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Dynamics of Pests, Natural Enemies and Pollinators of *Lycopersicon esculentum* Mill and Correlation with Weather Parameters

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Authors' contributions

This work was carried out in collaboration among all authors. Author NG designed, performed, analysed and visualised the experiment. Author MKJ did the writing the original draft, reviewing, editing and visualization. Author RRS did the visualisation. All authors have read and approved the manuscript.

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ABSTRACT

The experiment was carried out at K.V.K. Instructional Farm located near College of Agriculture, Odisha University of Agriculture and Technology (O.U.A.T.), Bhawanipatna, Kalahandi, during the cropping season 2020–21. The most significant pests found in *Lycopersicon esculentum* Mill were tomato fruit worm, serpentine leaf miner, and whitefly, while flea beetle was of minor importance.The population of whitefly had significant negative correlation with evening and mean relative humidity (RH). The population of leaf miner had significant positive correlation with maximum, minimum and mean temperature but significant negative correlation with mean RH. There was a significant positive correlation of flea beetle population with minimum temperature. The

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tomato fruit borer population had significant positive correlation with maximum, minimum and mean temperature but significant negative correlation with morning and mean RH. The natural enemies, lady bird beetles, spiders, praying mantis, rove beetle, red ant, dragonfly (red body) and damselflies (blue, brick red and black body) were found in the plots. The population of spider had significant negative correlation with maximum, minimum and mean temperature but significant positive correlation with bright sunshine hours (BSH). The population of spider had significant negative correlation with evening RH but significant positive correlation with BSH. There was a significant positive correlation of red ant population with BSH. The population of rove beetle had significant positive correlation with maximum, minimum and mean temperature. The pollinators recorded from experimental field were honey bee and carpenter bee. Of which, carpenter bee was the most frequent floral visitor and considered the main pollinator of tomato. The pollinators appeared in higher numbers during the blooming period and was the dominant species found in the field. There was a significant negative correlation of population of carpenter bee with maximum, minimum and mean temperature. The population of honey bee had significant negative correlation with evening RH.

Keywords: Dynamics; Lycopersicon esculentum; natural enemies; pests; pollinators; weather parameters.

1. INTRODUCTION

Vegetables are important parts of a healthy diet and good source of potassium, fiber, folic acid, and vitamins A, E, and C [1,2]. India is the world's second largest producer of vegetables having 2.8 per cent of total cropped area [3]. Tomatoes, *Lycopersicon esculentum* Mill, are one of the world's most important vegetables, and belong to the Solanaceae family. Next to China, India is the world's second-largest tomato producer, accounting for nearly 11 per cent of global production. The total area under tomato cultivation in India is 7.89 million hectares, with an annual production of 19.76 million tonnes and a productivity of 25 MT/ha [3]. Several factors are responsible for the reduction of the quality and the yield in tomato. Insect pests are one of the major causes that limit the production of tomato [4]. The insect pests infesting tomato include the fruit borer, *Helicoverpa armigera* (Hubner), whitefly, *Bemisia tabaci* (Genn)., jassids, *Amrasca biguttulla biguttula* (Ishida), thrips *Thrips tabaci* (Lind) and serpentine leaf miner, *Liriomyza trifolii* (Burgess) [5]. Many species of ladybird beetles, *Rodolia cardinalis, Cryptolaemus montrouzieri, Hippodamia variegata, Coccinella septempunctata* and *Propylea japonica* are the dominant predators of sucking pests in tomato [6,7,8]. Tomato flowers are self-fertile, but pollinators are required for the increase in fruit setting. Among pollinators carpenter bees and honey bees are the represented genera which help in increasing the percentage of fruit set and the quality of the fruit. Though these bees do not efficiently vibrate greenhouse tomato flowers, some benefit from honey bee pollination has been reported [9,10,11]. Abiotic factors influence the abundance and distribution of the pest. The interaction of pest activity with biotic and abiotic factors aids in the development of predictive models that aid in forecasting of pest incidence [5]. Moreover, the investigation on the dynamics of pests, natural enemies and pollinators is scarce particularly in this agro-climatic zone. Therefore, the present investigation was carried out to study the dynamics of pests, natural enemies and pollinators of *L. esculentum* and correlation of their occurrence with weather parameters.

2. MATERIALS AND METHODS

The experiment was carried out at K.V.K Instructional Farm located near College of Agriculture, O.U.A.T, Bhawanipatna, Kalahandi during the cropping season 2020–21 from November, 2020 to May, 2021. The field was cross ploughed with a tractor drawn cultivator, then harrowed and planked to obtain a well pulverized experimental field. The weeds and crop residues, left out from the previous sown crop, were removed. Tomato seeds of the *variety*, Pusa Hybrid-4, a cross between Pusa-120 and Chikoo, were sown in a plugged chamber in the green house on December 03, 2020, and after 21 days, seedlings were transplanted in the experimental field with a row to row spacing of 60 cm and a plant to plant spacing of 45 cm. The crop was fertilized with the recommended dose of 100:50:60 kg N, P, and K per hectare. N, P, and K were applied as a basal dose in furrows at the time of transplanting using

Urea, Single Super Phosphate (SSP), and Muriate of Potash (MOP), respectively. Glyphosate (All Clear), a total weed killer, was used as a non-selective herbicide and one manual hand weeding was done at 25 days after transplanting (DAT). Need based manual weeding was done, when weeds were observed.

2.1 Tomato Pests

Three leaves were selected *viz.*, one leaf from top (excluding two top most leaves), one from middle canopy and one from bottom (leaving one or two bottom most leaves) on main stem and observed very carefully and minutely with the help of hand lens (10x) for the presence of insect [12]. Mean population of the insects was expressed as numbers of insect/leaf/plant in each replication. Collection of insect pests were done usually by visual search and hand-picking method. The observation on the insect-pests population along with their natural enemies and pollinators was recorded at weekly intervals from germination of the plant till its harvest [2]. The weekly meteorological data on temperature, relative humidity, rainfall, BSH and wind velocity were also recorded throughout the cropping season from the meteorological observatory located at R.R.T.T.S., Bhawanipatna. Observations on the pests were taken from randomly selected five plants/plot at 10-day-interval starting from 10 DAT, excluding the border ones. For leaf miner, 10 young leaves/ plant were selected and % leaf miner infestation as well as number of active mines were worked out; for *Helicoverpa* larvae, 5 plants/plot were observed and % of infested fruits were worked out. For whitefly population, observations were taken from randomly selected 6 leaves/plant and @ 5 plants/plot and for calculating % infested plants, all the plants of all the replications were observed. For flea beetle, 5 plants/plot were randomly selected and the mean numbers/plant were worked out.

2.2 Natural Enemy Complex Usually Found in Tomato Field

Mature and immature stages of predatory coccinellids, *Cheilomenes sexmaculata* (Fab.), *Coccinella septempunctata* (L.), *Coccinella transversalis* (Fab.) and *Micraspis* sp. were counted altogether. Mixed population of common spiders, lynx, *Oxyopes* sp., jumping, *Phiddipus* sp. and wolf, *Marpissa* sp.) were counted altogether. Score was based on number/plot during observation for damselfly, praying mantis, *Mantis religiosa inornata* (Werner), (European mantis) and *Hierodula membranacea* (Burmeister) (Giant asian mantis), rove beetle (*Paederus* sp.) and red ant (*Solenopsis* sp.). For natural enemies, the observations were also taken from randomly selected 5 plants/plot at an interval of 15 days starting from 10 days after planting.

2.3 Pollinators in Tomato Field

For pollinators, total number of bees visiting rock bee, *Apis dorsata* Fabr., Indian honey bee, *A. cerana indica* Fabr., European honey bee, *Apis mellifera* L. and carpenter bee, *Xylocopa* sp., were counted as mixed population altogether. Plots were observed continuously for ten minutes and the means were worked out. Record of pollinators were taken at 20 days interval from four randomly selected plants per plot starting from 50 DAT. Collected data were analysed by correlation and regression.

3. RESULTS AND DISCUSSION

3.1 Insect Pests

3.1.1 Whitefly

The population of whitefly, *B. tabaci* was observed from the 1st Standard Meteorological Week (SMW) to the 17th SMW (Table 1 and Fig. 1). The highest population of whiteflies (14.20 whiteflies/6 leaves/plant) was observed during the 8th SMW, when the maximum, minimum, and mean temperature, morning, evening and mean RH, transformed rainfall, and BSH were 32.17°C, 15.69°C, 23.69°C, 64.00%, 34.29%, 49.143%, 2.63 mm and 6.96 hrs, respectively. The lowest population (4.60 whiteflies/6 leaves/plant) was observed during 1st SMW. Kumar et al. (2017) and Chavan et al. (2013) [13,14] indicated that the whitefly abundance began three weeks after transplanting and reached the maximum in the second week of March, which is consistent with current findings. Whitefly populations peaked from mid-February to mid-March [15,16], which partly confirms the current findings.

The population of whitefly had a significant negative correlation with evening and mean RH (r = -0.646 and r = -0.491, respectively), but nonsignificant positive relation with maximum, minimum and mean temperature and BSH (r = 0.137, r = 0.026, r = 0.078 and r = 0.487, respectively). There was a nonsignificant negative correlation of population of whitefly with morning RH and rainfall (r = -0.355 and r = -0.163) (Table 3).

Table 1. Incidence of different pests and pollinators in tomato field in different SMW

Standard Meteorological Week (SMW)	Pest				Pollinator	
	No. of Whitefly/ 6 leaves	Leaf miner infestation %	Flea beetle/ plant	No. of *H. armigera* larvae/ Plant	Carpenter bee/ Plot	Honey bee/ Plot
1	4.60	0.30	3.80	0.00	0.00	0.00
2	6.60	0.36	4.00	0.00	0.00	0.00
3	8.50	0.60	5.20	0.00	0.40	0.60
4	10.80	0.68	6.20	0.00	0.60	0.60
5	12.30	1.00	4.60	1.80	0.40	1.80
6	13.50	1.30	4.60	2.60	0.60	1.60
7	11.30	2.00	5.20	4.00	0.80	1.80
8	14.20	2.30	6.00	5.60	0.60	2.30
9	9.60	2.66	5.60	7.20	0.40	2.60
10	13.60	4.60	6.50	13.00	0.40	2.00
11	12.32	7.66	4.80	11.00	0.40	1.30
12	11.80	11.40	6.50	10.00	0.50	2.00
13	11.60	14.55	6.20	10.20	0.20	4.00
14	12.80	18.66	5.80	12.00	0.30	3.30
15	9.00	26.00	4.20	14.30	0.40	2.00
16	8.30	32.00	7.80	12.30	0.30	1.30
17	6.20	24.00	5.60	15.60	0.20	0.30

Table 2. Incidence of natural enemies in tomato field in different SMW

SMW	Natural enemies				
	[1]Coccinellids/ Plant	[2]Spiders / Plant	[3]Red ant/ Plant	Damselfly / Plot	Rove beetle/ Plant
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.80	0.80	0.80	0.40	0.20
4	1.20	0.80	0.68	0.00	0.10
5	2.80	3.20	0.60	0.00	0.20
6	2.60	3.60	0.26	0.30	0.20
7	3.00	4.40	2.00	0.20	0.20
8	3.30	3.30	1.30	0.30	0.10
9	3.00	2.40	1.80	0.20	0.20
10	3.40	2.20	1.20	0.00	0.00
11	2.60	1.80	1.40	0.60	0.60
12	2.30	1.80	2.00	0.00	0.20
13	2.00	1.80	1.20	0.20	0.20
14	3.20	2.20	0.60	0.30	0.60
15	2.20	0.80	1.00	0.60	1.00
16	1.20	0.60	0.60	0.40	0.30
17	0.60	0.80	0.60	0.20	0.20

[1]five species, [2]six species, [3]one species

Table 3. Correlation studies between pests, pollinators and natural enemies of tomato with weather parameters

Pests, natural enemies and pollinators	T_{Max}	T_{Min}	T_{Mean}	RH% Morning	RH% Evening	RH% Mean	RF	BSH
Whitefly	0.137	0.026	0.078	-0.355	-0.646**	-0.491*	-0.163	0.487
Leaf miner	0.842**	0.908**	0.893**	-0.611	-0.338	-0.516*	0.174	0.091
Flea beetle	0.436	0.495*	0.476	-0.477	-0.427	-0.472	-0.033	0.189
Fruit borer	0.930**	0.831**	0.898**	-0.744**	-0.369	-0.641*	0.090	-0.003
Carpenter bee	-0.737**	-0.769**	-0.770**	0.378	0.011	0.244	-0.116	0.405
Honey bee	0.219	0.163	0.192	-0.349	-0.548*	-0.460	0.192	0.165
Spiders	-0.534*	-0.613*	-0.589*	0.128	-0.264	-0.027	-0.126	0.495*
Coccinellids	-0.122	-0.301	-0.224	-0.172	-0.614*	-0.360	0.129	0.524*
Red ant	-0.074	-0.131	-0.107	-0.122	-0.467	-0.268	0.274	0.673*
Rove beetle	0.558*	0.491*	0.532*	-0.314	-0.261	-0.305	0.318	0.112
Damselfly	0.331	0.329	0.337	-0.263	-0.073	-0.196	0.230	0.197

(at 5% level of significance, **at 1% level of significance)*

(T_{Max} – Maximum temperature, T_{Min} – Minimum temperature, T_{Mean} – Mean temperature, RH% Morning – Morning relative humidity, RH% Evening - Evening relative humidity, RH% Mean- Mean relative humidity, RF – Rainfall, BSH - Bright Sunshine Hours)

Table 4. Multiple effect of abiotic parameters on the incidence of pests, natural enemies and pollinators in tomato ecosystem

Sl. No	Pests, natural enemies and pollinators	Regression	Equation	R^2	F-Value
1.	Whitefly	Multiple	Y= 28.164 -0.355 X1 + 0.278 X2 + 0.294 X3 - 0.711 X4 – 2.155 X5 – 0.066 X6	0.727	4.447*
		Stepdown	Y= 18.042 + 0.300 X3 - 0.658 X4 - 2.005 X6	0.707	10.468**
2.	Leaf miner	Multiple	Y= 8.939 -0.478 X1 + 1.839 X2 - 0.704X3 + 0.705X4 + 3.095 X5 – 0.354 X6	0.876	11.732**
		Stepdown	Y= -25.295 + 1.972 X2	0.822	69.473**
3.	Flea beetle	Multiple	Y= 21.655 -0.436 X1 + 0.345 X2 - 0.049X3 – 0.091X4 – 0.201 X5 – 0.156 X6	0.472	1.488
		Stepdown	Y= 3.569 – 0.109 X2	0.245	4.870*
4.	Fruit borer	Multiple	Y= - 12.460 + 0.606 X1 + 0.234 X2 - 0.250 X3 + 0.124 X4 + 1.773 X5 + 0.539 X6	0.947	29.58**
		Stepdown	Y= 0.937 - 0.028 X2	0.592	18.824**
5.	Carpenter bee	Multiple	Y= 1.127 -0.036 X1 + 0.009 X2 + 0.010 X3 - 0.014 X4 – 0.074 X5 + 0.066 X6	0.799	5.285*
		Stepdown	Y= 0.937 – 0.028 X2	0.592	18.824**
6.	Honey bee	Multiple	Y= 12.987 -0.206 X1 + 0.187 X2 + 0.076 X3 - 0.278 X4 + 0.103 X5 – 0.344 X6	0.604	2.033*
		Stepdown	Y= 5.274 – 0.101 X4	0.341	6.724*
7.	Coccinellids	Multiple	Y= 3.425 + 0.007 X1 + 0.002 X2 + 0.122 X3 - 0.250X4 – 0.120 X5 + 0.036 X6	0.760	4.00*
		Stepdown	Y= 4.189 + 0.115X3 - 0.248X4	0.746	17.604**
8.	Spiders	Multiple	Y= 9.994 -0.283 X1 + 0.121 X2 + 0.088 X3 – 0.195 X4 – 0.616 X5 + 0.310 X6	0.726	3.525*
		Stepdown	Y= 4.929 – 0.160 X2	0.373	7.743*
9.	Red ant	Multiple	Y= 0.206 -0.092 X1 + 0.112 X2 + 0.066 X3 – 0.101X4 – 0.036 X5 + 0.283 X6	0.697	3.072*
		Stepdown	Y= -0.925 + 0.309 X6	0.457	10.931**
10.	Damselfly	Multiple	Y= - 0.641 + 0.013 X1 - 0.007 X2 - 0.020 X3 + 0.034X4 + 0.124 X5 + 0.063 X6	0.342	0.692
		Stepdown	Y= -0.925 + 0.309 X6	0.312	0.931
11.	Rove beetle	Multiple	Y= -3.321 + 0.085 X1 - 0.021 X2 + 0.016 X3 – 0.006X4 + 0.100 X5 + 0.028 X6	0.457	1.123*
		Stepdown	Y= - 1.032 + 0.038 X6	0.301	5.842*

(at 5% level of significance, **at 1% level of significance)*

(X1 = Maximum temperature, X2 = Minimum temperature, X3 = RH% morning, X4 = RH% evening, X5 = Rainfall, X6 = Bright sunshine hour)

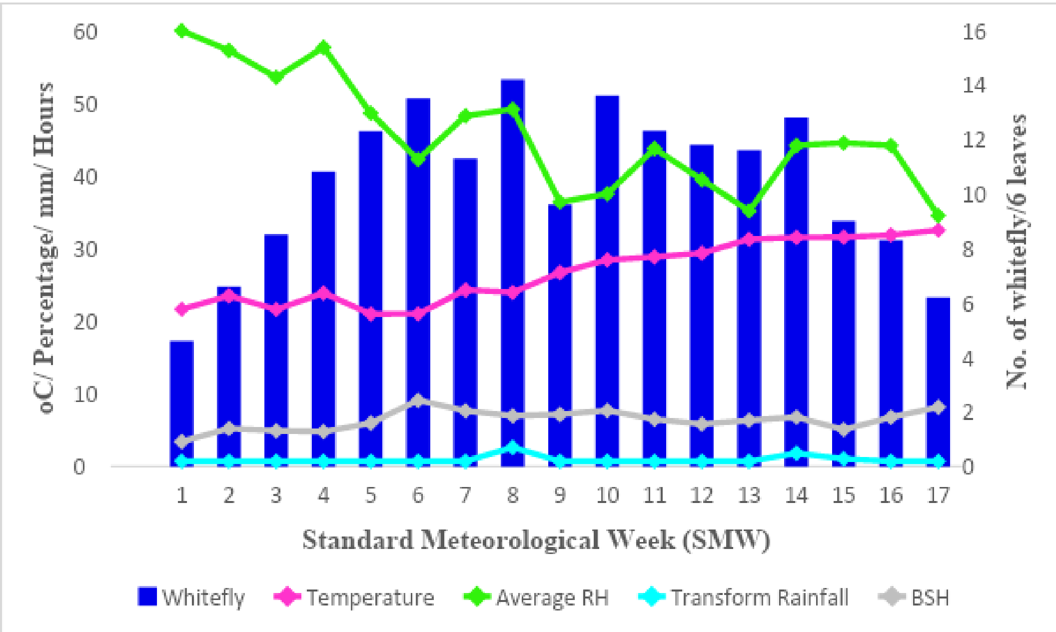

Fig. 1. Population fluctuation of whitefly in different SMW during 2020-21

The present findings are similar to those of Ashfaq et al*.* (2010), Kaur et al*.* (2010), and Sarangdevot et al. (2010) [17,18,19], who observed that the whitefly abundance was positively correlated with average temperature and negatively correlated with average relative humidity. The positive correlation between temperature and whitefly population can be related to the enhanced rate of development and reproductive success of whitefly, and it has been noticed that whitefly oviposition behaviour is the highest between 33 to 37°C temperature. Weekly whitefly population numbers exhibited a positive correlation with rainfall but a significant negative correlation with relative humidity [20]. The negative relationship between the whitefly population and relative humidity, and rainfall was associated with a number of factors. Rains ultimately influenced the behaviour of *B. tabaci* adults, especially when massive showers and wind gusts were prevalent on a regular schedule. Cooler weather, high relative humidity, and rain had a negative impact on whitefly abundance and their distribution. As a natural consequence, either through agronomic alteration or chemical control, an approach to minimise pest and disease incidence were formulated. *B. tabaci* was prevalent from one week after transplanting and continued to remain throughout the period [21]. During the years 2005 and 2006, Hasan et al*.* (2008) [22] observed that the 60-day-old crop had the highest whitefly population and the 30-day-old crop had the least. According to regression analysis, all six seasonal variations accounted for 72.70 per cent of difference, whereas step-down regression evaluation revealed that the morning relative humidity, evening relative humidity, and BSH combined accounted for 70.70 per cent of alteration in whitefly abundance in the tomato ecology (Table 4).

3.1.2 Leaf miner

The population of leaf miners, *Liriomyza trifoli,* was observed from the 1st SMW and persisting till the 17th SMW. The population of leaf miners per plant usually ranged from 0.3 to 32.00 leaf miners (Table-1 and Fig. 2). It attained the peak during 16th SMW, when the maximum, minimum, and mean temperature, morning, evening, and mean RH, transformed rainfall, and BSH were 39.59°C, 24.06°C, 31.82°C, 50.57%, 37.71%, 44.41%, 0.71 mm and 6.76%, respectively. These findings are in line with those of Chaudhuri et al*.* (2001), Marcano and Issa (2000) and Asalatha (2002) [15,23,24], who found that *Liriomyza* sp. is a major tomato insect pest. The highest (76.67%) leaf infestation by *L. trifolii* was noticed in the middle of March [25]. The results are also consistent with those of Nitin et al*.* (2017) [26], who observed that *T. absoluta* intensity reached at its peak (30-100 larvae/plant) throughout March-April, and the infestations did not reach 25 larvae/plant during October-November. The maximum prevalence of *L. trifolii* on tomato, was noted during March–April, which interfered with the vegetative and reproductive crop growth stages [27].

The population of *L. trifolii* had a significant positive correlation with maximum, minimum, and mean temperature (r = 0.842, r = 0.908, and r = 0.893, respectively) but nonsignificant positive correlation (r= 0.174 and r = 0.091, respectively) with rainfall and BSH. Morning and mean RH had a significant negative correlation (r= -0.611 and r = -0.516, respectively), whereas the evening RH had a non-significant negative correlation (r= -0.338). The findings of Selvaraj et al. (2016) [28], who observed a significant negative correlation between pest population and maximum and average relative humidity, are similar to the present findings. According to Variya and Patel (2012) [29], the number of mines and larvae were found to be significantly and negatively correlated with evening relative humidity. Senguttuvan (1999) [30] observed a significant and positive relationship between leaf miner population and maximum temperature (Table 3). In step-down regression analysis, only minimum temperature contributed to 82.20 per cent variation in leaf miner abundance in tomato ecosystem, whereas regression analysis showed that all six weather parameters were responsible for 87.60 per cent variation (Table 4).

3.1.3 Flea beetle

The tomato flea beetle was first seen in the 1st SMW and continued until the 17th SMW. The highest population of 7.80 insects per plant was recorded in the 16th SMW, when the maximum, minimum, and mean temperature, morning, evening, and mean RH, transformed rainfall, and BSH were 39.95°C, 24.06°C, 31.82°C, 50.57%, 37.71%, 44.41%, 0.71 mm and 6.76 hrs, respectively (Table 1 and Fig. 3).

It had a significant positive relationship (r = 0.495) with minimum temperature but nonsignificant correlation with maximum and mean temperature, morning, evening and mean RH, rainfall and BSH (Table 3). Suresh (2006) [6] observed a relationship between tomato flea beetle population and maximum, minimum and average relative humidity and rainfall (r= -0.477, r= -0.472, r = -0.472, r = -0.689, and r= -0.033, respectively). In step-down regression analysis, only minimum temperature contributed to 24.50 per cent variation in the abundance of flea beetle in tomato ecosystem, whereas regression analysis showed that all six weather parameters are responsible for 47.20 per cent variation (Table 4).

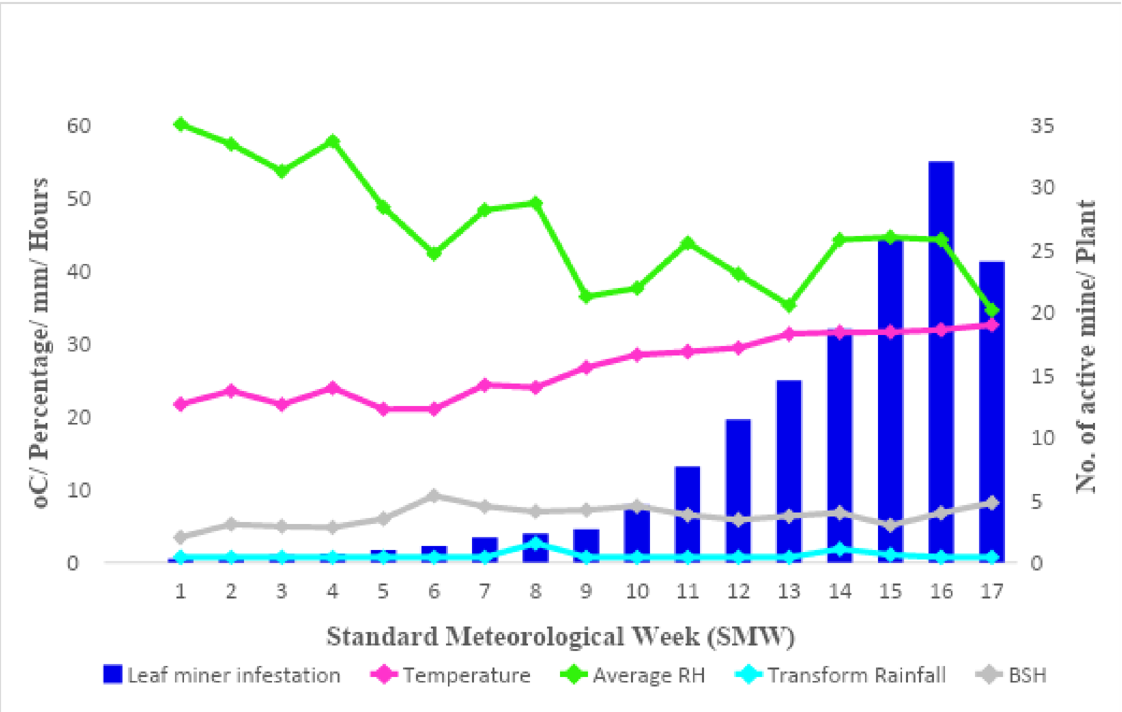

Fig. 2. Population fluctuation of leafminer in different SMW during 2020-21

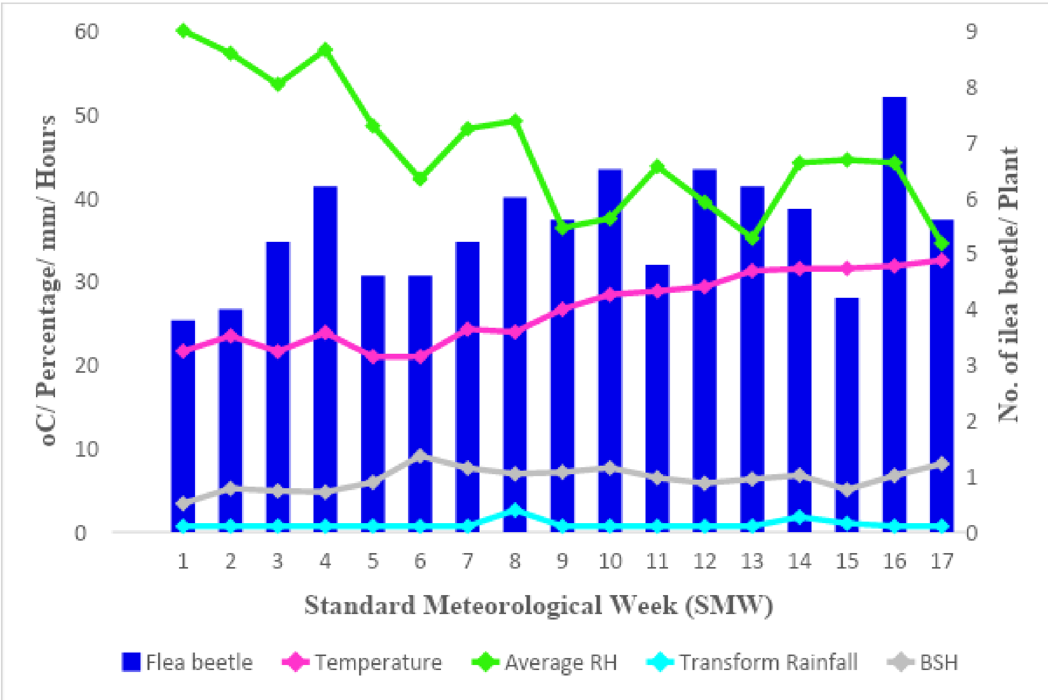

Fig. 3. Population fluctuation of flea beetle in different SMW during 2020-21

3.1.4 Fruit borer

The tomato fruit borer, *Helicoverpa armigera* was observed between the 5th (1.80 larva/plant) and the 17th SMW (15.06 larva/plant). It attained the peak during the 16th SMW (15.06 larva/plant), when the maximum, minimum, and mean temperature, morning, evening and mean RH, transformed rainfall, and BSH were 39.95°C, 24.06°C, 31.82°C, 50.57%, 37.71%, 44.41%, 0.71 mm, and 6.76 hrs, respectively (Table 1 and Fig. 4). The pest was prevalent, throughout the reproductive cycle of the crop, causing circular or irregular holes within the fruit. The present findings are in line with the findings of Reddy and Kumar (2004) [5], who found that the *H. armigera*, was active from March to April. Kharpuse and Bajpai (2006) [31] reported a higher fruit borer population in the third week of February throughout Rabi 2004-05. According to Pandey et al. (2012) [32], *H. armigera* populations reached at its peak in March. The peak period of *H. armigera* larval population occurred in April, (Yadav, 1980) [33]. According to Lal and Lal (1966) [34], the tomato fruit borer infestation peaked in late March. *H. armigera* was abundant from March to May with a peak population in April (Pandey et al. 1997) [35]. Mahapatra et al. (2007) [36] observed a higher population of the pest in March and April. Ravi and Verma (1997) [37] noticed the pest in the first week of January, and the population peaked in the middle of March. It had a significant positive correlation with maximum, minimum, and mean temperature (r = 0.930, r = 0.831, and r = 0.898, respectively). Evening RH and BSH had a nonsignificant negative correlation (r= -0.369 and r = -0.003), while morning and mean RH had a significant negative correlation (r= -0.744 and r = -0.641, respectively). Rainfall and temperature had a nonsignificant positive correlation (r=0.090) (Table 3).

The present findings are similar to those of Sharma and Chaudhari (1997) [38], who found that temperature had a positive impact on *H. armigera* population growth on tomato plants. Devi et al. (1991) [39] observed that *H. armigera* populations thrive at a maximum temperature of 25.9-27.5°C. The *H. armigera* larval population grew steadily from 1st April to 12th April [40]. In regression analysis, all six weather variables are accountable for 94.70% of the variation, whereas step-down regression analysis revealed that only minimum temperature contributed to 59.20 per cent of variation in fruit borer abundance in the tomato ecosystem (Table 4).

3.2 Natural Enemies

3.2.1 Coccinellid

A group of predatory coccinellid beetles, *Coccinella septempunctata*, *Cheilomenes* *sexmaculatus* and *Coccinella transversalis* were noticed in the 3rd SMW, with a population of 0.80 beetles per plant, and attained the peak at 3.40 beetles per plant during the 10th SMW, when the maximum and minimum temperature, morning and evening RH were 37.74°C, 19.06°C, 46.71% and 28.29%, respectively (Table 2 and Fig. 5).

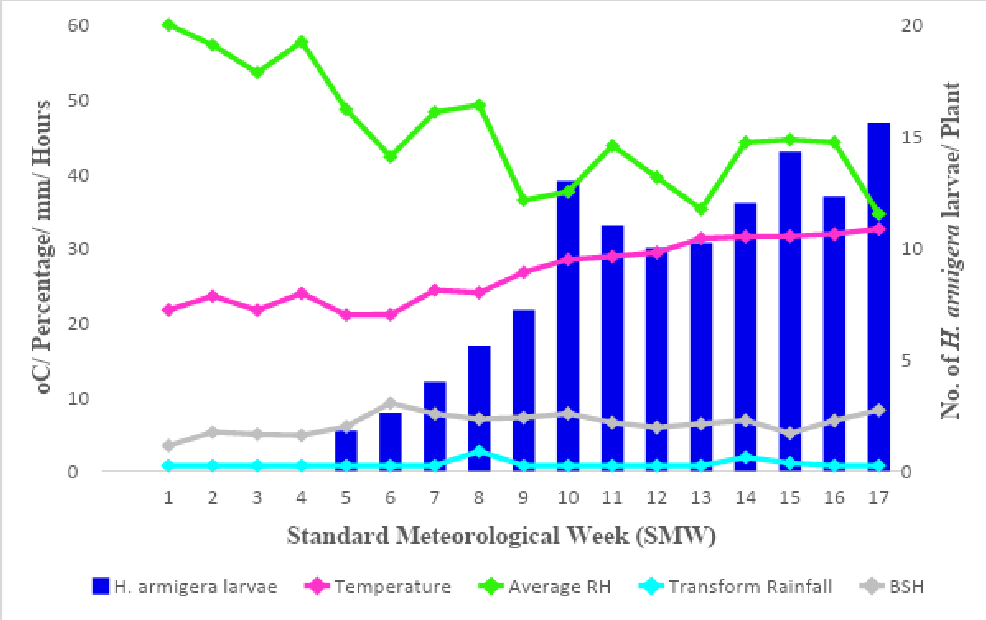

Fig. 4. Population fluctuation of *H. armigera* in different SMW during 2020-21

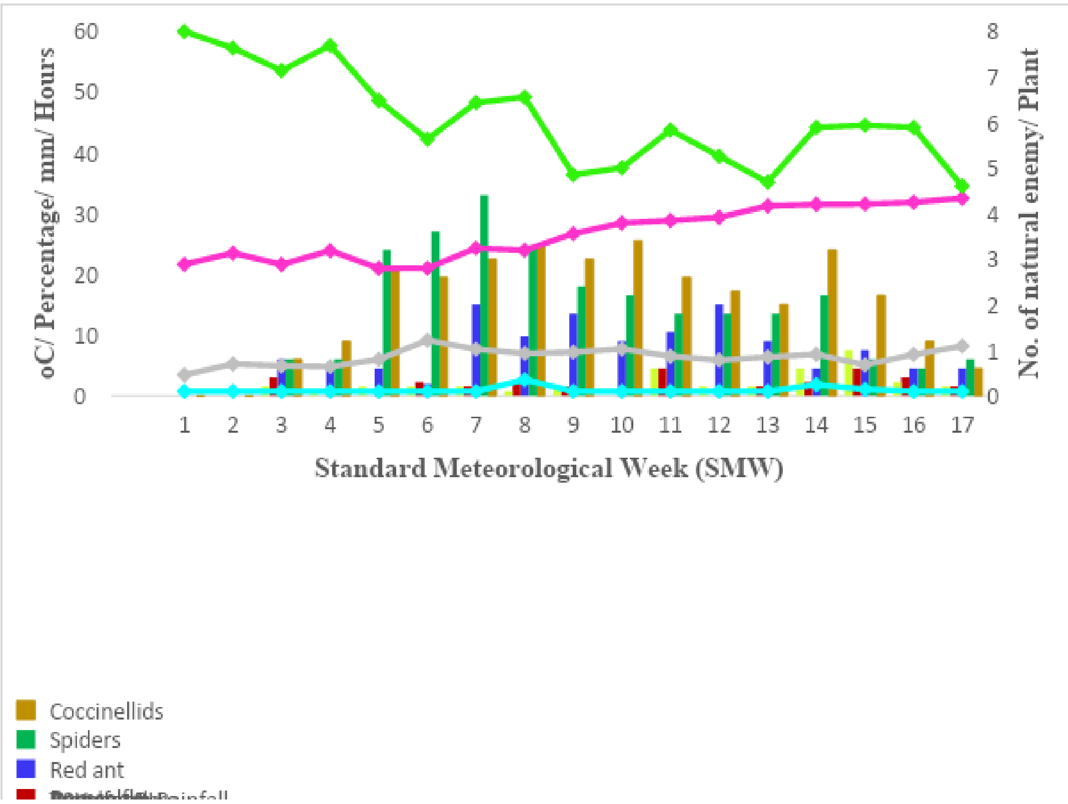

Fig. 5. Population fluctuation of natural enemies at different SMW during 2020-21

The coccinellids had a significant positive correlation with BSH (r = 0.524) and a significant negative correlation with evening RH (r = -0.614). The larva and adults of the ladybird beetle are predators. They ate the nymphs and adult of soft-bodied insects like aphids, jassids, and whiteflies. The coccinellid population was primarily dependent on the presence of soft-bodied insects in the field as well as the relative humidity and BSH (Table 3). In step-down regression analysis, only maximum relative humidity and minimum relative humidity together contributed to 74.6 per cent variation in abundance of coccinellids in tomato ecosystem, whereas regression analysis showed that all six weather parameters were responsible for 76.0 per cent variation (Table 4).

3.2.2 Spider

The spiders, lynx, *Oxyopes* sp., jumping, *Phiddipus* sp., wolf, *Marpissa* sp. were emerged in the 3rd SMW, with a population of 0.80 spiders per plant. The population attained its peak at 4.40 spiders per plant during the 8th SMW, when the maximum and minimum temperature, morning and evening RH were 32.17°C, 15.69°C, 64.71% and 34.29%, respectively (Table 2 and Fig. 5). It had a significant positive correlation with BSH (r = 0.495) but a significant negative correlation with maximum, minimum, and mean temperature and morning RH (r = -0.534, r = -0.613, r = -0.589, and r = 0.128, respectively). The existence of hemipteran and dipteran insects in the field was critical for the spider population (Table 3). According to regression analysis, all six weather variables were responsible for 72.6 per cent of the variation, whereas step-down regression analysis revealed that only the minimum temperature was responsible for 37.3 per cent of the variation in spider abundance in the tomato ecosystem (Table 4).

3.2.3 Red ant

The red ant, *Solenopsis* sp. was first emerged in the 3rd SMW with a population of 0.80 per plant. It attained the peak at 2 per plant during the 7th SMW, when the maximum and minimum temperature, morning and evening RH were 32.0°C, 16.0°C, 60.86% and 35.57%, respectively (Table 2 and Fig. 5). The red ant population had a significant positive correlation with BSH (Table 3). In the field, red ants rely primarily on insects, spiders, arthropod eggs, and ticks. According to regression analysis, all six weather variables were responsible for 69.7 per cent of the variation, whereas step-down regression analysis revealed that only BSH contributed to 45.7 per cent of the variation in red ant number in the tomato ecosystem (Table 4).

3.2.4 Rove beetle

The rove beetle, *Paederus* sp. was first emerged in the 3rd SMW, with a population of 0.20 per plant. The population attained its peak at 0.60 per plant in the 10th SMW, when the maximum and minimum temperature, morning and evening RH were 37.74°C, 19.06°C, 46.71% and 26.29%, respectively (Table 2 and Fig. 5). It had a significant positive correlation with maximum, minimum, and mean temperature (r = 0.558, r = 0.491, and r = 0.532, respectively) (Table 3). The occurrence of tiny insects and mites in the field was essential for its survival. In step-down regression analysis, only BSH contributed to 30.1 per cent variation in rove beetle abundance in tomato ecosystem, whereas regression analysis showed that all six weather parameters were responsible for 45.7 per cent variation (Table 4).

3.2.5 Damselfly

The damselfly was first emerged in the 3rd SMW, with a population of 0.40 per plant. The population attained its peak at 0.60 per plant in the 10th SMW, when the maximum and minimum temperature, morning and evening RH were 37.74°C, 19.06°C, 46.71% and 26.29%, respectively (Table 2 and Fig. 5). The damselfly population had a non-significant positive correlation with maximum, minimum, and mean temperature, rainfall and BSH (r = 0.331, r = 0.329, r = 0.024, r = 0.337, r = 0.230 and r = 0.197, respectively) but a non-significant negative correlation with evening and mean RH (r = -0.263, r = -0.073 and r = -0.196, respectively) (Table 3). Its population was prevalence on the existence of small flying insects in the field. It had no direct effect on weather parameters in the field population. In step-down regression analysis, only BSH contributed to 31.2 per cent variation in damselfly abundance in tomato ecosystem, whereas regression analysis showed that all six weather parameters were responsible for 34.2 per cent variation (Table 4).

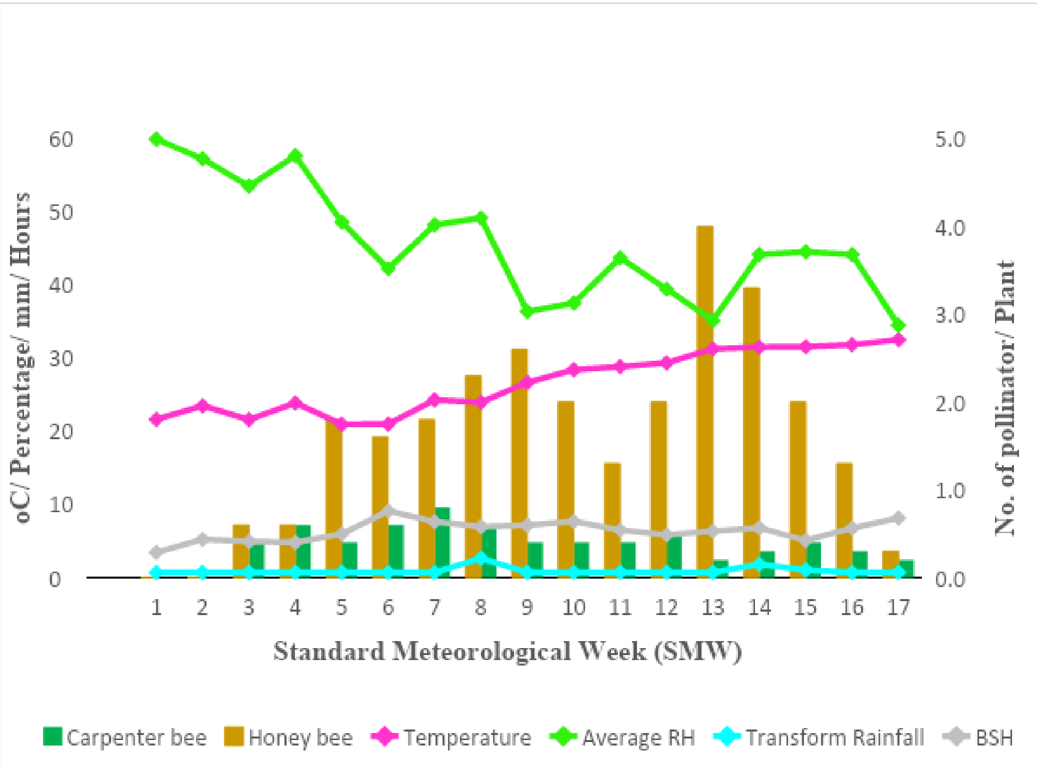

Fig. 6. Population fluctuation of pollinators in different SMW during 2020-21

3.3 Pollinators

3.3.1 Carpenter bee

The flower-visiting Carpenter bees, *Xylocopa* sp. were emerged in the 3rd SMW, with a population of six per plot, and peaked at twelve per plot in the 7th SMW (Table 1). It was the most abundant during the peak of blooming. It had a significant negative correlation with maximum, minimum, and mean temperatures (r = -0.737, r = -0.769, and r = -0.770, respectively) (Table 3). In regression analysis, all six weather variables were responsible for 79.9% of the variation, whereas step-down regression analysis revealed that only the minimum temperature contributed to 59.2% of the difference in carpenter bee abundance in tomato ecosystem (Table 4).

3.3.2 Honey bee

The flower-visiting honey bees, *A. mellifera, A. dorsata* and *A. cerena indica,* were monitored throughout the blooming stage of the tomato crop. It was first appeared in the 3rd SMW with a population of 8 per-plot, and peaked at 30 in the 13th SMW (Table-1). It was the most abundant during the maximum of blooming. It had a significant negative correlation (r = -0.548) with evening RH (Table 3). In regression analysis, all six weather variables accounted for 60.4 per cent of the variation, whereas step-down regression analysis revealed that only BSH accounted for 34.1 per cent of the variation in honey bee population in the tomato ecosystem (Table 4).

4. CONCLUSION

The major pests recorded on tomato were tomato fruit borer, serpentine leaf miner, whitefly while flea beetle was of minor significance. Tomato field was abundant in natural enemies, *C. septempunctata*, *C. transversalis*, *C. sexmaculata* and *Micraspis* sp., spiders, jumping, *Phiddipus* sp., lynx, *Oxyopes* sp. and wolf, *Marpissa* sp., praying mantis, *H. membranacea* (Giant asian mantis) and *M. religiosa inornata* (European mantis) and one species each of rove beetle, *Paederus* sp., red ant, *Solenopsis* sp., dragonfly (red body) and damselflies (blue, brick red and black body). The population of the pests and natural enemies were greatly effected by the prevailing environmental condition. Among pollinators carpenter bee was the most frequent floral visitor and considered the main pollinator of tomato. The pollinators appeared in higher numbers during the blooming period and was the dominant species found in the field.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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