International Journal of Ecotoxicology and Ecobiology
2022; 7(3): 49-59
http://www.sciencepublishinggroup.com/j/ijee
doi: 10.11648/j.ijee.20220703.13
ISSN: 2575-1727 (Print); ISSN: 2575-1735 (Online)

Conservation of Predatory Fauna and Decline of Insect Pests Status in Ecologically Engineered Tomato Ecosystem of Kashmir

Baber Parvaiz, Akhtar Ali Khan*

Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar, India

Email address:
mirbaber31@gmail.com (Baber Parvaiz), akhtaralikhan47@rediffmail.com (Akhtar Ali Khan)
*Corresponding author

To cite this article:
Baber Parvaiz, Akhtar Ali Khan. Conservation of Predatory Fauna and Decline of Insect Pests Status in Ecologically Engineered Tomato Ecosystem of Kashmir. *International Journal of Ecotoxicology and Ecobiology*. Vol. 7, No. 3, 2022, pp. 49-59.
doi: 10.11648/j.ijee.20220703.13

Received: June 30, 2022; **Accepted**: July 15, 2022; **Published**: August 15, 2022

Abstract: Tomato (*Solanum lycopersicum*) is one of the most important culinary vegetables throughout the world. Tomato crop was maintained in Ecologically Engineered field conditions at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India in 2019. Abiotic factors play an important role and was showed a significant positive correlation with temperature, Relative humidity, and a non-significant negative correlation with rainfall. Temperature with Biotic factors plays a significant positive correlation. Agro-ecosystem analysis of biological factors with respect to pests and beneficial insects, to understand the intricate interactions in the ecosystem, revealed that the ecosystem has created favorable conditions for natural enemies. Natural enemies were controlling tomato pests in the absence of external forces like chemical pesticides. Hence mean pest population, *Myzus persicae* (14.20 aphids/plant), and *Helicoverpa armigera* (0.96 larvae/plant) in an ecologically engineered field were significantly reduced from that of the control were 31.74 aphids/plants and 2.69 larvae/plant, respectively. Among predatory natural enemies distribution and relative abundance, the family Syrphidae was maximum followed by order Araneae and total enhancement and conservation of natural enemies population was 3.86/plant as compared to control plot (1.09/plant) was certainly helps in the minimizing the population of *Myzus persicae* and *Helicoverpa armigera* in ecologically engineered field conditions.

Keywords: Insect Pests, Natural Enemies, Ecological Engineering, Tomato Field, Vegetable Ecosystem

1. Introduction

Intricate agricultural arenas support a diverse community of beneficial insects and ecosystem services that in turn support crop productivity [1, 2]. Management of crop pests by their natural enemies is an important ecosystem function that supports crop production and provides agriculture with a valuable, but poorly quantified, ecosystem service [3, 4]. Natural or semi-natural habitats, such as forests, field margins, permanent grasslands, or hedgerows, are key habitats for natural enemies in the agricultural landscape as they provide overwintering sites, asylum from disturbance, and alternative prey [5, 6]. However, an important caveat is that relatively few studies have estimated the impact of natural enemies on the growth, and hence actual clampdown of pest populations along with landscape complexity or rise gradients. In addition to manipulating natural enemy abundance and diversity, landscape structure may also alter natural enemy relations and the stability of pest clampdown [7, 8].

Intercropping is one of the important pest-management alternatives used to control pests. Numerous types of intercropping have been recognized based on the spatial and temporal overlap of plant species, and depend on the associated crop and their evaluation after harvest [9]. One practice that has been explored in a number of cropping systems is the addition of wildflowers to crop borders [10]. Wildflowers provide resources to natural enemies of crop pests including shelter from disturbance and overwintering habitat as well as a source of nectar, pollen, and alternative prey [11, 12]. Wildflowers of borders have been found to increase predator populations in the crop when planted next to tomatoes [13]. However, wildflower plantings are not always fruitful at increasing natural enemy populations [14, 15] due to both local and landscape-level effects [16]. Landscape-level effects include a lack of a source population of natural enemies in the surrounding habitat or that the natural habitat surrounding the crops can be too small and/or too far away for natural enemies to colonize the wildflowers and crop habitats. Local effects include farm management practices that can affect the establishment of natural enemies such as the use of broad-spectrum insecticides [17, 18].

Trap crops are stands of plants that attract further pests and may keep them away from the main crop [19-21]. The use of trap plants in association with crops has been known for centuries to protect crops from insect attack, and this method has been exploited in many traditional farming systems [22, 23]. The use of these plants in cropping systems is based on the fact that insects show a marked preference for certain plant organs, cultivars, species, or phenological stages [24, 25]. Hence, trap plants are more attractive to the pest and easier to find than the host plants. In many instances, a trap crop has been used in a push-pull plan (the so-called stimulodeterrent diversionary (SDD)) which requires the involvement of another component such as semiochemicals [26]. However, trap cropping is not overly developed for aphids because their host selection is often considered a passive method that mainly depends on wind [27, 28]. Potting et al. [29] determined that small insects such as whiteflies, mites, and aphids have limited ability to detect their hosts. They suggested that trap crops act as a barrier when they are taller than the main crop and planted in the borders. Companion Plants (CP) altering host plant selection such as searching behavior and the selection of dynamic resources for insects such as aphids can be divided into three steps: habitat location, host location, and host acceptance [30]. During these three steps, positive and negative external stimuli interact also with the internal factors of the insect, allowing for the acceptance or rejection of the Host Plant [31].

Using companion plant in intercropping with target crops is a promising substitute method to chemicals to improve aphid management [32]. We showed that many companion planting schemes have been designed to reduce the aphid population, and several mechanisms have been considered [33]. However, the high quality of adapted CP remains an issue and their effectiveness might not be guaranteed in all cases [34, 35]. Indeed, many factors that affect the success of an intercropping system design need to be considered. For instance, intercropping CP may take several forms, and its efficiency may depend on the arrangement, the density, and the distance between CP and HP [36]. Similarly, the timing of the most effective phenological stage of CP with respect to the aphid infestation period and the aphid life cycle must to be taken into account [37]. A CP also should not offer a home for other pests per se [38, 39], and a CP needs to be in the most suitable phenological stage to provide shelter and food resources, especially for early natural enemies such as hoverflies [40].

In this study, we hypothesized that (1) natural enemy abundance will be conserved and greater in tomato crop plantings with buckwheat three rows grown as a cover crop for pollen, nectars and shelter of natural enemies; after that one row of marigold grown as a trap crop for tomato fruit borer for egg-laying and avoid damage of main tomato crop plots; after each plots of tomato crops one row of maize crop grown as barrier crop for aphids and flying insect such as tomato fruit borer for egg-laying and avoid damage of main tomato crop and one row of cowpea grown as trap crop opposite direction of maize for aphid and tomato fruit borer for egg-laying and avoid damage of main tomato crop which will be (2) decline the status of two major insect pests viz., *Myzus persicae* and *Helicoverpa armigera* compared with control plots (Tomato fields adopted general practices).

2. Materials and Methods

A study was conducted in ecologically engineered field conditions at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India during 2019 and a survey was carried out to record the population density of tomato fruit borer, *Helicoverpa armigera*, peach aphid, *Myzus persicae* and distribution as well as relative abundance of their predatory natural enemies.

2.1. Status of Pests and Natural Enemies in the Arena of Ecological Engineered Tomato

In order to study the status of insect pests and natural enemies a hybrid tomato variety (Shalimar Hybrid 1) was raised in ecologically engineered field conditions in the plots of size 10 ft. x 11 ft. In order to maintain healthy crop growth, all the recommended agronomic practices were carried out except pesticide application. In Tomato field, buckwheat (*Fagopyrum esculentum* Moench.) three line row (width of row = one foot) grown as cover crop on boarder for pollen, nectars and shelter of natural enemies; after that one row of marigold (Tagetes spp.) was grown as trap crop (width of row = one foot) for avoid egg laying of tomato fruit borer damage of main tomato crop, after each plots of tomato crops one row of maize (*Zea mays* L.) crop in between two plots of tomato, grown as barrier crop for aphid and flying insect such as tomato fruit borer for avoid egg laying on main tomato crop and similarly, one row of cowpea (Vigna unguiculata L.) grown as trap crop opposite direction of maize crop for aphid and avoid egg laying of tomato fruit borer damage of tomato crop [41].

2.2. Population Density of Insect Pests

The population density of these pests was recorded from 15th June to 15thSeptember on weekly intervals during 2019. Population counts were recorded throughout the crop season i.e., during the vegetative and reproductive stages of the crop. Observations were recorded from three randomly selected plants in each plot/replication (4 replications). Tagging of randomly selected plants was also done in order to make the recording of observations convenient. The methodology employed for the estimation of the population of insect pests is as follows:

The population density of the tomato fruit borer, *Helicoverpa armigera* was estimated by counting the number of larvae on each of the 3 randomly selected plants at weekly intervals by direct visual counting method. Observations were taken throughout the season right up to the harvesting of the tomato crop. The population obtained was later expressed as larvae/plant. Population density of aphids, *Myzus persicae* was counted from 3 leaves per plant (aphids/3 leaf count method) selected from the top of the crop canopy in three directions on each of the three randomly selected plants of each replication. All the visible immature and mature stages were recorded (Nymph, Alate, and Apterous). The selected leaves were tapped against the black cardboard and the population of aphids obtained was expressed as aphids/plant and compared with control plots (Tomato fields with general practices).

2.3. Correlation Coefficients and Regression Analysis

The data on pest population density was subjected to correlation and regression studies with meteorological parameters during the experimental period like temperature (T_{max} and T_{min}), relative humidity (RH morning and RH evening) and rainfall (abiotic factors). Moreover, correlation and regression studies were conducted between the incidence of *Myzus persicae* and *Helicoverpa armigera* on tomato and their natural enemies (biotic factors). Meteorological data of abiotic factors i.e., weather parameters were collected from Agro-metrology Unit Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India. All analysis was made by R-software [42].

2.4. Population Distribution and Abundance of Predatory Natural Enemy

The distribution and abundance of the natural enemy were recorded from 15th June to 15th September on weekly intervals during 2019 and compared with control plots (Tomato fields with general practices). The natural enemy population was recorded by collecting the adult natural enemies using insect collection nets. Collections were carried out by sweep net method (2 sweeps/day) amounting to a total of 12 sweeps/week in the morning and afternoon and a total number of 144 sweeps were done. Samples collected were preserved for identification.

2.5. Relative Abundance

In order to study the relative abundance of predatory natural enemies, observations were made on the species of various natural enemies. The relative abundance of natural enemies was worked out by dividing the number of individuals of a species by the total number of individuals of all species and expressed as a percentage:

$$\text{Relative Abundance} = \frac{\text{Total number of individuals of each species}}{\text{Total number of individuals of all species}} \times 100$$

3. Results

3.1. Population Density of Myzus Persicae

Data on the population density of *Myzus persicae* in ecologically engineered field on tomato is presented in Table 1 and Figure 1. It is evident from the table that the infestation of aphid was initially low in the 24th standard week of observation i.e., second week of June with 8.93 aphids per plant which increased gradually attained peak of 16.90 aphids/plant (ecologically engineered field) and 36.65 aphids/plant (untreated control) in second week of July. From there it started decreasing the entire growing season, the mean aphid population in control (31.74 aphids/plant) was more than the mean aphid population in the ecologically engineered field (14.42 aphids/plant). Among the various forms of aphid, i.e. Nymph, Alate, and Apterous, the mean nymph population was maximum and the alate form was minimum. Taking into account the importance of abiotic factors (weather parameters) and biotic factors (natural enemies) in the population buildup of *Myzus persicae*, a correlation, and regression analysis was performed (Table 3). It showed that there was a significant positive correlation between the maximum temperature (r=0.702), natural enemy population (r=0.698) and minimum temperature (r=0.617) with the population of *Myzus persicae*. In addition, there was a positive, but non-significant correlation with a mean relative humidity morning. The rainfall and mean relative humidity evening showed negative non-significant correlation with the mean aphid population. The multiple regression model demonstrated that 81.50 per cent (R^2 = 0.815) of the total variability in the aphid population was due to the above-mentioned weather parameters and natural enemy population put together.

3.2. Population Density of Fruit Borer, H. armigera

Table 2 presents the data that indicates the observations on the population density of *Helicoverpa armigera* larvae in the ecologically engineered field. From the table, it is evident that the *Helicoverpa armigera* larvae were recorded on tomatoes, starting from the crop establishment till the crop maturity stage. The fruit borer first appeared in the last week of June (1.05 larvae per plant) and the peak infestation of 1.57 larvae per plant in an ecologically engineered field and 4.67 larvae per plant in untreated control was noticed in the last week of July. After this, a declining pattern in the pest population was observed up to crop maturity, with a minimum infestation of 0.65 larvae per plant in the first week of September (Figure 2). Overall, the mean fruit borer population recorded in the ecologically engineered field (0.96 larvae/plant) remained lesser than the mean population recorded in untreated control (2.689 larvae/plant).

Correlation studies on the population of *Helicoverpa armigera* with weather parameters and natural enemy population (Table 4) revealed that it exhibits significant positive correlation with minimum temperature (r=0.753), natural enemy population (r=0.616) and maximum temperature (r=0.576). While as mean relative humidity morning and rainfall showed positive but non-significant correlation and relative humidity evening showed negative but non-significant correlation. From the regression analysis it was revealed that above mentioned parameters explained 83.7% variation in *Helicoverpa armigera* population.

Table 1. *Population density of Myzus persicae in ecologically engineered tomato ecosystem of Kashmir during 2019.*

Standard Week	Mean aphid population (per plant)*					Metrological parameters					Total natural Enemy population***	
	Ecologically engineered field				Control**	Temperature (^oC)		Relative Humidity (%)		Rainfall (mm)		
	Nymphs	Alate	Apterous	Total		Maximum	Minimum	Morning	Evening		E.E	Control
24 (11/06/19)	7.18	0.98	0.77	8.93	27.92	25.07	10.63	77.29	59.43	7.91	3.27	0.73
25 (18/06/19)	9.06	1.05	1.14	11.25	29.76	26.71	10.67	74.57	62.43	3.03	2.80	0.85
26 (25/06/19)	10.43	1.12	1.96	13.51	31.89	27.71	11.43	72.14	47.14	0	3.27	0.92
27 (02/07/19)	11.24	1.47	2.42	15.13	33.99	30.64	14.14	68.57	41.71	0.86	4.87	1.33
28 (09/07/19)	11.15	2.4	3.35	16.90	36.65	32.00	17.29	74.14	46.71	0	5.00	1.51
29 (16/07/19)	12.67	1.37	2.74	16.78	36.42	30.93	15.93	76.29	47.57	0.71	4.20	1.22
30 (23/07/19)	10.73	1.29	2.08	14.10	34.72	28.07	17.59	85.14	63.29	12.34	3.93	0.71
31 (30/07/19)	12.18	1.02	3.15	16.35	32.92	30.14	17.54	88.14	57.29	1.06	5.13	2.02
32 (06/08/19)	10.46	2.05	2.02	14.53	31.74	30.79	18.57	88.71	58.57	8.83	2.93	1.11
33 (13/08/19)	9.58	1.55	4.28	15.41	29.71	28.21	16.71	84.00	68.14	7.2	3.60	0.82
34 (20/08/19)	9.02	1.33	6.18	16.53	30.97	29.14	13.07	77.57	46.57	0.8	4.20	1.73
35 (27/08/19)	8.30	2.03	4.09	14.42	29.72	28.13	16.43	82.57	60.71	0	3.87	0.76
36 (03/09/19)	9.18	1.51	3.07	13.76	29.12	31.57	13.8	77.14	48.71	0	3.07	0.81
37 (10/09/19)	9.79	1.87	2.67	14.33	28.90	32.14	10.23	70.14	41.86	0	3.93	0.75
Mean	10.07	1.50	2.85	14.42	31.74	-	-	-	-	-	3.86	1.09
SD	1.49	0.44	1.38	2.20	2.82	-	-	-	-	-	0.73	0.4

*Mean of 4 replications
**Control = Tomato field with general field practices; E. E. = Ecologically Engineered Field
*** Total Natural enemy population = Mean of 12 sweeps, major natural enemies = Syrphids, Coccinellids, Spiders etc.

Table 2. *Population density of fruit borer (Helicoverpa armigera) in ecologically engineered tomato ecosystem of Kashmir during 2019.*

Standard Week	Mean fruit borer larval population (per plant)*		Metrological parameters				Rainfall (mm)	Total natural Enemy population***	
			Temperature (°C)		Relative Humidity (%)				
	Ecologically engineered field	Control**	Maximum	Minimum	Morning	Evening		E.E	Control
24 (11/06/19)	0	0	25.07	10.63	77.29	59.43	7.91	3.27	0.73
25 (18/06/19)	0	0	26.71	10.67	74.57	62.43	3.03	2.80	0.85
26 (25/06/19)	1.05	2.09	27.71	11.43	72.14	47.14	0	3.27	0.92
27 (02/07/19)	1.34	3.34	30.64	14.14	68.57	41.71	0.86	4.87	1.33
28 (09/07/19)	1.41	3.77	32	17.29	74.14	46.71	0	5.00	1.51
29 (16/07/19)	1.51	3.91	30.93	15.93	76.29	47.57	0.71	4.20	1.22
30 (23/07/19)	1.49	3.89	28.07	17.59	85.14	63.29	12.34	3.93	0.71
31 (30/07/19)	1.57	4.67	30.14	17.54	88.14	57.29	1.06	5.13	2.02
32 (06/08/19)	1.36	2.63	30.79	18.57	88.71	58.57	8.83	2.93	1.11
33 (13/08/19)	0.97	3.79	28.21	16.71	84	68.14	7.2	3.60	0.82
34 (20/08/19)	0.76	2.45	29.14	13.07	77.57	46.57	0.8	4.20	1.73
35 (27/08/19)	0.68	1.78	28.13	16.43	82.57	60.71	0	3.87	0.76
36 (03/09/19)	0.65	2.89	31.57	13.8	77.14	48.71	0	3.07	0.81
37 (10/09/19)	0.7	2.43	32.14	10.23	70.14	41.86	0	3.93	0.75
Mean	0.96	2.69	-	-	-	-	-	3.86	1.09
SD	0.53	1.4	-	-	-	-	-	0.73	0.4

*Mean of 4 replications
**Control = Tomato field with general field practices; E.E. = Ecologically Engineered Field
*** Total natural enemy population = Mean of 12 sweeps, major natural enemies = Syrphids, Coccinellids, Spiders and etc.

Table 3. *Correlation coefficients and regression model of Myzus persicae population with biotic and abiotic factors.*

Characters	R Value
X_1= Maximum temperature (°C)	0.702**
X_2= Minimum temperature (°C)	0.617**
X_3= Mean relative humidity morning (%)	0.170
X_4= Mean relative humidity evening (%)	-0.321
X_5= Rainfall (mm)	-0.357
X_6 = Natural enemy population	0.698**
Regression Model	$Y= - 3.875+ 0.264X_1 + 0.310X_2 - 0.061X_3 - 0.031X_4 - 0.148X_5+ 0.855X_6 (R^2 = 0.815)$

*Correlation is significant at 0.05 level
**Correlation is significant at 0.01 level
Where, Y= Total aphid population.

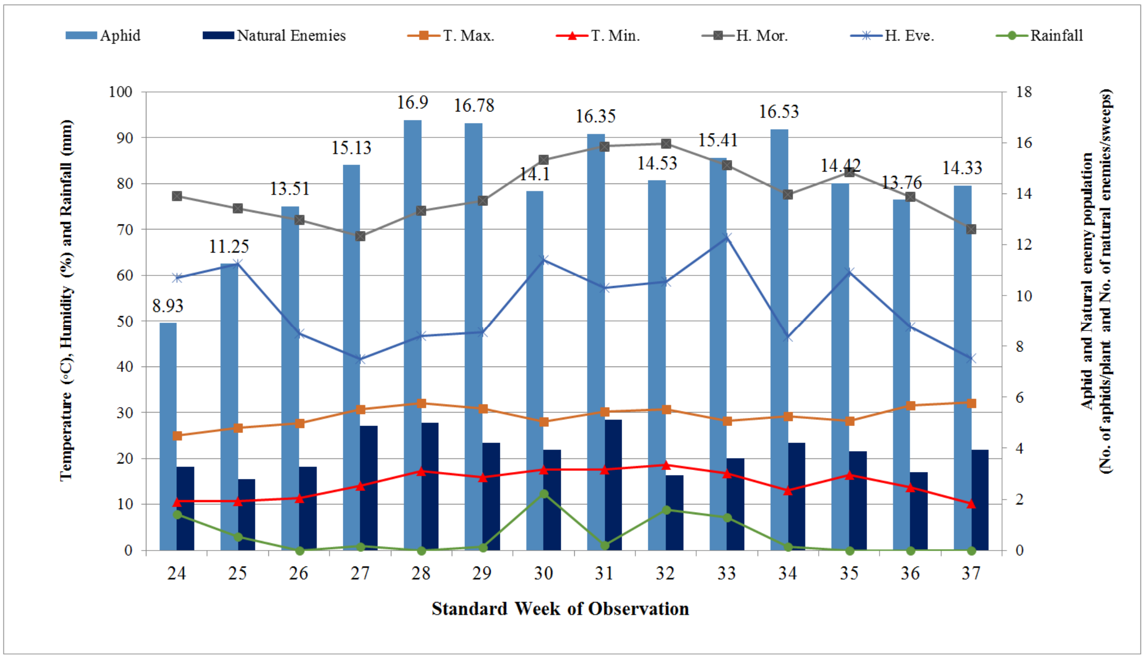

Figure 1. Graphical representation of correlation of Myzus persicae population with biotic and abiotic factors.

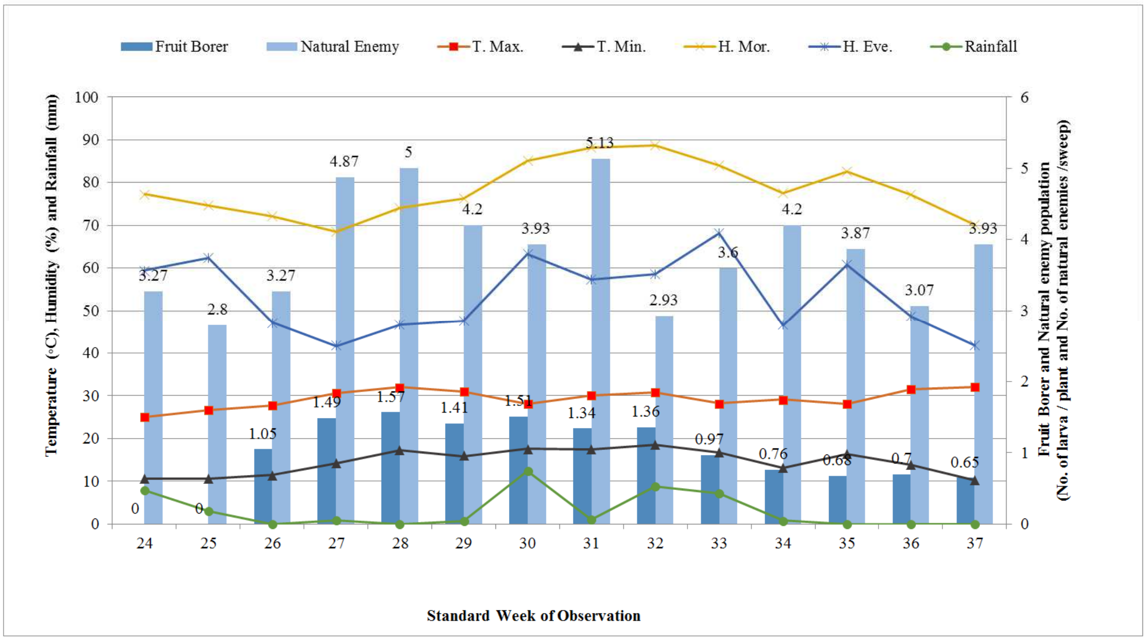

Figure 2. Graphical representation of correlation of Helicoverpa armigera population with biotic and abiotic factors.

Table 4. Correlation coefficients and regression model of fruit borer (Helicoverpa armigera) population with biotic and abiotic factors.

Characters	R Value
X_1= Maximum temperature (°C)	0.576**
X_2= Minimum temperature (°C)	0.753**
X_3= Mean relative humidity morning (%)	0.285
X_4= Mean relative humidity evening (%)	-0.203
X_5= Rainfall (mm)	0.024
X, = Natural enemy population	0.616**
Regression Model	$Y = 0.612 - 0.016X_1 + 0.148X_2 + 0.001X_3 - 0.038X_4 + 0.029X_5 + 0.119X_6$ ($R^2 = 0.837$)

*Correlation is significant at 0.05 level
**Correlation is significant at 0.01 level
Where, Y= Total fruit borer population.

Table 5. *Distribution of natural enemies in the ecologically engineered tomato ecosystem of Kashmir during 2019.*

Order/family	Species	Population of natural enemies /12 sweeps*														Total	Mean
		SW 24	SW 25	SW 26	SW 27	SW 28	SW 29	SW 30	SW 31	SW 32	SW 33	SW 34	SW 35	SW 36	SW 37		
Syrphidae	*Episyrphus balteatus*	3	3	4	8	6	4	5	5	2	4	3	2	4	5	58	4.14
	Scaeva pyrastri	7	1	3	5	6	2	3	4	1	3	0	1	2	3	41	2.93
	Sphaerophoria scripta	0	6	5	8	7	5	6	3	2	1	4	1	3	2	53	3.79
	Sphaerophoria Indiana	3	4	2	5	7	5	3	4	2	3	1	5	1	7	52	3.71
	Syrphus sp.	3	1	3	7	5	4	4	6	3	2	8	4	3	5	58	4.14
	Sub-Total	16	15	17	33	31	20	21	22	10	13	16	13	13	22	262	18.71
Coccinellidae	*Hippodamia variegata*	3	3	3	8	5	3	4	4	4	2	6	4	1	5	55	3.93
	Adalia tetraspilota	3	2	5	2	4	2	3	5	1	2	8	7	3	3	50	3.57
	Cheilomenes sexmaculata	1	1	2	4	2	0	3	6	3	4	1	3	2	2	34	2.43
	Coccinella septumpunctata	2	1	2	0	4	4	1	3	3	5	4	2	2	6	39	2.79
	Coccinella transversalis	3	2	2	2	3	2	1	4	2	1	1	5	1	1	30	2.14
	Sub-Total	12	9	14	16	18	11	12	22	13	14	20	21	9	17	208	14.86
Odonata	Dragonfly	1	3	2	3	2	1	3	3	1	3	1	2	2	1	28	2.00
	Damselfly	1	2	1	0	7	10	3	8	2	1	4	3	3	2	47	3.36
	Sub-Total	2	5	3	3	9	11	6	11	3	4	5	5	5	3	75	5.36
Chrysopidae	*Chrysoperla z.sillemi*	2	1	1	3	3	4	3	1	0	3	2	4	2	2	31	2.21
Araneidae	Hunting spiders	12	9	10	13	10	12	12	15	13	14	14	11	12	10	167	11.93
	Web building spiders	5	3	4	5	4	5	5	6	5	6	6	4	5	5	68	4.86
	Sub-Total	17	12	14	18	14	17	17	21	18	20	20	15	17	15	235	16.79
	Total no. of predators	49	42	49	73	75	63	59	77	44	54	63	58	46	59	811	57.93
	Weekly Mean population	3.27	2.80	3.27	4.87	5.00	4.20	3.93	5.13	2.93	3.60	4.20	3.87	3.07	3.93	54.07	-

*Sampling method=Sweep net, Number of sweeps=2 sweeps/day or 12 sweeps/week (Total=144 sweeps)
#SW = Standard week of observation.

3.3. Distribution and Relative Abundance of Predatory Natural Enemies

Distribution of natural enemies in the ecologically engineered tomato field is presented in Table 5. Observations were the mean of 12 sweeps/week. Population of natural enemies was recorded from the first week of observation which increased gradually and attained peak of 5.13 in last week of July. Natural enemies of families/orders (Syrphidae, Araneae, Coccinellidae, Odonata and Chrysopidae) were recorded throughout the growing season. The studies on the relative abundance of the natural enemies (Table 6) revealed that among those recorded, family Syrphidae was dominant followed by order Araneae and family Chrysopidae was least dominant. From the most dominant family Syrphidae (24.13%), species *Episyrphus balteatus* (5.36%) was relatively more abundant than other species followed by *Syrphus* sp. (5.25%), *Sphaerophoria scripta, Sphaerophoria indica* and *Scaeva pyrastri*. In Coccinellidae the presence of five species was observed *viz*., *Hippodaia variegata*, *Adalia tetraspilota*, *Cheilomenes sexmaculata*, *Coccinella septumpunctata* and *Coccinella transversalis*. Among them *Hippodaia variegata* (5.05%) and *Adalia tetraspilota* (4.74%) were relatively dominant and *Coccinella transversallis* was least dominant. In order Odonata (6.70%), natural enemies related to sub-order Zygoptera (damselfly) and Epiprocta (dragonfly) were recorded among which Damselfly dominant was having 4.04% population from the total population. In family Chrysopidae one species *Chrysoperla zastrowi sillemi* was recorded. In order Araneae two types of spiders were recorded hunting type and web-building type among which hunting type spiders were dominant.

Table 6. *Relative abundance of natural enemies in the ecologically engineered tomato ecosystem of Kashmir.*

Order/family	Species	Relative abundance of natural enemies /12 sweeps								
		SW 24	SW 25	SW 26	SW 27	SW 28	SW 29	SW 30	SW 31	SW 32
Syrphidae	*Episyrphus balteatus*	6.12	7.14	8.16	10.96	8.00	6.35	8.47	6.49	4.55
	Scaeva pyrastri	14.29	2.38	6.12	6.85	8.00	3.17	5.08	5.19	2.27
	Sphaerophoria scripta	0.00	14.29	10.20	10.96	9.33	7.94	10.17	3.90	4.55
	Sphaerophoria Indiana	6.12	9.52	4.08	6.85	9.33	7.94	5.08	5.19	4.55
	Syrphus sp.	6.12	2.38	6.12	9.59	6.67	6.35	6.78	7.79	6.82
	Sub-Total	32.65	35.71	34.69	45.21	41.33	31.75	35.59	28.57	22.73
Coccinellidae	*Hippodamia variegata*	6.12	7.14	6.12	10.96	6.67	4.76	6.78	5.19	9.09
	Adalia tetraspilota	6.12	4.76	10.20	2.74	5.33	3.17	5.08	6.49	2.27
	Cheilomenes sexmaculata	2.04	2.38	4.08	5.48	2.67	0.00	5.08	7.79	6.82
	Coccinella septumpunctata	4.08	2.38	4.08	0.00	5.33	6.35	1.69	3.90	6.82
	Coccinella transversalis	6.12	4.76	4.08	2.74	4.00	3.17	1.69	5.19	4.55
	Sub –Total	24.49	21.43	28.57	21.92	24.00	17.46	20.34	28.57	29.55
Odonata	Dragonfly	2.04	7.14	4.08	4.11	2.67	1.59	5.08	3.90	2.27
	Damselfly	2.04	4.76	2.04	0.00	9.33	15.87	5.08	10.39	4.55
	Sub-Total	4.08	11.90	6.12	4.11	12.00	17.46	10.17	14.29	6.82

Order/family	Species	Relative abundance of natural enemies /12 sweeps								
		SW 24	SW 25	SW 26	SW 27	SW 28	SW 29	SW 30	SW 31	SW 32
Chrysopidae	*Chrysoperla z.sillemi*	4.08	2.38	2.04	4.11	4.00	6.35	5.08	1.30	0.00
Araneidae	Hunting spiders	24.49	21.43	20.41	17.81	13.33	19.05	20.34	19.48	29.55
	Web building spiders	10.20	7.14	8.16	6.85	5.33	7.94	8.47	7.79	11.36
	Sub-Total	34.69	28.57	28.57	24.66	18.67	26.98	28.81	27.27	40.91
	Sub -Total of predators	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 6. *Continued.*

Order/family	Species	Relative abundance of natural enemies /12 sweeps							
		SW 33	SW 34	SW 35	SW 36	SW 37	Mean	Ranking	Ranking
	Episyrphus balteatus	7.41	4.76	3.45	8.70	8.47	5.36	1	
	Scaeva pyrastri	5.56	0.00	1.72	4.35	5.08	3.87	5	
Syrphidae	*Sphaerophoria scripta*	1.85	6.35	1.72	6.52	3.39	4.84	3	1
	Sphaerophoria Indiana	5.56	1.59	8.62	2.17	11.86	4.80	4	
	Syrphus sp.	3.70	12.70	6.90	6.52	8.47	5.25	2	
	Sub-Total	24.07	25.40	22.41	28.26	37.29	24.13	-	
	Hippodamia variegata	3.70	9.52	6.90	2.17	8.47	5.05	1	
	Adalia tetraspilota	3.70	12.70	12.07	6.52	5.08	4.74	2	
Coccinellidae	*Cheilomenes sexmaculata*	7.41	1.59	5.17	4.35	3.39	3.13	4	3
	Coccinella septumpunctata	9.26	6.35	3.45	4.35	10.17	3.65	3	
	Coccinella transversalis	1.85	1.59	8.62	2.17	1.69	2.83	5	
	Sub –Total	25.93	31.75	36.21	19.57	28.81	19.40	-	
Odonata	Dragonfly	5.56	1.59	3.45	4.35	1.69	2.66	2	4
	Damselfly	1.85	6.35	5.17	6.52	3.39	4.04	1	
	Sub-Total	7.41	7.94	8.62	10.87	5.08	6.70	-	
Chrysopidae	*Chrysoperla z.sillemi*	5.56	3.17	6.90	4.35	3.39	2.86	-	5
Araneidae	Hunting spiders	25.93	22.22	18.97	26.09	16.95	15.83	1	2
	Web building spiders	11.11	9.52	6.90	10.87	8.47	6.45	2	
	Sub-Total	37.04	31.75	25.86	36.96	25.42	22.28	-	
	Sub -Total of predators	100.00	100.00	100.00	100.00	100.00	75.37	-	-

#SW = Standard week of observation

* Ranking within the species of same family; ** ranking among orders/families.

4. Discussion

Tomato plants are attacked by a number of insect pests such as fruit borers, cutworms, aphids, jassids, green bugs, leaf bugs, thrips, white flies and leaf hoppers (Khan et al., 2020b). Among them *Helicoverpa armigera* (Hubner) is present throughout the Kashmir valley and in India loss caused due to this pest ranges from 50-100% [43] and *Myzus persicae* (Sulzer) is a highly polyphagous species of aphids present throughout the world which is considered as pest principally due to its nature of being a very competent vector of viruses presenting an ominous threat to commercial tomato production [44]. In order to manage the population of these insect pests a large number of synthetic insecticides have been put to use since a long time [45-49]. No doubt that we have been able to manage these insect pests up to a large extent but the use of insecticides has a flip side also and that flip side is that indiscriminate and excessive use of insecticides has led to adverse effects on human health as well as environment. Besides causing serious damage, these pests have also developed resistance to almost all major groups of synthetic insecticides [50]. So, in order to minimize the harmful effects of the excessive use of these insecticides for the pest management we must devise effective strategies in this direction. And one among them is biocontrol which is being accepted as one of the main components of pest management. As part of biological control, endemic natural enemies offer a potential but understudied approach to control insect pests in agricultural systems. For the utilization of endemic natural enemies in pest management, ecological engineering which is also referred to as habitat manipulation helps in the conservation and enhancement of natural enemies by enhancing the plant diversity and providing adequate refugia in the agro-ecosystem [51]. For the purpose of blending the benefits of ecological engineering for pest management, a study was carried out in which tomato crop was maintained in ecologically engineered field conditions at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, in 2019. Discussion of the results of the investigations is given under the following headings.

4.1. Status of Pests and Natural Enemies in the Arena of Ecologically Engineered Tomato

In the study it was found that the differences in population of pests (*Helicoverpa armigera* and *Myzus persicae*) and their natural enemies were non-significant in the ecologically engineered tomato field. It suggested that the insect population and the population of natural enemies were homogenous. This demonstrates that regardless of the management practices adopted other than ecological engineering; the pest population was kept under check by natural enemies. These results are in synchrony with the findings of Latha *et al*. [52] who reported that favorable conditions for natural enemies are present in ecosystem and in the absence of chemical pesticides (external forces) natural enemies control the tomato pests in ecologically engineered field. An increase in the number of parasitoids and predators is seen through enhancement of biodiversity by using different flowering plants in and around the field due to availability of food and shelter [53]. Zhu *et al*. [54] also reported that pest management through ecological engineering, a human activity to modify the environment, involves selection of practices from agronomically feasible options.

4.2. Population Density of Myzus Persicae

Data on the population density of *Myzus persicae* in ecologically engineered field revealed that the infestation of aphid was initially low in the second week of June (24th standard week) which increased gradually with the increase in temperature and attained peak in second week of July (28th standard week). Thereafter, a decrease in the population was seen as the crop advanced towards maturity. The possible reason for the decrease in population may be due to the increase in natural enemy population which were continuously keeping the aphid population under check. These findings are in partial agreement with that of Tomar [55] who found out that population of aphid started from 28th standard week and remained up to a first standard week with peak infestation in 37th standard week. Contrary to this, Hath and Das [56] found that the population of aphid was low from third week of February to the last week of March, whereas Reddy and Kumar [57] reported peak population of two aphid species (*Aphis gossypii and Myzus persicae*) during November and February on tomato at Bangalore, Karnataka. The reason behind this contrast may be the climatic difference in the two regions (Kashmir and Karnataka).

During the entire growing season, the mean aphid population in control was more than the mean aphid population in the ecologically engineered field, which again proved the effect of trap and cover crops which were helpful in increasing the natural enemy population to keep the pest population under check. Among the various forms of aphid, i.e., Nymph, Alate and Apterous, the mean nymph population was maximum and the alate form was minimum.

The results of the study revealed that there is a significant positive correlation between the aphid population and maximum temperature, minimum temperature and the natural enemy population. In addition, there was a positive, but non-significant correlation with a mean relative humidity morning. The rainfall and mean relative humidity evening exhibits negative non-significant correlation. The multiple regression model demonstrated that 81.50 percent (R^2= 0.815) of the total variability in the aphid population was due to the above-mentioned weather parameters and natural enemy population put together. The results differ some extent from that of Sarangdevot *et al*. [58] who reported that the aphid population was significantly negatively correlated with mean temperature and positively correlated with relative humidity. Shakeel *et al*. [59] found that there was a significant negative correlation between aphid population and minimum and maximum temperature, further a positive correlation with relative humidity. It may be due to the climatic difference of the regions; in Kashmir temperature hardly exceeds the limits that are not feasible for the growth and development of aphid. While as Tomar [55] and Neupane and Subedi [60] reported a significant positive correlation between maximum and minimum temperature which is in line with the present study. During the present study, it was found that rainfall has negative nonsignificant correlation with the mean aphid population which is contrary to most of the authors, the probable reason behind this is that during current season there was no significant rainfall which would have lowered the aphid population significantly.

4.3. Population Density of Fruit Borer, H. armigera

The population density data of *Helicoverpa armigera* in the ecologically engineered field conditions revealed that the infestation of *Helicoverpa armigera* on tomato started in the last week of June with a peak infestation observed on the last week of July. After this, declining pattern in the pest population was observed with a minimum infestation in first week of September. These results are in synchrony with the findings of Boukhris-Bouhachem *et al*. [61] who found out that the pest was active from May to November and maximum trap catch of adults, eggs and larvae stages were observed in the month of July. While as Ganai *et al*. [62] found out that the pest first appeared from the 7th standard week and was prevalent till the 18th standard week with the 15th standard week as its peak activity period which is in contrast with this study, which may be due to the climatic difference in two regions i.e., Jammu and Kashmir.

The mean borer population recorded in the ecologically engineered field was less than the population recorded in untreated control indicating the efficacy of trap crop marigold in reducing the pest population.

Correlation studies on the population of *Helicoverpa armigera* with weather parameters and natural enemy population revealed that it exhibits a significant positive correlation with minimum temperature, natural enemy population and maximum temperature. While as mean relative humidity morning and rainfall showed positive but non-significant correlation and relative humidity evening showed negative but non-significant correlation. From the regression analysis it was revealed that above mentioned parameters explained 83.7% variation in *H. armigera* population. Ganai *et al*. [62] revealed that the larval population of *H. armigera* shows a highly significant positive correlation with mean maximum temperature and mean minimum temperature while a negative but non-significant correlation with mean relative humidity (evening) and mean rainfall which is in conformity with this study. They also found out that *H. armigera* has got highly significant negative association with mean relative humidity (morning) which contradicts with the results of present study again the probable reason may be the difference in climate in the two regions. Singh *et al*. [63] found out that maximum and minimum temperature has significant positive correlation with larval population *H. armigera* while as relative humidity (morning and evening) are non-significantly correlated with the population of *H. armigera* which is in partial agreement with this study, similar results were also reported by Reddy *et al*. [64] and Kumar *et al*. [65].

4.4. Distribution and Abundance of Predatory Natural Enemies

Distribution of natural enemies in the ecologically engineered tomato field revealed that population of natural enemies was recorded from the first week of observation which increased gradually and attained peak in second week of July. This may be due the reason of the availability of enough prey. Natural enemies of families/orders (Syrphidae, Araneae, Coccinellidae, Odonata and Chrysopidae) were recorded throughout the growing season. The studies on the relative abundance of the natural enemies revealed that among the recorded families Syrphidae was dominant followed by order Araneae and family Chrysopidae was least dominant. From the most dominant family Syrphidae, the species *Episyrphus balteatus* was relatively more abundant than other species followed by *Syrphus* sp. and *Scaeva pyrastri* was least dominant. In Coccinellidae *Hippodaia variegata* and *Adalia tetraspilota* were relatively dominant and *Coccinella transversalis* was least dominant. In order Odonata, natural enemies related to sub-order Zygoptera (damselfly) and Epiprocta (dragonfly) were recorded among which Damselfly was relatively dominant. In family Chrysopidae one species *Chrysoperla zastrowi sillemi* was recorded. In order Araneae two types of spiders were recorded hunting type and web-building type among which hunting spiders were dominant. These results are in conformity with the studies of Khan *et al*. [66] who surveyed different districts of Kashmir to identify potential natural enemies in vegetable ecosystem and reported that the natural enemies of the families such as Coccinellids, Chrysoperla, Syrphid flies, spiders, Dragonflies, Damselflies, etc. were prevalent in the Valley. Also, Khan *et al*. [67] found out that in the horticulture ecosystem of Kashmir valley 15 species of coccinellids were present among which *Adalia tetraspilota* was dominant followed by *Hippodamia variegata* which is in partial agreement with this study.

5. Conclusion

The population density of *Myzus persicae* in ecologically engineered field revealed that the aphid population in control (31.74 aphids/plant) was significantly high than the aphid population in the ecologically engineered field (14.42 aphids/plant). Similarly, the overall fruit borer population recorded in the ecologically engineered field (0.96 larvae/plant) remained lesser than the population recorded in untreated control (2.689 larvae/plant). Natural enemies of families/orders Syrphidae, Araneae, Coccinellidae, Odonata and Chrysopidae were recorded throughout the growing season. Among the recorded families/orders Syrphidae was dominant followed by order Araneae and family Chrysopidae was least dominant. Total enhancement and conservation of natural enemies population was 3.86/plant as compared to control plot (1.09/plant) was certainly helps in the minimized the population of *Myzus persicae* and *Helicoverpa armigera* in ecologically engineered field conditions. Due to high natural enemy population in ecologically engineered tomato field the prey: defender ratio was balanced in the field. In future needs to works on the patchy application of insecticides/inoculative release of natural enemies when the insect population will much high on particular plants of ecological engineered tomato crops and not managed by this techniques. This method will be very useful pest management in future if the pest population will increase above Economic Injury Level in ecological engineered tomato crop.

Acknowledgements

Authors are grateful to Department of Science and Technology, New Delhi (India) for sanction of a project “Ecological Engineering for Conservation Biological Control of Insect Pests in Vegetable Ecosystem of Kashmir” for a period of 2016-2019 with financial assistance and provide platform for this research work.

References

[1] Altieri, M. (1999). The ecological role of biodiversity in agroecosystem. Agric. Ecosyst. Environ. 74: 19–31.

[2] Pywell, R. F.; Heard, M. S.; Woodcock, B. A.; Hinsley, S.; Ridding, L.; Nowakowski, M., & Bullock, J. M. (2015). Wildlife-friendly farming increases crop yield: Evidence for ecological intensification. Proc. R. Soc. B Biol. Sci., 282.

[3] Landis, D. A., Gardiner, M. M., van der Werf, W., & Swinton, S. M., (2008). Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proc. Natl. Acad. Sci. U. S. A. 105: 20552–20557.

[4] Tschumi, M., Albrecht, M., Entling, M. H., & Jacot, K., (2015). High effectiveness of tailored flower strips in reducing pests and crop plant damage. Proc. R. Soc. B., 282: 2015-1369.

[5] Latha, S. E., Ranjan, J. S., Yadav, S. K., & Sathish, R. (2018). Agro ecosystem analysis and ecological engineering-based plant health management in organic tomato (*Lycopersicon esculentum*) cultivation. *International Journal of Agriculture Sciences* 10 (5): 5379-5382.

[6] Rusch, A., Valantin-Morison, M., Sarthou, J. P., & Roger-Estrade, J. P. (2010). Biological control of insect pests in agroecosystems: effects of crop management, farming systems and semi-natural habitats at the landscape scale. A review. Adv. Agron. 109: 219–260.

[7] Martin, E. A., Reineking, B., Seo, B., & Steffan-Dewenter, I. (2013). Natural enemy interactions constrain pest control in complex agricultural landscapes. Proc. Natl. Acad. Sci. U. S. A. 110: 5534–5539.

[8] Rusch, A., Bommarco, R., Jonsson, M., Smith, H. G., & Ekbom, B. (2013). Flow and stability of natural pest control services depend on complexity and crop rotation at the landscape scale. J. Appl. Ecol. 50: 345–354.

[9] Foster, S. P.; Harrington, R.; Dewar, A. M.; Denholm, I.; & Devonshire, A. L. (2002). Temporal and spatial dynamics of insecticide resistance in Myzus persicae (Hemiptera: Aphididae). Pest Manag. Sci. 58: 895–907.

[10] Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J.-S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9: 1146–1156.

[11] Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45: 175–201.

[12] van Emden, H. F.; Emden, V.; & Helmut, F. (2002). Conservation Biological Control: From Theory to Practice. In Proceedings of the International Symposium on Biological Control of Arthropods, Honolulu, HI, USA, 14–18 January 2002.

[13] Balzan, M. V.; Bocci, G.; Moonen, A. C. (2014). Augmenting flower trait diversity in wildflower strips to optimise the conservation of arthropod functional groups for multiple agroecosystem services. J. Insect Conserv. 18: 713–728.

[14] Olson, D. M., & Wäckers, F. L. (2007). Management of field margins to maximize multiple ecological services. J. Appl. Ecol. 44: 13–21.

[15] Phillips, B. W., & Gardiner, M. M. (2016). Does local habitat management or large-scale landscape composition alter the biocontrol services provided to pumpkin agroecosystems? Biol. Control, 92: 181–194.

[16] Tscharntke, T.; Karp, D. S.; Chaplin-Kramer, R.; Batáry, P.; DeClerck, F.; Gratton, C.; Hunt, L.; Ives, A.; Jonsson, M.; Larsen, A. (2016). When natural habitat fails to enhance biological pest control—Five hypotheses. Biol. Conserv. 204: 449–458.

[17] Bommarco, R.; Miranda, F.; Bylund, H. & Björkman, C. (2011). Insecticides suppress natural enemies and increase pest damage in cabbage. J. Econ. Entomol. 104: 782–791.

[18] Mayse, M. A. (1983). Culture control in crop fields: A habitat management technique. Environ. Manag. 7: 15–22.

[19] Hokkanen, H. M. T. (1991). Trap cropping in pest management. Annu. Rev. Entomol. 36: 119–138.

[20] Hooks, C. R. R., & Johnson, M. W. (2003). Impact of agricultural diversification on the insect community of cruciferous crops. Crop Prot. 22: 223–238.

[21] Hurej, M. (2000). Trap plants and their application in plant protection against pests. Prog. Plant Prot. 40: 249–253.

[22] Shelton, A., & Badenes-Perez, F. (2006). Concepts and applications of trap cropping in pest management. Annu. Rev. Entomol. 51: 285–308.

[23] Banks, J. E., & Ekbom, B. (1999). Modelling herbivore movement and colonization: Pest management potential of intercropping and trap cropping. Agric. For. Entomol. 1: 165–170.

[24] Foster, S., & Harris, M. (1997). Behavioral manipulation methods for insect pest-management. Annu. Rev. Entomol. 42: 123–146.

[25] Hassanali, A.; Herren, H.; Khan, Z. R.; Pickett, J. A., & Woodcock, C. M. (2008). Integrated pest management: The push–pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Philos. Trans. R. Soc. B Biol. Sci. 363: 611–621.

[26] Potting, R. P. J.; Perry, J. N., & Powell, W. (2005). Insect behavioural ecology and other factors affecting the control efficacy of agro-ecosystem diversification strategies. Ecol. Model. 182: 199–216.

[27] Vargas, R. R.; Troncoso, A. J.; Tapia, D. H.; Olivares-Donoso, R., & Niemeyer, H. M. (2005). Behavioural differences during host selection between alate virginoparae of generalist and tobacco-specialist Myzus persicae. Entomol. Exp. Appl. 116: 43–53.

[28] Finch, S., & Collier, R. (2000). Host-plant selection by insects–a theory based on ‘appropriate/inappropriate landings’ by pest insects of cruciferous plants. Entomol. Exp. Appl. 96: 91–102.

[29] Andersson, M. (2007). The effects of non-host volatiles on habitat location by phytophagous insects. In Introductory Paper at the Faculty of Landscape Planning, Horticulture and Agricultural Science, Swedish University of Agricultural Sciences; Alnap: London, UK, pp. 1–38.

[30] Döring, T., & Röhrig, K. (2016). Behavioural response of winged aphids to visual contrasts in the field. Ann. Appl. Biol.168: 421–434.

[31] Ben Issa, R.; Gautier, H., & Gomez, L. (2017). Influence of neighbouring companion plants on the performance of aphid populations on sweet pepper plants under greenhouse conditions. Agric. For. Entomol.19: 181–191.

[32] Moreno, C. R., & Racelis, A. E. (2015). Attraction, repellence, and predation: Role of companion plants in regulating Myzus persicae (Sulzer) (Hemiptera: Aphidae) in organic kale systems of south Texas. Southwest. Entomol. 40: 1–14.

[33] Kalinova, J., N. Vrchotova, & J. Triska. (2007). Exudation of allelopathic substances in buckwheat (Fagopyrum esculentum Moench). J. Agric. Food Chem. 55: 6453–6459.

[34] Mutiga, S. K.; Gohole, L. S., & Auma, E. O. (2010). Effects of integrating companion cropping and nitrogen application on the performance and infestation of collards by Brevicoryne brassicae. Entomol. Exp. Appl.134: 234–244.

[35] Renwick, J. (1989). Chemical ecology of oviposition in phytophagous insects. Cell. Mol. Life Sci. 45: 223–228.

[36] Wäckers, F. L., & Van Rijn, P. C. (2012). Pick and mix: Selecting flowering plants to meet the requirements of target biological control insects. Biodivers. Insect Pests, 9: 139–165.

[37] Woltz, J. M., Isaacs, R., & Landis, D. A., (2012). Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape. Agric. Ecosyst. Environ. 152: 40–49.

[38] Rusch, A., Delbac, L., Muneret, L., & Thiéry, D. (2015). Organic farming and host density affect parasitism rates of tortricid moths in vineyards. Agric. Ecosyst. Environ. 214: 46–53.

[39] Khan, A. A., Kundoo, A. A., & Khan, Z. H. (2020a). Identification of the most conservative plant species for promising natural enemies of arthropods pests of Vegetable crops. *Journal of Entomology and Zoology Studies* 8 (5): 2244-2250.

[40] Khan, A. A. (2020). Bio-efficacy of botanical pesticides against green apple aphid (Aphis pomi) and biosafety against its natural enemies in apple orchard of Kashmir. *Journal of Entomology and Zoology Studies* 8 (4): 1445-1448.

[41] Khan, A. A., & Reyaz S. 92017a). Effect of insecticides on distribution, relative abundance, species diversity and richness of syrphid flies in vegetable ecosystem of Kashmir. *Journal of Entomology and Zoology Studies* 5 (4): 808-817.

[42] R Development Core Team. (2016). R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria. ISBN 3-900051-07- 0, URL http://www.R-project.org.

[43] Puri, S. N. (1995). Present status of IPM in India. Proceedings of National Seminar on Integrated Pest Management in Agriculture. Nagpur, Maharashtra.

[44] Barkat, H. and Bilal, S. (2008). Marigold as a trap crop against tomato fruit borer (Lepidoptera: Noctuidae). *International Journal of Agricultural Research* 2 (2): 185-188.

[45] Khan, A. A. (2017). Effect of insecticides on biodiversity of aphidophagous syrphid flies in fruit ecosystem of Kashmir. *Journal of Entomology and Zoology Studies* 5 (4): 117-125.

[46] Khan, A. A., & Reyaz S. (2017b). Diversity and Distribution of Syrphid Fly Communities in Temperate Fruit Orchard of Kashmir, India. Int. J. Curr. Microbiol. App. Sci., 6 (7): 2794-2805.

[47] Khan, A. A. (2015). Report of Department of Science and Technology on Biodiversity and management of aphid in temperate horticultural ecosystem of Kashmir, Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India.

[48] Khan, A. A. (2012). Comparison of spider diversity in relation to pesticide use in apple orchards of Kashmir. Journal of Biological Control, 26 (1): 1-10, 2012.

[49] Khan, A. A., & Shah, M. A. (2018). Population dynamics of green apple aphid Aphis pomi De Geer (Homoptera: Aphididae) and its natural enemies in apple orchard of Kashmir. Indian Journal of Entomology. 80 (2):320-329.

[50] Andrei, A., Yolanda, H. C., Maxim U., Galina B. & Leena L. (2013). *Evolutionary considerations in potato pest management* pp. 543-571. In: Insect Pests of Potato (Eds. A. Andrei, C. Vincent and P. Giordanengo). Academic Press.

[51] Muneer, A. & Pathania, S. S. (2017). Ecological engineering for pest management in Agro-ecosystem. Int. J. Curr. Microbiol. App. Sci., 6 (7): 176-185.

[52] Shankar, G., Sharma, O. P., Boina, D. R., & Varshney, R. (2014). AESA based IPM package number 18. AESA Based IPM-Tomato, NIPHM pp. 22.

[53] Tomar, S. P. S. (2010). Impact of weather parameters on aphid population in cotton. *Indian Journal of Agricultural Research* 44 (2): 125 – 130.

[54] Hath, T. K. & Das, B. R. (2004). Incidence of insect pests in late planted tomato under terai agro ecology of West Bengal. *Env. Eco*., 22 (1): 136-140.

[55] Gurr G. M,, Wratten, S. D. & Altieri, M. A. (2004). Ecological engineering: a new direction for agricultural pest management. *AFBM Journal*, 1 (1): 28-35

[56] Sarangdevot, S. S., Kumar, S., Naruka, P. S., & Pachauri, C. P. (2010). Population dynamics of *Aphis gossypii* Glover, *Myzus persicae* Sulzer and *Amrasca biguttula biguttulla* Ishida of tomato in relation to abiotic factors. *Pestology* 34 (3): 14-16.

[57] Shakeel, M., Akram, W., Hamza, A., Ali, M. W. & Rajput. A. A. (2014). Population dynamics of aphid (*Aphis gossypii* G.) on tomato agro-ecosystem in Faisalabad region. *International Journal of Research in Agricultural Sciences* 1 (3): 182-184.

[58] Lavandero, B., Wratten, S. D., Didham, R. K. & Gurr, G. M. (2006). Increasing floral diversity for selective enhancement of biological control agents: a double-edged sward? Basic and Applied Ecology, 7: 236–243.

[59] Neupane, S. and Subedi, S. (2019). Climatic factors affecting the population dynamics of lentil aphid in inner terai region of Nepal. *SAARC J. Agric*., 17 (2): 155-164.

[60] Boukhris-Bouhachem, S., Hdider, C., Souissi, S., Ghazel, I., & Pizzol, J. (2007). Seasonal activity of *Helicoverpa armigera* (Lepidoptera: Noctuidae) for improved control management strategies in processing tomatoes. *Acta Horticulture* 758: 89-94.

[61] Ganai, S. A., Ahmad, H., Sharma, D., Khaliq, N., Sharma, S., Kaur, R., & Norboo, T. (2017). Effect of abiotic factors on the populations of pod borer, *Helicoverpa armigera* (Hubner) on marigold, *Tagetes erecta* in Jammu. *International Journal of Current Microbiological Applied Science* 6 (9): 181-185.

[62] Singh, D., Singh, S. K., &Vennila, S. (2015). Weather parameters influence population and larval parasitization of *Helicoverpa armigera* (Hubner) in chickpea ecosystem. *Legume Research* 38 (3): 402-406.

[63] Gupta, R. K., & Desh, R. (2002). Monitoring of *Helicoverpa armigera* (Hubner) through light trap and pheromone traps and relationship of catch data with abiotic factors and larval infestation on chickpea in Himachal Pradesh. *Pest Mgt. Eco. Zool.,* 10 (2): 103-110.

[64] Reddy, C. N., Singh, Y., & Singh, V. S. (2001). Influence of abiotic factors on the major insect pests of pigeonpea. *Indian Journal of Entomology* 63 (3): 211-214.

[65] Kumar, L. Yogi, M. K., & Jagdish, J. (2013). Habitat Manipulation for Biological Control of Insect Pests: A Review. *Research Journal of Agriculture and Forestry Sciences* 1 (10): 27-31.

[66] Khan, A. A., Zaki, F. A., Khan, Z. H., & Mir, R. A. (2009). Biodiversity of predacious ladybird beetles (Coleoptera: Coccinellidae) in Kashmir. *Journal of Biological Control* 23: 43-47.

[67] Khan, A. A., Kundoo, A. A., Khan, Z. H., & Hussain, K. (2020b). Identification of potential and suitable natural enemies of arthropod pests for conservation biological control in vegetable ecosystem of Kashmir. *Journal of Entomology and Zoology Studies* 8 (5): 2251-2255.