	0	15.78	66
16	0.33	1	0.33	0.67	0.33	0.67	0.17	0.67	0	0.33	0.17	0.33	0	19.64	58.1
17	0.17	0.67	0	0.33	0	0	0	0.33	0	0	0	0	0	16.21	65.45
18	0.17	0.67	0	0.33	0	0.33	0.17	0.33	0.17	0.33	0	0	0	19.14	58.7
19	0.5	1.33	0.33	1	0.33	1	0.5	1	0.33	0.67	0.33	0.67	0	21.14	69.88
20	0.33	1	0.33	0.67	0.33	0.67	0	0.67	0	0.67	0.17	0	0	19.62	67.55
21	0.33	1	0.33	0.67	0.17	0.33	0	0.67	0	0.33	0	0	0	19.2	68.7

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 5: Distribution of *Episyrphus balteatus* recorded in Tomato and Brinjal in Srinagar district during Summer 2021

Standard week	Population distribution											
	Tomato						Brinjal					
	Harwan		Shalimar		Batpora		Harwan		Shalimar		Batpora	
	A	L	A	L	A	L	A	L	A	L	A	L
23	1	1	0	0	0	0	0	0	0	0	0	0
24	2	2	1	1	1	0	0	0	0	0	0	0
25	3	3	2	2	1	2	1	2	0	1	0	1
26	3	3	1	2	1	1	1	1	0	1	0	0
27	3	4	2	3	2	2	2	2	1	1	0	1
28	3	4	2	2	1	2	2	2	1	1	0	1
29	6	9	5	7	4	6	5	6	3	5	2	4
30	5	8	4	7	3	5	3	5	3	4	2	3
31	3	4	2	4	1	3	2	3	1	2	0	1
32	2	2	1	2	1	2	1	2	0	1	0	1
33	4	6	3	5	3	4	2	4	2	3	1	2
34	3	3	2	2	1	2	2	2	0	1	1	1
35	2	2	1	1	1	1	1	1	0	0	0	0
Total	40	51	26	38	20	30	22	30	11	20	6	15

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 6: Distribution of *Episyrphus balteatus* recorded in Tomato and Brinjal in Budgam district during Summer 2021

Standard week	Population distribution											
	Tomato						Brinjal					
	Chadoora		Narkara		Proper Budgam		Chadoora		Narkara		Proper Budgam	
	A	L	A	L	A	L	A	L	A	L	A	L
23	0	0	0	0	0	0	0	0	0	0	0	0
24	1	1	1	0	1	0	0	0	0	0	0	0
25	2	2	2	2	1	1	1	2	0	1	0	0
26	2	2	1	1	0	0	1	1	0	0	0	0
27	3	3	2	2	2	2	2	2	1	1	0	1
28	2	3	2	2	1	1	2	2	1	1	0	1
29	5	8	3	7	3	6	3	5	2	4	2	4
30	4	7	3	6	2	4	2	4	2	3	2	3
31	2	3	2	2	1	2	1	3	1	2	0	1
32	1	1	1	1	0	0	1	2	0	1	0	0
33	3	6	2	5	1	4	2	4	2	2	1	2
34	2	2	1	1	1	1	1	2	0	1	0	1
35	1	1	1	0	0	0	0	1	0	0	0	0
Total	28	39	21	29	13	21	16	28	9	16	5	13

A=Mean number of adults caught per sweep.
L=Mean number of larvae collected per 5 plants.

Table 7: Distribution of *Episyrphus balteatus* recorded in Cabbage and Kale in Srinagar district during Spring- Summer 2021

Standard week	Population distribution											
	Cabbage						Kale					
	Harwan		Shalimar		Batpora		Harwan		Shalimar		Batpora	
	A	L	A	L	A	L	A	L	A	L	A	L
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	1	1	0	1	0	0	0	1	0	0	0	0
13	1	1	0	1	0	1	0	1	0	1	0	0
14	1	2	1	2	1	2	1	2	0	1	0	1
15	1	2	1	1	0	1	0	1	0	1	0	0
16	1	3	1	3	1	2	2	3	1	2	0	1
17	1	2	1	2	0	1	0	2	0	1	0	0
18	2	3	1	2	0	1	2	2	1	1	1	1
19	4	5	3	4	2	3	3	4	2	3	2	2
20	2	4	2	3	1	2	2	3	0	2	0	2
21	2	3	2	3	2	2	0	2	0	2	0	1
Total	16	26	12	22	7	15	10	21	4	14	3	8

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 8: Distribution of *Episyrphus balteatus* recorded in Cabbage and Kale in Budgam district during Spring- Summer 2021

Standard week	Population distribution											
	Cabbage						Kale					
	Chadoora		Narkara		Proper Budgam		Chadoora		Narkara		Proper Budgam	
	A	L	A	L	A	L	A	L	A	L	A	L
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	0	0	0	0	0	0	0
13	0	1	0	1	0	0	0	1	0	0	0	0
14	1	2	1	2	0	1	0	1	0	1	0	0
15	1	1	0	1	0	0	0	1	0	0	0	0
16	2	3	2	2	2	2	1	2	0	1	1	1
17	1	2	0	1	0	0	0	1	0	0	0	0
18	1	2	0	1	0	1	1	1	1	1	0	0
19	3	4	2	3	2	3	3	3	2	2	2	2
20	2	3	2	2	2	2	0	2	0	2	1	0
21	2	3	2	2	1	1	0	2	0	1	0	0
Total	13	22	9	15	7	10	5	14	3	8	4	3

A=Mean number of adults caught per sweep.

L=Mean number of larvae collected per 5 plants.

Table 9: Correlation between population density of *Episyrphus balteatus* recorded at the given locations of Srinagar district with weather parameters of mean temperature (T) and mean relative humidity (RH) Cropwise

District	Crop	Location	Stage	Mean T	Mean RH
SRINAGAR	Tomato	Harwan	A	0.953**	0.254
			L	0.943**	0.337
		Shalimar	A	0.934**	0.370
			L	0.931**	0.284
		Batpora	A	0.862**	0.193
			L	0.921**	0.327
	Brinjal	Harwan	A	0.893**	0.287
			L	0.921**	0.327
		Shalimar	A	0.878**	0.412
			L	0.905**	0.317
		Batpora	A	0.772**	0.329
			L	0.884**	0.451
	Cabbage	Harwan	A	0.832**	0.422
			L	0.953**	0.346
		Shalimar	A	0.848**	0.565*
			L	0.948**	0.314
		Batpora	A	0.688*	0.487
			L	0.902**	0.444
	Kale	Harwan	A	0.728*	0.047
			L	0.934**	0.250
		Shalimar	A	0.578*	0.015
			L	0.913**	0.471
		Batpora	A	0.476	0.220
			L	0.792**	0.331

A=Mean adult population density recorded/sweep.

L=Mean larval population density recorded/per five plants.

**=Significant at 1% level of significance ($p \leq 0.01$).

*=Significant at 5% level of significance ($p \leq 0.05$).

Table 10: Correlation between population density of *Episyrphus balteatus* recorded at the given locations of Budgam district with weather parameters of mean temperature (T) and mean relative humidity (RH) Cropwise

District	Crop	Location	Stage	Mean T	Mean RH
Budgam	Tomato	Chadoora	A	0.963**	0.213
			L	0.939**	0.284
		Narkara	A	0.913**	0.423
			L	0.921**	0.353
		Proper Budgam	A	0.812**	0.455
			L	0.894**	0.310
	Brinjal	Chadoora	A	0.927**	0.210
			L	0.917**	0.246
		Narkara	A	0.867**	0.300
			L	0.882**	0.438
		Proper Budgam	A	0.775**	0.4188
			L	0.885**	0.375
	Cabbage	Chadoora	A	0.887**	0.424
			L	0.948**	0.314
		Narkara	A	0.728*	0.354
			L	0.902**	0.444
		Proper Budgam	A	0.686*	0.288
			L	0.785**	0.250
	Kale	Chadoora	A	0.544*	0.153
			L	0.913**	0.471
		Narkara	A	0.476	0.221
			L	0.792**	0.331
		Proper Budgam	A	0.594*	0.309
			L	0.491	0.210

A=Mean adult population density recorded/sweep.

L=Mean larval population density recorded/per five plants.

**=Significant at 1% level of significance ($p \leq 0.01$).

*=Significant at 5% level of significance ($p \leq 0.05$).

4.2 Prey and temperature dependent functional response of marmalade syrphid fly *Episyrhus balteatus* De Geer on two different aphid species

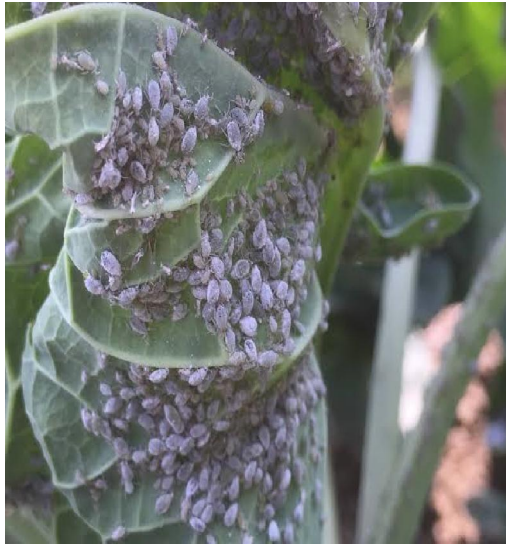
4.2.1 Prey of marmalade syrphid fly *Episyrhus balteatus* De Geer.

The field sampling at the all the six locations of two districts revealed that the larvae of *E. balteatus* were predated upon many aphid species including *Myzus persicae*, *Aphis gossypii* and *Macrosiphum euphorbiae* in Solanaceous crops and *Brevicoryne brassicae*, *Lipaphis pseudobrassicae* and *Brachycaudus helichrysi* in Cruciferous crops as presented in table-11. *Brevicoryne brassicae* Lineaus and *Myzus persicae* Sulzer were the most abundant aphid species found in Cruciferous and solanaceous crops respectively which were found to be important preys of the larvae of *Episyrhus balteatus* in the the respective crops.

4.2.2 Temperature dependent functional response of *Episyrhus balteatus* De Geer on two different aphid species.

4.2.2.1 Prey consumption rates and nature of functional response.

The prey consumption rates and per cent prey consumed by 2nd and 3rd instar larvae of *Episyrhus balteatus* on two aphid species viz. *Brevicoryne brassicae* Lineaus and *Myzus persicae* Sulzer at four different temperatures of 20^oC, 25^oC, 30^oC and 35^oC are presented in Table 12 to 15. A perusal of the data indicates that both the instars of *E. balteatus* consume *B. brassicae* nymphs the most, followed by *M. persicae*. The 2nd instar larvae of *E. balteatus* consumed a maximum of 30.8±0.67 *B. brassicae* nymphs per day followed by 27.3±0.76 nymphs of *Myzus persicae* at 20^oC. The 3rd instar larvae of *E. balteatus* consumed a maximum of 44.4±0.86 *B. brassicae* nymphs per day followed by 40.9±0.81 nymphs of *M. persicae* at 20^oC. The percentage of prey consumed increased from prey density of 2 to 16 for both the instars on both the aphids; however, it declined thereafter. The similar trend was followed by both the larval instars at 25^oC, 30^oC and 35^oC. As far as the two larval instars are concerned the 3rd instar showed the highest consumption of both the aphid species at all the temperatures



(a)



(b)



(c)



(d)

Plate 5: Prey of marmalade syrphid fly recorded in the crops under study: (a) *Brevicorne brassicae* on cabbage (b) *Myzus persicae* on tomato (c) *Macrosiphum euphorbiae* on tomato and (d), *Lipaphis pseudobrassicae* on kale

as compared to 2nd instar larvae. As far as the effect of temperature on prey consumption is concerned the highest prey consumption by both the instars on both the aphid species was observed at 30⁰C followed by 25⁰C and the least consumption of both the prey species was observed at 35⁰C followed by 20⁰C (Figure 1 and 2; Table 12-15).

Percentage of prey consumed by both the predatory stages decreased as the offered prey density increased. The percentage of prey consumed by each predatory stage of the predator on both the prey species used at all the four temperatures, 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 both the predatory stages of the predator on both the prey species used at all the four temperatures. 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 both the larval instars on both prey species at all the four temperatures (Table 16 to 23).

4.2.3 Parameters of functional response

The handling time (*Th*) 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 both the larval instars of *Episyrphus balteatus* on both the prey species namely, *Brevicoryne brassicae* Lineaus and *Myzus persicae* Sulzer, the data on predation rates was fitted to the random predator equation to estimate the handling time (*Th*) and attack rate (*a*). The estimates are presented in Table 24 to 25.

The maximum handling time was noted for 2nd larvae of *E. balteatus* when *M. persicae* was used as prey (0.673 ± 0.027) at 35⁰C followed by 2nd instar larvae on *M. persicae* (0.667 ± 0.024) at 20⁰C and 2nd instar larvae on *B. brassicae* (0.664 ± 0.023) at 35⁰C respectively (Table 24-25). The lowest handling time was

noted for 3rd instar larvae of *E. balteatus* when *B. brassicae* was used as prey (0.394± 0.01) at 30^oC followed by 3rd instar larvae on *B. brassicae* (0.401± 0.010) at 25^oC and 3rd instar larvae on *M. persicae* (0.405± 0.021) at 30^oC respectively (Table 24-25). The highest attack rate was noted for 3rd instar larvae (0.232 ± 0.017) when *B. brassicae* was used as prey at 30^oC followed by 3rd instar larvae again when *B. brassicae* was used as prey (0.221 ± 0.015) at 25^oC (Table 24).

With *B. brassicae* as prey, the minimum handling time was noted for 3rd instar larvae (0.394± 0.01) at 30^oC followed by 3rd instar larvae (0.401± 0.010) at 25^oC (Table 23). The maximum attack rate was noted for 3rd instar larvae (0.232 ± 0.017) at 30^oC followed by 3rd instar larvae (0.221 ± 0.015) at 25^oC (Table 24). Same trend was noted for both handling time and attack rate when *M. persicae* was used as prey for evaluating the functional response of 2nd and 3rd instar larvae of *E. balteatus* (Table 24). Among the two prey species, minimum handling time was exhibited by 3rd instar larvae on *B. brassicae* (0.394± 0.01) at 30^oC and maximum attack rate was also exhibited by 3rd instar larvae against *B. brassicae* (0.232 ± 0.017) at 30^oC.

As far as the effect of temperature on functional response is concerned, the temperature of 30^oC was found to be the most ideal temperature for both the larval instars among all the four temperatures employed as the lowest handling (0.394±0.010) time as well as the highest search rate (0.232±0.017) were reported at this temperature on both the prey species. The search rate (*a*) recorded was found to be increasing with increase in temperature and reached the peak value at 30^oC. The handling time was found to be decreasing with increase in temperature and reached its lowest value at 30^oC for both the instars and on both the prey species (Table 24 & 25).

Table 11: Prey of marmalade syrphid fly *Episyrphus balteatus* De Geer recorded in the concerned crops

Crop	Prey
Tomato	<ul style="list-style-type: none"> • <i>Myzus persicae</i> Sulzer. • <i>Aphis gossypii</i> Glover. • <i>Macrosiphum euphorbiae</i> Thomas.
Brinjal	<ul style="list-style-type: none"> • <i>Myzus persicae</i> Sulzer. • <i>Aphis gossypii</i> Glover. • <i>Macrosiphum euphorbiae</i> Thomas.
Cabbage	<ul style="list-style-type: none"> • <i>Brevicoryne brassicae</i> Linnaeus. • <i>Brachycaudus helichrysi</i> Kaltenbach.
Kale	<ul style="list-style-type: none"> • <i>Brevicoryne brassicae</i> Linnaeus. • <i>Brachycaudus helichrysi</i> Kaltenbach. • <i>Lipaphis pseudobrassicae</i> Davis.

Table 12: Predation rates (Mean \pm S.E.) and percent prey consumption for 2nd and 3rd instar larvae of *Episyrphus balteatus* on two prey species at 20^o C

Stage	Prey density offered (N ₀)	Replications	Prey species			
			<i>Brevicoryne brassicae</i>		<i>Myzus persicae</i>	
			Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed
2 nd instar	2	10	1.2 \pm 0.21	60.00	1.1 \pm 0.21	55.00
	4	10	2.8 \pm 0.18	70.00	2.5 \pm 0.21	62.5
	8	10	6.1 \pm 0.37	76.25	5.6 \pm 0.31	70.00
	16	10	12.8 \pm 0.41	80.00	12.1 \pm 0.37	75.62
	32	10	25.4 \pm 0.65	79.37	24.1 \pm 0.52	75.31
	64	10	28.5 \pm 0.70	44.53	27.0 \pm 0.71	42.18
	128	10	30.6 \pm 0.98	23.90	29.6 \pm 0.89	23.12
	256	10	30.8 \pm 0.67	12.03	27.3 \pm 0.76	11.60
3 rd instar	2	10	1.4 \pm 0.16	70.00	1.4 \pm 0.16	70.00
	4	10	3.2 \pm 0.25	80.00	3.1 \pm 0.28	77.50
	8	10	6.9 \pm 0.31	86.25	6.7 \pm 0.31	83.75
	16	10	14.4 \pm 0.45	90.00	13.9 \pm 0.53	86.87
	32	10	28.5 \pm 0.48	89.06	27.7 \pm 0.37	86.56
	64	10	42.1 \pm 1.00	65.78	40.9 \pm 0.78	63.90
	128	10	44.2 \pm 1.69	34.53	42.8 \pm 1.45	33.43
	256	10	44.4 \pm 0.86	17.34	40.9 \pm 0.81	16.75

Table 13: Predation rates (Mean ± S.E.) and percent prey consumption for 2nd and 3rd instar larvae of *Episyrphus balteatus* on two prey species at 25^oC

Stage	Prey density offered (N ₀)	Replications	Prey species			
			<i>Brevicoryne brassicae</i>		<i>Myzus persicae</i>	
			Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed
2 nd instar	2	10	1.5±0.15	75.00	1.3±0.17	65.00
	4	10	3.2±0.17	80.00	2.7±0.25	67.50
	8	10	6.7±0.30	83.75	6.0±0.31	75.00
	16	10	13.9±0.26	86.87	12.7±0.53	79.37
	32	10	27.0±0.48	84.37	25.5±0.38	79.68
	64	10	34.9±1.03	54.53	30.2±0.95	47.18
	128	10	38.9±0.93	30.39	32.1±0.71	25.07
	256	10	39.1±1.03	15.27	32.2±0.58	12.57
3 rd instar	2	10	1.9±0.10	95.00	1.6±0.16	95.00
	4	10	3.7±0.15	92.50	3.4±0.22	85.00
	8	10	7.5±0.17	93.75	7.1±0.31	88.75
	16	10	15.6±0.22	97.50	14.9±0.31	93.12
	32	10	31.00±0.42	96.87	29.1±0.38	90.93
	64	10	48.2±0.77	75.31	42.8±0.47	66.87
	128	10	52.3±0.79	40.85	44.7±0.54	34.92
	256	10	52.4±0.79	20.46	44.8±0.74	17.50

Table 14: Predation rates (Mean ± S.E.) and percent prey consumption for 2nd and 3rd instar larvae of *Episyrphus balteatus* on two prey species at 30^oC

Stage	Prey density offered (N ₀)	Replications	Prey species			
			<i>Brevicoryne brassicae</i>		<i>Myzus persicae</i>	
			Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed
2 nd instar	2	10	1.6±0.15	80.00	1.4±0.16	70.00
	4	10	3.4±0.15	85.00	3.0±0.17	75.00
	8	10	6.9±0.17	86.25	6.3±0.20	78.75
	16	10	14.1±0.25	88.12	13.3±0.30	83.12
	32	10	28.1±0.36	87.81	25.5±0.31	79.68
	64	10	36.9±1.52	57.65	34.3±1.49	53.59
	128	10	39.5±0.64	30.85	35.4±0.72	27.65
	256	10	39.6±0.91	15.46	35.5±0.70	13.86
3 rd instar	2	10	1.9±0.10	95.00	1.8±0.13	90.00
	4	10	3.8±0.13	95.00	3.6±0.16	90.00
	8	10	7.7±0.15	96.25	7.5±0.17	93.75
	16	10	15.6±0.22	97.50	15.3±0.21	95.62
	32	10	30.8±0.42	96.25	29.8±0.49	93.12
	64	10	49.2±0.99	76.87	47.6±0.82	73.90
	128	10	53.5±1.09	41.79	50.6±0.67	39.53
	256	10	53.7±1.10	20.97	50.8±0.71	19.84

Table 15: Predation rates (Mean \pm S.E.) and percent prey consumption for 2nd and 3rd instar larvae of *Episyrphus balteatus* on two prey species at 35^oC

Stage	Prey density offered (N ₀)	Replications	Prey species			
			<i>Brevicoryne brassicae</i>		<i>Myzus persicae</i>	
			Prey consumed (N)	% Prey consumed	Prey consumed (N)	% Prey consumed
2 nd instar	2	10	1.0 \pm 0.23	50.00	0.7 \pm 0.18	35.00
	4	10	2.5 \pm 0.29	62.50	2.0 \pm 0.22	50.00
	8	10	5.9 \pm 0.37	73.75	3.8 \pm 0.21	47.50
	16	10	12.5 \pm 0.50	78.12	11.2 \pm 0.31	70.00
	32	10	24.8 \pm 0.55	77.50	22.1 \pm 0.42	69.06
	64	10	27.2 \pm 0.97	42.50	25.8 \pm 0.75	40.31
	128	10	29.8 \pm 0.95	23.28	28.0 \pm 0.52	21.87
	256	10	29.9 \pm 0.80	11.67	26.4 \pm 0.52	10.97
3 rd instar	2	10	1.2 \pm 0.10	60.00	1.1 \pm 0.13	55.00
	4	10	2.9 \pm 0.11	72.50	2.7 \pm 0.14	67.50
	8	10	6.6 \pm 0.13	82.50	5.4 \pm 0.15	67.50
	16	10	13.9 \pm 0.20	86.87	13.00 \pm 0.19	81.25
	32	10	27.5 \pm 0.40	85.93	26.4 \pm 0.47	82.50
	64	10	39.7 \pm 0.95	62.03	37.7 \pm 0.80	58.90
	128	10	42.1 \pm 1.07	32.89	39.6 \pm 0.65	30.93
	256	10	42.4 \pm 1.08	16.56	38.9 \pm 0.70	15.54

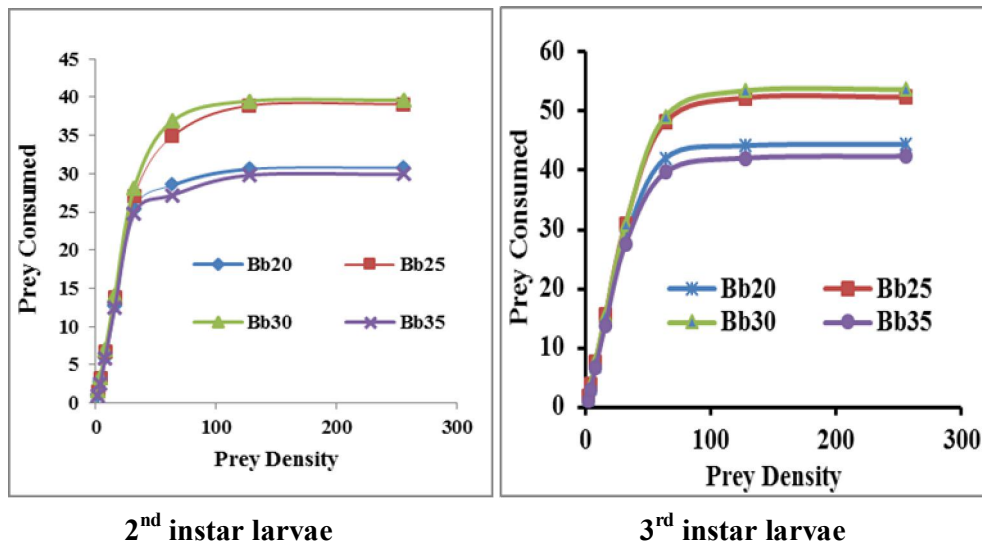


Figure 1: Prey consumption versus prey density offered to 2nd and 3rd instar larvae of *E. balteatus* predating on *Brevicoryne brassicae* at four different temperatures of 20, 25, 30 and 35°C. (Bb=*Brevicoryne brassicae*)

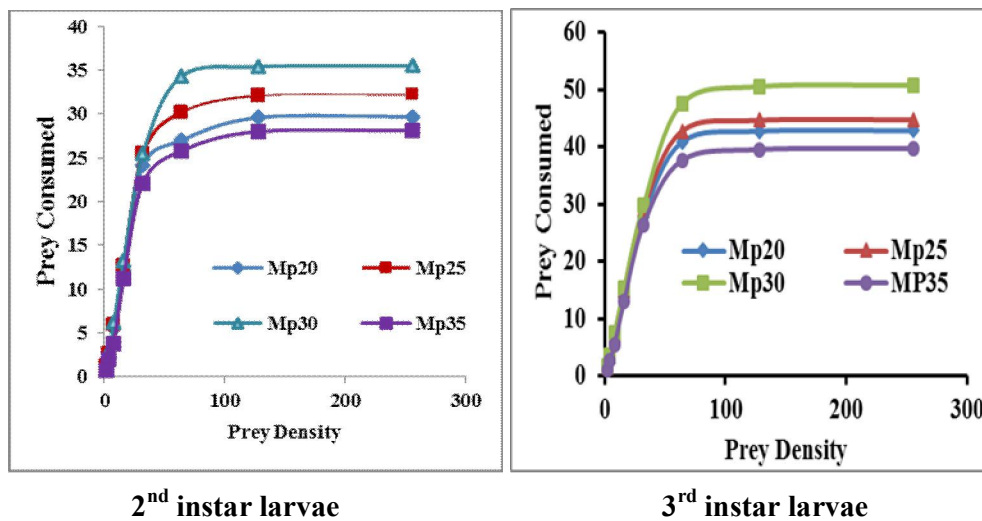


Figure 2: Prey consumption versus prey density offered to 2nd and 3rd instar larvae of *E. balteatus* predating on *Myzus persicae* at four different temperatures of 20, 25, 30 and 35°C. (Mp=*Myzus persicae*).

Table 16: Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 20°C

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	1.786**	0.193	9.257	< 0.01
	Linear	-0.03436**	0.007158	-4.801	<0.01
	Quadratic	0.00009714	0.00006785	1.432	>0.05
	Cubic	-0.0000008003	0.0000001682	-0.476	>0.05
3 rd instar	Intercept	2.291**	0.2344	9.776	< 0.01
	Linear	-0.02169*	0.008287	-2.617	<0.05
	Quadratic	-0.00004682	0.00007628	-0.614	>0.05
	Cubic	0.0000002842	0.0000001861	1.528	>0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 17: Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 25^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	2.355**	0.2236	10.532	< 0.01
	Linear	-0.04042**	0.007925	-5.1	< 0.01
	Quadratic	0.0001448*	0.00007318	1.979	<0.05
	Cubic	-0.0000001914	0.000000179	-1.069	>0.05
3 rd instar	Intercept	4.295**	0.4211	10.200	< 0.01
	Linear	-0.06278**	0.01323	-4.746	< 0.01
	Quadratic	0.0002515*	0.0001137	2.212	<0.05
	Cubic	-0.0000003612	0.0000002678	-1.349	>0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 18: Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 30^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	2.653**	0.2436	10.889	< 0.01
	Linear	-0.04378**	0.008446	-5.183	< 0.01
	Quadratic	0.000155*	0.00007708	2.011	<0.05
	Cubic	-0.0000001969	0.0000001875	-1.05	>0.05
3 rd instar	Intercept	4.551**	0.4548	10.005	< 0.01
	Linear	-0.06808**	0.01413	-4.819	< 0.01
	Quadratic	0.0002908*	0.0001205	2.413	<0.05
	Cubic	-0.0000004476	0.0000002828	-1.583	>0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 19: Maximum likelihood estimates from logistic regression analysis of the proportion of *Brevicoryne brassicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 35^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	1.539**	0.1837	8.38	< 0.01
	Linear	-0.02953**	0.006927	-4.263	<0.01
	Quadratic	0.00006259	0.00006622	0.945	>0.05
	Cubic	-0.00000006053	0.0000001649	-0.037	>0.05
3 rd instar	Intercept	1.859**	0.2083	8.38	< 0.01
	Linear	-0.01489*	0.007586	-1.963	<0.05
	Quadratic	-0.00008879	0.00007093	-1.252	>0.05
	Cubic	0.000000367*	0.0000001744	2.105	<0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 20: Maximum likelihood estimates from logistic regression analysis of the proportion of *Myzus persicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 20^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	1.394**	0.1789	7.79	<0.01
	Linear	-0.02657**	0.006807	-3.903	<0.01
	Quadratic	0.0000428	0.00006535	0.655	>0.05
	Cubic	0.00000003427	0.000000163	0.21	>0.05
3 rd instar	Intercept	2.009**	0.2169	9.264	<0.01
	Linear	-0.01702*	0.007818	-2.177	<0.05
	Quadratic	-0.00007669	0.00007271	-1.055	>0.05
	Cubic	0.000000344	0.0000001782	1.930	>0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 21: Maximum likelihood estimates from logistic regression analysis of the proportion of *Myzus persicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 25^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	1.673**	0.1902	8.795	<0.01
	Linear	-0.02815**	0.007076	-3.979	<0.01
	Quadratic	0.00004376	0.00006714	0.652	>0.05
	Cubic	0.000000435	0.0000001665	0.261	>0.05
3 rd instar	Intercept	2.828**	0.2689	10.518	<0.01
	Linear	-0.0353**	0.009172	-3.849	<0.01
	Quadratic	0.00005759	0.00008283	0.695	>0.05
	Cubic	0.00000005275	0.0000002002	0.263	>0.05

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 22: Maximum likelihood estimates from logistic regression analysis of the proportion of *Myzus persicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 30^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	1.823**	0.199	9.159	<0.01
	Linear	-0.02612**	0.007296	-3.579	<0.01
	Quadratic	0.00001968	0.00006864	0.287	>0.05
	Cubic	0.0000001042	0.0000001695	0.615	>0.05
3 rd instar	Intercept	3.421**	0.3304	10.352	<0.01
	Linear	-0.04103**	0.01087	-3.774	<0.01
	Quadratic	0.00008392	0.00009604	0.874	>0.05
	Cubic	0.00000001113	0.0000002295	0.048	>0.05

**=Significant at 1% level of significance.
 *=Significant at 5% level of significance.

Table 23: Maximum likelihood estimates from logistic regression analysis of the proportion of *Myzus persicae* eaten by 2nd and 3rd instar larvae of *Episyrphus balteatus* against initial number of aphids offered at 35^oC

Growth stage	Parameters	Estimates	S.E.	T- value	Pr (T)
2 nd instar	Intercept	0.5932**	0.1616	3.671	<0.01
	Linear	-0.005546	0.006371	-0.87	>0.05
	Quadratic	-0.0001268*	0.00006227	-2.036	<0.05
	Cubic	0.0000004198*	0.0000001566	2.68	<0.05
3 rd instar	Intercept	1.245**	0.1826	6.819	<0.01
	Linear	-0.001299	0.006916	-0.188	>0.05
	Quadratic	-0.0001929*	0.00006593	-2.925	<0.05
	Cubic	0.0000005982**	0.0000001636	3.658	<0.01

**=Significant at 1% level of significance.

*=Significant at 5% level of significance.

Table 24: Estimates of attack rate (a) and handling time (T_h) for 2nd and 3rd instar larvae of *Episyrphus balteatus* preying upon *Brevicoryne brassicae* for random predator equation at 20^oC, 25^oC, 30^oC & 35^oC

Temperature	Growth stage	Parameters*	Estimates	S.E.	T-value	Pr (T)
20 ^o C	2 nd instar	a	0.097176**	0.006619	14.682	< 0.01
		T_h	0.650392**	0.022483	28.928	< 0.01
	3 rd instar	a	0.1335417**	0.0080886	16.510	< 0.01
		T_h	0.4478374**	0.0131018	34.181	< 0.01
25 ^o C	2 nd instar	a	0.119678**	0.0078	15.367	< 0.01
		T_h	0.524675**	0.0166	31.661	< 0.01
	3 rd instar	a	0.221169**	0.015486	14.282	< 0.01
		T_h	0.400930**	0.010161	39.457	< 0.01
30 ^o C	2 nd instar	a	0.135841**	0.008867	15.319	< 0.01
		T_h	0.516124**	0.015559	33.173	< 0.01
	3 rd instar	a	0.2320298**	0.0166429	13.942	< 0.01
		T_h	0.3944746**	0.0099519	39.638	< 0.01
35 ^o C	2 nd instar	a	0.087556**	0.005978	14.648	< 0.01
		T_h	0.664205**	0.023772	27.941	< 0.01
	3 rd instar	a	0.1138313 **	0.0068252	16.678	< 0.01
		T_h	0.4638307 **	0.0143513	32.320	< 0.01

* a in hours⁻¹ and T_h in hours.

**=Significant at 1% level of significance.

Table 25: Estimates of attack rate (a) and handling time (T_h) for 2nd and 3rd instar larvae of *Episyrphus balteatus* preying upon *Myzus persicae* for random predator equation at 20^oC, 25^oC, 30^oC & 35^oC

Temperature	Growth stage	Parameters*	Estimates	S.E.	T-value	Pr (T)
20 ^o C	2 nd instar	a	0.082478**	0.005666	14.556	< 0.01
		T_h	0.667375**	0.024492	27.249	< 0.01
	3 rd instar	a	0.1211467**	0.0072903	16.617	< 0.01
		T_h	0.4591880**	0.0139289	32.967	< 0.01
25 ^o C	2 nd instar	a	0.095361**	0.006341	15.038	< 0.01
		T_h	0.615729**	0.021211	29.029	< 0.01
	3 rd instar	a	0.1546824**	0.0097608	15.847	< 0.01
		T_h	0.4515601**	0.0127177	35.507	< 0.01
30 ^o C	2 nd instar	a	0.104929**	0.006796	15.44	< 0.01
		T_h	0.559026**	0.018484	30.244	< 0.01
	3 rd instar	a	0.186374**	0.012049	15.467	< 0.01
		T_h	0.405180**	0.010732	37.755	< 0.01
35 ^o C	2 nd instar	a	0.059925**	0.004109	14.584	< 0.01
		T_h	0.672684**	0.027478	24.481	< 0.01
	3 rd instar	a	0.092172**	0.005456	16.894	< 0.01
		T_h	0.478911**	0.015914	30.093	< 0.01

* a in hours⁻¹ and T_h in hours.

**=Significant at 1% level of significance.

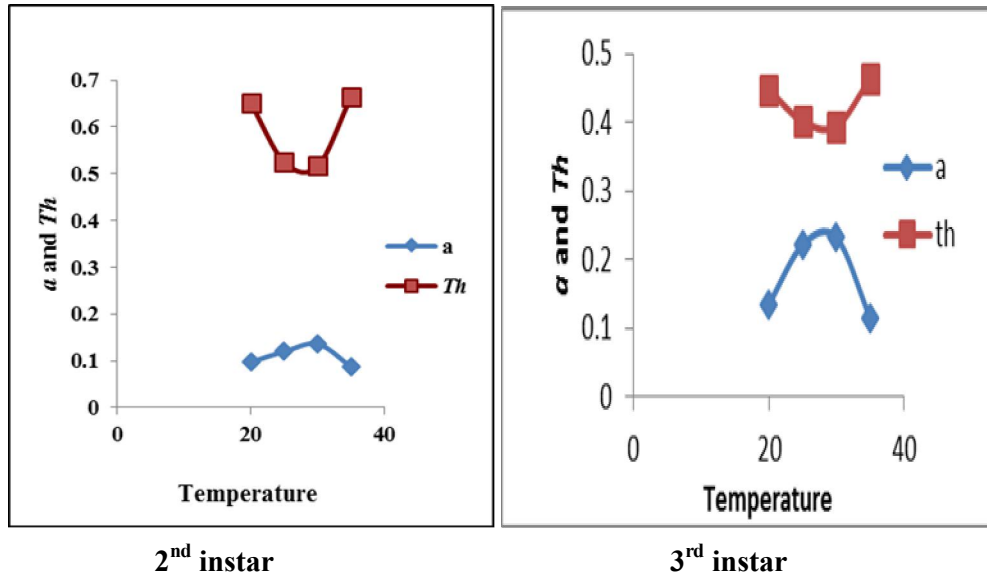


Figure 3: Attack rate (*a*) and Handling time (*Th*) versus temperature given to 2nd and 3rd instar larvae of *Episyrphus balteatus* preying upon *Brevicoryne brassicae* under laboratory conditions.

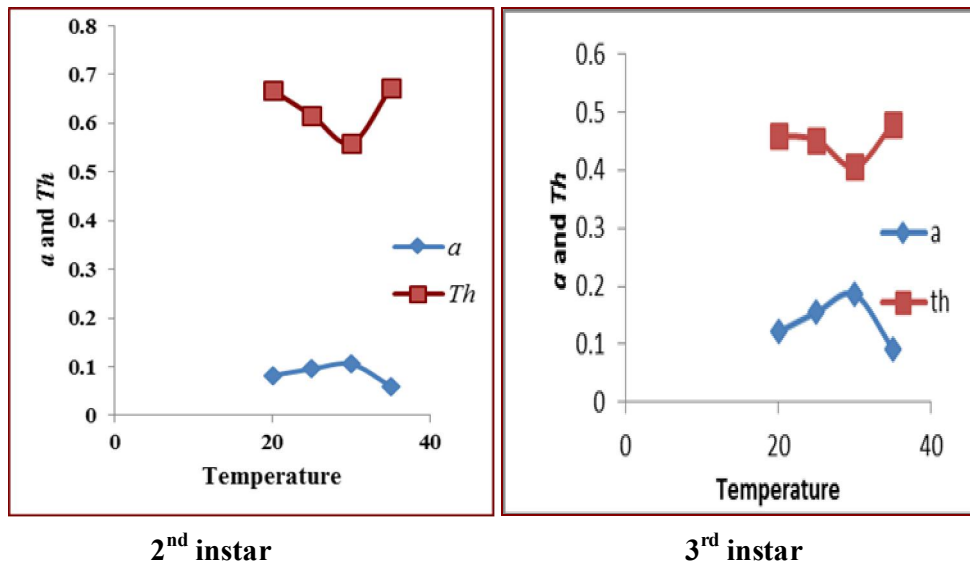


Figure-4: Attack rate (*a*) and Handling time (*Th*) versus temperature given to 2nd and 3rd instar larvae of *Episyrphus balteatus* preying upon *Myzus persicae* under laboratory conditions

Chapter 5

DISCUSSION

5.1 Population density of *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir during 2021

The sampling on predaceous *Episyrphus balteatus* in four vegetable crops i.e. tomato and brinjal from Solanaceae family and cabbage and kale from Cruciferae family at six different locations of Kashmir valley i.e. three in Srinagar district and three in Budgam district revealed that the population density of both the adults and larvae of *E. balteatus* was low in all the crops initially at the beginning of cropping season i.e. 23rd standard week of observation in case of tomato and brinjal (second week of June) and 9th standard week of observation in case of cabbage and kale (first week of March) which increased gradually due to increase in mean temperature and attained peak in the 29th standard week of observation observation in case of tomato and brinjal (fourth week of July) and 19th standard week of observation in case of cabbage and kale (2nd week of May) respectively. There-after it started decreasing again till the end of growing season due to decreasing food reserves. These findings are in close conformity with the results of Jennifer and Gilbert (1989) who observed that syrphid flies are less abundant in harsh months due to unfavourable weather conditions and Srinivasu and Gayatri (2005) who observed that the depleting food reserves/ prey population results in the depletion of their natural enemies respectively. The results differs to some extent from that of Ramzan *et al.* (2010) who reported that the highest population of syrphid flies was observed in the 2nd week of September, It may be due to the micro-climatic difference of the regions.

The highest population density of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district in all the four crops followed by Chadoora area of Budgam. This may be due to the less usage of pesticides by the farmers, rich micro-flora and higher altitude of the area. These findings are in

close conformity with the results of Khan and Riyaz (2013-14) who observed that the highest species diversity of aphidophagous syrphid flies in fruit orchards of Kashmir valley was reported in fruit orchards of Harwan area of Srinagar. The lowest population density of both the adults and larvae of *E. balteatus* was recorded at proper Budgam. This may be due to the excessive usage of pesticides by the farmers of the respective area, less microflora and vegetation. Population density of both the adults and larvae was recorded more in Solanaceous crops of tomato and brinjal as compared to the Cruciferous crops of cabbage and kale. This, may be due to the fact that Solanaceous crops are grown in summer when the abiotic factors (temperature and relative humidity) are quite favourable for the growth and development of the predators. These findings are in close conformity with the results of Farooq (2008) who observed that syrphid flies were more abundant during the spring and summer months and less abundant during winter months.

Correlation studies on population density of both adult and larvae with weather parameters of mean temperature and mean relative humidity revealed that there was a significant positive correlation between the mean temperature and the adult and larval population density of *E. balteatus*. In addition, there was a positive, but non-significant correlation between the mean relative humidity and the adult and larval population density of *E. balteatus*. These results are in synchrony with the findings of Ramzan *et al.* (2018) who reported that there was a significant positive correlation between the temperature and population of syrphid flies and a positive but insignificant correlation between the relative humidity and population of syrphid flies. Devi *et al.* (2012) found out that the temperature shows significant positive correlation with both adult and larval population of *E. balteatus* where as relative humidity shows negative correlation with both adult and larval population of *E. balteatus* which is in partial agreement with this study. The probable reason for the partial deviation in results may be the difference in climate in the two regions.

5.2 Population distribution of *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir during 2021

Distribution of *Episyrphus balteatus* in Vegetable ecosystem of Kashmir revealed that population of adult and larvae of *E. balteatus* was recorded from the first week of observation which increased gradually and attained peak in the fourth week of July in case of tomato and brinjal and 2nd week of May in case of cabbage and kale. This may be due the reason of the availability of enough prey for the larval instars and enough nectar and pollen availability to the adults due to flowering of the concerned crops at this time. These results are in synchrony with the findings of Xuenqing *et al.* (2021) who reported the increase in the population of beneficial predators at the time of flowering. The highest weekly distribution of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district in all the four crops followed by Chadoora area of Budgam. These results are in synchrony with the findings of Khan and Riyaz (2013-14) who observed that the highest species distribution of aphidophagous syrphid flies in fruit orchards of Kashmir valley was reported in Harwan area of Srinagar. This may be due to the less usage of pesticides by the farmers, rich micro-flora and higher altitude of the area. Population distribution of both the adults and larvae was recorded more in Solanaceous crops of tomato and brinjal as compared to the Cruciferous crops of cabbage and kale. This, may be due to the fact that Solanaceous crops are grown in summer when the abiotic factors (temperature and relative humidity) are quite favourable for the growth and development of the predators. These findings are in close conformity with the results of Farooq (2008) who observed that syrphid flies were more abundant during the spring and summer months and less abundant during winter months.

5.3 Prey of *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir

A perusal of the data on prey species revealed that the larvae of *Episyrphus balteatus* were predating on many aphid species. *Brevicoryne brassicae* and

Myzus persicae were the most abundant aphid species found in Cruciferous and solanaceous crops respectively, which were found to be potential preys of the larvae of *E. balteatus* in the the respective crops. These results are in synchrony with the findings of Farooq (2008) who reported larvae of *E. balteatus* preying upon *B. brassicae*; Jalilian *et al.* (2011) who reported larvae of *E. balteatus* preying upon *M. persicae* and Khan (2017) who reported larvae of *E. balteatus* preying upon *B. brassicae*.

5.4 Functional response of 2nd and 3rd instar larvae of *Episyrphus balteatus* to two aphid species

5.4.1 Prey consumption rates and nature of functional response

A perusal of the data on prey consumption rates of 2nd and 3rd instar larvae of *Episyrphus balteatus* indicated that the 3rd instar larvae of *Episyrphus balteatus* consumed highest number of aphids, irrespective of the prey species. The observation that 3rd instar larvae consumed greatest proportion of prey over 24 hours, at all the temperatures, is consistent with the observations of many other workers like those of Jalilian *et al.* (2011) for *E. balteatus* preying upon *Myzus persicae*; Khan (2017) for *E. balteatus* preying upon *Brevicoryne brassicae*; Khan (2015) for *E. balteatus* preying upon *Aphis pomi*, Faheem *et al.* (2019) for *E. balteatus* preying upon *Schizaphis graminum* and Baskaran *et al.* (2009) for *E. balteatus* preying upon *Aphis gossypii*. Beddington *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 four temperatures given to *E. balteatus* in the study the highest prey consumption by both the instars was recorded at 30^oC followed by 25^oC. These results are in synchrony with the findings of Bui *et al.* (2010) who recorded the highest prey consumption by larval instars of *E. balteatus* at 30^oC.

Among the two prey species used it was observed that both the instars of *E. balteatus* consume *B. brassicae* nymphs the most, followed by *M. persicae*. Predator consumption rates on different prey species might vary for a variety of reasons, including prey mobility (Dixon, 2000), prey suitability (Shah and Khan 2014), predator and prey size (Putra and Yasuda, 2006; Short and Bergh, 2004), experimental conditions (Farhadi *et al.*, 2010), geographical variation (Dobzhansky, 1933), nutritional status (Thompson, 1999), suitability of the prey for the growth and reproduction of the predator (Shah and Khan, 2014) and effect of host plant (Sobhani *et al.*, 2013) etc.

The current study revealed the estimates of maximum number of aphids attacked per day as 39.6 for 2nd instar larvae and 53.7 for 3rd instar larvae of *E. balteatus* when *B. brassicae* was used as prey at a temperature of 30°C. The results are consistent with those of Khan (2017) who reported the maximum prey consumption by 2nd and 3rd instar larvae of *E. balteatus* as 38.5 and 52.8 respectively when *B. brassicae* was used as prey. Jalilan *et al.* (2015) reported the maximum prey consumption per day by 2nd and 3rd instar larvae of *E. balteatus* as 36.82 and 64.33 respectively when *A. pomi* was used as prey, which is in partial agreement with this study. The deviation shown by 3rd instar larva may be due to different prey species used and different environmental conditions. Makhmoor and Verma (1987), also reported the maximum consumption by 2nd and 3rd instar larvae of *E. balteatus* as 35 and 53 aphids, per day respectively. Similarly, when *M. persicae* was used as prey the maximum number of aphids attacked per day for 2nd and 3rd instar larvae of *E. balteatus* was 35.5 and 50.8, respectively. The results are consistent with those of Jalilan *et al.* (2011) who reported the maximum prey consumption by 2nd and 3rd instar larvae of *E. balteatus* as 34.2 and 51.5, respectively when *M. persicae* was used as prey. Roy and Basu (1977) reported maximum prey consumption by 2nd and 3rd instar larvae of *E. balteatus* as 30.3 and 49, respectively when *M. persicae* was used as prey.

Polynomial logistic regression findings and the trend-line analysis of the percent prey consumption suggested a type II functional response. 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 inferences (Pervez and Omkar, 2005). In order to address these concerns, a higher number of replications for the lowest two offered prey densities in the first instance and subsequent curve-fitting using polynomial logistic regression were applied.

5.4.2 Parameters of functional response.

The coefficient of attack rate (a) and handling time (Th) were the parameters used to find out the magnitude of the functional responses exhibited by the 2nd and 3rd instar larvae of *E. balteatus* on the two prey species, namely *B. Brassicae* and *M. persicae*. Their values differed for both the instars for the two prey species tested and the different temperatures used. The parameter values for the two larval instars followed the similar trend. It indicates that various stages of a predator have different abilities to respond to increasing prey densities, so do the various stages for a particular prey species and towards various prey species. These results are in conformation with those of Khan (2017) who investigated the functional responses of four syrphid predators associated with *B. Brassicae* and Hopper *et al.* (2011) who studied the growth, development and consumption by four syrphid species associated with the lettuce aphid, *Nasonovia ribisnigri*, in California. 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 do not differ as much as those of the handling time. This observation is consistent with that of Athhan (2010) and Pervez and Omkar (2005). The handling time indicates the time required for catching, killing, subduing, and digesting the prey, making it

an excellent indicator of a predator's consumption rate and effectiveness. (Veervel and Baskaran, 1997). The lowest handling times were regularly noted for 3rd instar larvae at all the temperatures. Among the two prey species, lowest handling time was exhibited by the 3rd instar larvae on *B. brassicae* (0.394 h) at 30^oC. Clearly, *E. balteatus* larvae are better predators at devouring *B. Brassicae* nymphs.

The practical implication of these studies is that the 3rd instar larvae 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 (3rd instars). Such releases would facilitate rapid killing of prey immediately after release.

According to laboratory tests, among the two predatory stages the 3rd instar is a better bioagent, and among the studied prey species, predators may react to patches of *B. brassicae* the best. However, the prey consumption rates are relatively lower, and the unpredictable field conditions could drastically alter the predators' functional response (Farhadi *et al.*, 2010). The effectiveness of the predator in controlling the prey population is also greatly influenced by other factors, including intrinsic growth rates, host patchiness, predation and competition, host features, etc. Consequently, functional response, while a valuable tool, cannot explain success or failure of biocontrol efforts on its own. However, the laboratory findings reveal how these predators will react to rising prey density under simplified experimental conditions. Additional field-based research are required for a comprehensive assessment of their biocontrol capability.

Chapter-6

SUMMARY AND CONCLUSION

The summary and conclusion of the present study “Population dynamics and predatory activities of marmalade Syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir” is presented as under:

The population dynamics of *E. balteatus* was worked out in major vegetable growing belts of Kashmir valley (Budgam and Srinagar) during the cropping season of 2021. Three locations from each district, were selected and sampling of *E. balteatus* was carried out in four vegetable crops (tomato, brinjal, cabbage and kale) at each location. The study revealed that the highest population density of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district in all the four crops followed by Chadoora area of Budgam. Solanaceous crops of tomato and brinjal were found to be supporting more number of adults and larvae as compared to the Cruciferous crops of cabbage and kale. Correlation studies on population density of both adult and larvae with weather parameters of mean temperature and mean relative humidity revealed that there was a significant positive correlation between the mean temperature and the adult and larval population density of *E. balteatus*. In addition, there was a positive, but non-significant correlation between the mean relative humidity and the adult and larval population density of *E. balteatus*.

Studies on functional response of 2nd and 3rd instar larvae of *E. balteatus* on two different prey species *B. brassicae* and *M. persicae* 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 2nd and 3rd instar larvae of *E. balteatus* on two prey species used.

The 3rd instar larvae of *E. balteatus* consumed highest number of aphids, irrespective of the prey species. The current study revealed the estimates of maximum number of aphids attacked per day as 39.6 for 2nd instar larvae and 53.7 for 3rd instar larvae of *E. balteatus* when *B. brassicae* was used as prey at a temperature of 30⁰C.

The coefficient of attack rate (a) and handling time (Th) were the parameters used to find out the magnitude of the functional responses exhibited by the 2nd and 3rd instar larvae of *E. balteatus* on the two prey species, namely *B. Brassicae* and *M. persicae*. Their values differed for both the instars for the two prey species tested and the different temperatures used. The parameter values for the two larval instars followed the similar trend. It suggests that different stages of a predator have varying capacities to react to rising prey populations, much as different stages do for a specific prey species and towards other 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 3rd instar larvae at all the temperatures. Among the two prey species, lowest handling time was exhibited by the 3rd instar larvae on *B. brassicae* (0.394 h) at 30⁰C. Clearly, *E. balteatus* larvae are better predators at devouring *B. Brassicae* nymphs. Among the two predatory stages, according to laboratory research, the 3rd instar is more effective as a bioagent, and among the studied prey species, predators may be more responsive to patches of *B. brassicae*.

CONCLUSION

- The highest population density and distribution of both the adults and larvae of *E. balteatus* was recorded at Harwan area of Srinagar district.
- The population density and distribution of both the adults and larvae of *E. balteatus* is consistently higher in Solanaceous vegetable crops as compared to Cruciferous vegetable crops.
- Both *B. brassicae* and *M. persicae* are essential preys for *E. balteatus*, the former being more suitable.
- Prey species and prey abundance has significant effect on the biological parameters of the aphidophagous syrphid predators.
- The optimum biological performance of the syrphid predators lies in the prey density range of 40-80 nymphs per day per predator.
- Both the predatory stages of the *E. balteatus* exhibit type II functional response to various densities of *B. brassicae* and *M. persicae*.
- The 3rd instar larvae exhibits the maximum predation rates.
- The 3rd instar larvae of *E. balteatus* are best at devouring *B. brassicae* patches.

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner **Dr. Uma Shankar** during Viva-Voce examination held on **04-11-2022** have been incorporated in the manuscript entitled “**Population dynamics and predatory activities of marmalade syrphid fly *Episyrphus balteatus* De Geer in vegetable ecosystem of Kashmir**” submitted by **Mr. Rasikh Ahmad Parray (Regd. No. MSH-2020-296)**.

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