International Journal of Environment and Climate Change

Volume 13, Issue 5, Page 276-289, 2023; Article no.IJECC.98196
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Seasonal Incidence of Insect-pests, Natural Enemies and Pollinators of *Solanum melongena* L. and Correlation between Their Daily Occurrences with Weather Parameters

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Authors' contributions

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

Article Information

DOI: 10.9734/IJECC/2023/v13i51769

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/98196

Original Research Article

Received: 27/01/2023
Accepted: 29/03/2023
Published: 31/03/2023

ABSTRACT

The investigation was carried out at K.V.K Instructional Farm of Bhawanipatna, Kalahandi, Odisha, India during the cropping season 2020-21. Brinjal shoot and fruit borer (BSFB), whitefly, and jassid were the most significant pests found in brinjal, *Solanum melongena* L. while epilachna beetle was of minor importance as it was found in much lower numbers and caused less damage. They were found from 2nd to 16th Standard Meteorological Week (SMW). The population of whitefly had significant negative correlation with morning, evening and mean Relative Humidity (RH). There was a significant negative correlation of population of jassids with evening and mean RH but significant

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positive correlation with bright sunshine hours. The population of epilachna had significant negative correlation with morning, evening and mean RH but positive correlation with maximum, minimum and mean temperature. BSFB infestation on fruit had significant negative correlation with morning, evening and mean RH but positive correlation with maximum and mean temperature. There was a significant positive correlation of BSFB infestation on shoot with maximum, minimum and mean temperature but significant negative correlation with rainfall. The natural enemies found in brinjal ecosystem from 4th to 16th SMW and belonged to ladybird beetles, spiders, preying mantids, black ant, carabid beetle, syrphid flies, damselfly and chrysopids. The population of spiders had significant negative correlation with evening and mean RH but positive correlation with bright sunshine hours. There was a significant negative correlation of population of coccinellids with evening RH. The pollinators recorded from experimental field were honeybee and carpenter bee from 3rd to 16th SMW. Among them, carpenter bee, *Xylocopa* sp. was the most dominant visitor of brinjal flower in the field and was identified as potentially important in brinjal. The pollinators appeared in higher numbers during the blooming period and was the dominant species found in the field. The population of honey bees had significant negative correlation with evening RH.

Keywords: Insect pests; natural enemies; pollinators; seasonal incidence; Solanum melongena; weather parameters.

1. INTRODUCTION

Vegetable farming plays an important role in Indian agriculture due to nutritional, medicinal, and land-commercial value of vegetables [1]. Brinjal, *Solanum melongena* L., also known as egg-plant or aubergine or guinea squash, is the most popular and important vegetable crop in the world, earning it the title of "king of vegetables." It belongs to the nightshade family Solanaceae and is native to Asia [2]. India is one of the world's largest brinjal producers, with an area of 0.71 million hectares and a production of 13.56 million tons [3]. The major brinjal growing states in India are Andhra Pradesh, Karnataka, West-Bengal, Tamil Nadu, Maharashtra, Odisha, Uttar Pradesh, Bihar and Rajasthan. Brinjal fruits are rich in calcium, phosphorus, iron, and vitamins [4]. Several factors influence the yield, or the amount of harvested crop product in a given area. Insect pests are one of the major factors effecting the yield [5]. Brinjal is attacked by a variety of insect pests, shoot borer, *Leucinodes orbonalis*, aphids *Aphis gossypii*, leaf miner *Phytomyza atricornis*, white spotted flea beetles *Monolepta signat* and *Chaetocnema basalis*, whitefly *Bemisia tabaci*, thrips *Thrips palmi*, spider mite *Tetranychus urticae*, jassids *Amrasca biguttula bigutulla*. Minor pests like leaf roller and hairy caterpillar are also considered the main constraints as they damage the crop throughout the year [6]. 70-92% reduction of yield occurs due to the major pests attacking Egg-plant [7]. The most destructive of these is the brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee [8]. Ladybird beetles, ground beetles, lacewings, praying mantids, spiders, earwigs, predatory bugs, syrphid flies, *Trathala*, true bugs, predatory flies, predatory mites, and other natural enemies are frequently active and play an important role against insect pests of brinjal in the cultivating field. Spiders, ladybird beetles, and black ants are among the most common predators [9]. Brinjal flowers are monoecious and they can pollinate themselves as well as by others. These flowers self-pollinate and produce fruits when pollinators are scarce. Cross- pollination, on the other hand, has been shown to increase fruit set when compared to self-pollinating plants due to heterosis [10]. Vibration is required for pollen release in brinjal flowers. In open conditions, wind can pollinate brinjal flowers, but in polyhouses, pollination by other insects, such as carpenter bees, is required. Carpenter bees and honey bees can work together to pollinate brinjal. The loss of insect pollinators as a result of agricultural intensification may have a negative impact on brinjal production [11]. A thorough knowledge of seasonal activity of insect-pest helps in developing efficient pest management strategies in a particular set of agro-climatic conditions. Information on the incidence of insect pests, natural enemies and pollinators of brinjal crop ecosystem, particularly in this agro-climatic situation in the recent past, is too little. Therefore, the present investigation was carried out to study the seasonal incidence of insect pests, natural enemies and pollinators.

2. MATERIALS AND METHODS

The present investigation was carried out at K.V.K Instructional Farm of Bhawanipatna, Kalahandi, Odisha during the cropping season 2020-21 from November, 2020 to May, 2021.

The experimental field was prepared by cross ploughing with a tractor drawn cultivator, followed by harrowing and planking. Weed and crop residues were removed to achieve a weed and stubble-free field. Seeds of brinjal (*Var.* VNR-212) were sown in a green-house plugged chamber on November 25, 2020. After 25 days, seedlings were transplanted in the well pulverised main field with a row to row and plant to plant spacing of 70 × 45 cm. The crop received the recommended fertiliser dose of 120:80:60 kg N, P, and K per hectare. The 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 was used as a non-selective herbicide and one manual hand weeding was done at 25 DAT to keep the experimental plots weed-free. After 131 days of sowing, harvesting was done manually *i.e.* from March 4, 2021 to April 29, 2021. A total of nine plucking of brinjal fruits were done until final harvest.

2.1 Brinjal Pests

Three leaves from each sampled plant's upper, middle, and lower canopies were selected and examined very carefully and minutely with a hand lens (10x) for the presence of insects. In each replication, the mean population of insects was expressed as the numbers of insects/leaf/plant. Visual search and hand picking were the most common methods for collecting insect pests. Following [12-14] observation commenced from the first week after transplantation of one- month-old seedlings and lasted until harvest. For observation on the number of insect pests, four plants per plot were randomly selected excluding the peripheral ones. For epilachna, all the leaves of the four plants were examined and all stages were counted altogether. For whitefly and jassid, three leaves (upper, middle and lower canopy zones) per plant @ four plants/plot were observed. All the observations were taken at 7 days interval starting from 50 DAT (2^{nd} SMW). For fruit and shoot borer infestation, all the shoots of four plants/plot were examined at weekly interval and the means were worked out. Fruit damage was recorded at each harvest and larval counts and bore hole counts were also taken at the same time.

2.2 Natural Enemy Complex Usually Found in Brinjal Field

Natural enemies include general predators like spiders, coccinellids, wood ant and chrysopid. Immature and mature stages were counted altogether. Mixed populations of predatory coccinellids like *Cheilomenes sexmaculata* (Fab.), *Coccinella septempunctata* (L.), *Coccinella transversalis* (Fab.) and *Micraspis* sp. Mature and immature stages were counted altogether. Mixed population of common spiders found included lynx (*Oxyopes* sp.), jumping (*Phiddipus* sp.) and wolf (*Marpissa* sp.) were counted altogether; for damselfly, score was based on number/plot during observation; for praying mantids like *Mantis religiosa inornata* (Werner) (European mantis) and *Hierodula membranacea* (Burmeister) (Giant asian mantis), rove beetle (*Paederus* sp.), wood ant (*Tetraponera* sp.) and red ant (*Solenopsis* sp.), 4 plants/plot were randomly selected and the number/plant was worked out, taken at 20 days interval starting from 50 DAT (2^{nd} SMW).

2.3 Pollinators in Brinjal Field

For pollinators, total numbers of bees visiting a plot were observed continuously for ten minutes and the means were worked out. Four species of common bees (Rock bee - *Apis dorsata* Fabr., Indian honey bee - *Apis cerana indica* Fabr., European honey bee - *Apis mellifera* L. and one carpenter bee, *Xylocopa* sp.; Apidae, Hymenoptera) may be found in the experimental fields and these were counted as mixed population altogether. Record of pollinators were taken at 20 days interval from randomly selected 4 plants per plot starting from 50 DAT (2^{nd} Standard Meteorological Week). Collected data were analysed using correlation and regression.

The data recorded was calculated using the following formula:

% plant/shoot/fruit infestation = (Number of infested plant/shoot/fruit ÷ Total number of plant/shoot/fruit) × 100

3. RESULTS AND DISCUSSION

3.1 Insect Pests

3.1.1 Whitefly

The activity of whitefly, *B. tabaci,* was started from 2^{nd} SMW and continued up to 16^{th} SMW (Table 1). The whitefly population varied from 6.0 to 20.0 whiteflies/3 leaves per plant. The peak population of *B. tabaci* was 20.0 whiteflies/3 leaves/plant which was recorded during 12^{th} SMW, when the maximum, minimum and mean

Table 1. Incidence of different pests and pollinators in brinjal in different SMW

SMW	Insect pests					Pollinators	
	Whitefly/ 3 leaves	Epilachna (adult)/ Plant	Jassid/ 3 leaves	BSFB shoot infestation percentage	BSFB fruit infestation percentage	Carpenter bee/Plot	Honey bee/Plot
2	6.00	0.50	1.50	0.00	0.00	0.00	0.00
3	7.50	1.00	2.50	0.00	0.00	0.25	0.00
4	7.25	1.75	3.50	2.66	0.00	25.00	1.00
5	8.25	2.75	4.00	5.00	0.00	0.33	1.33
6	12.75	3.25	11.40	7.36	0.00	0.40	2.00
7	12.50	4.75	18.00	13.00	0.00	0.50	2.50
8	12.75	5.75	22.00	15.20	4.50	0.66	3.00
9	14.75	6.00	26.00	18.60	8.50	0.75	3.60
10	16.50	7.50	19.20	20.00	15.20	1.00	4.00
11	19.00	9.75	21.00	18.20	16.20	0.60	4.50
12	20.00	12.00	11.20	14.20	18.30	50.00	2.50
13	14.25	13.25	8.20	16.20	10.20	0.33	2.00
14	11.25	12.75	12.80	12.20	14.40	0.25	2.50
15	6.75	13.00	13.40	10.20	15.50	0.13	1.00
16	5.75	10.50	10.60	13.60	16.80	0.00	0.25

Table 2. Incidence of different pollinators in brinjal in different SMW

SMW	Natural enemies				
	[1]Coccinellids/ Plant	[2]Spiders/ Plant	[3]Wood ant /Plant	Damselfly/ Plant	[4]Chrysopids /Plant
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	1.25	3.00	2.00	0.25	0.25
5	1.75	3.30	2.00	0.25	0.20
6	2.55	5.60	3.00	0.15	0.13
7	3.75	4.00	3.00	0.25	0.25
8	3.00	5.00	2.00	0.35	0.30
9	2.66	6.50	2.50	0.50	0.20
10	3.75	7.50	1.50	0.25	0.50
11	3.50	5.80	2.00	0.33	0.35
12	3.00	4.60	2.50	0.33	0.40
13	2.00	4.00	3.25	0.25	0.50
14	2.20	4.60	2.60	0.13	0.35
15	1.60	3.60	2.00	0.00	0.25
16	1.00	4.20	3.00	0.00	0.00

[1]five species, [2]six species, [3]one species and [4]one species

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

Insect pest, pollinators and naturalenemies	$T_{Max.}$	$T_{Min.}$	T_{Mean}	M.R.H.%	E.R.H.%	Mean RH%	RF	B.S.H.
Whitefly	0.300	0.167	0.233	-0.545*	-0.78**	-0.664**	-0.003	0.442
Jassid	0.340	0.250	0.297	-0.487	-0.643**	-0.572*	0.327	0.577*
EpilachnaBeetle	0.901**	0.917**	0.929**	-0.750**	-0.523*	-0.689**	0.172	0.073
BFSB fruitinfestation	0.548*	0.725*	0.693*	-0.312	0.253	-0.092	-0.596*	-0.349
BFSB shootinfestation	0.585*	0.421	0.508*	-0.688**	-0.670*	-0.721**	0.082	0.321
Carpenter bee	0.068	0.103	0.089	-0.002	-0.012	-0.006	-0.153	-0.295
Honey bee	0.066	-0.077	-0.012	-0.246	-0.631*	-0.411	0.119	0.386
Spiders	0.199	-0.065	0.056	-0.494	-0.714**	-0.609*	-0.007	0.633*
Coccinelids	-0.116	-0.179	-0.154	-0.166	-0.505*	-0.309	0.069	0.519*
Wood ant	0.189	0.079	0.132	-0.277	-0.219	-0.270	-0.190	0.342
Chrysopids	0.336	0.256	0.299	-0.292	-0.457	-0.374	0.097	-0.132
Damselfly	-0.239	-0.421	-0.347	0.000	-0.447	-0.176	0.024	0.099

(at 5% level of significance, **at 1% level of significance), $T_{Max.}$ – Maximum temperature, $T_{Min.}$ – Minimum temperature, T_{Mean} – Mean temperature, M.R.H. – Morning relative humidity, E.R.H. - Evening relative humidity, Mean R.H. - Mean relative humidity, RF rainfall, B.S.H. - Bright SunshineHour*

Table 4. Multiple effect of abiotic parameters on the incidence of insect-pests, theirnatural enemies and pollinator fauna in brinjal ecosystem

Sl. No.	Insect pests,natural enemies andpollinators	Regression	Equation	R^2	F-Value
1.	Whitefly	Multiple	$Y= 46.174 -1.091 X_1 + 0.968 X_2 + 0.109X_3 - 0.640 X_4 - 0.357 X_5 + 0.199 X_6$	0.793	5.118*
		Stepdown	$Y= 31.365 – 0.600 X_5$	0.396	9.197**
2.	Epilachnabeetle	Multiple	$Y= 22.844 -0.515X_1 + 1.105 X_2 - 0.106X_3 - 0.302X_4 + 0.991 X_5 – 0.372 X_6$	0.969	42.308**
		Stepdown	$Y= - 17.529 + 0.907X_3$	0.719	35.870**
3.	Jassid	Multiple	$Y= 22.998 -0.809 X_1 + 1.090 X_2 + 0.223X_3 – 0.917X_4 + 2.714 X_5 + 2.169 X_6$	0.600	2.003*
		Stepdown	$Y= 31.365 – 0.600 X_5$	0.396	9.917**
4.	BSFB shootinfestation	Multiple	$Y= 21.076 - 0.239 X_1 + 0.772 X_2 + 0.002X_3 - 0.678 X4 + 1.062 X_5 + 1.018 X_6$	0.671	2.037*
		Stepdown	$Y= 39.990 - 0.619 X_5$	0.520	11.940**
5.	BSFB fruitinfestation	Multiple	$Y= 34.570 – 4.092 X_1 + 4.482 X_2 - 0.169X_3 - 0.131 X_4 – 2.966 X_5 + 2.672 X_6$	0.781	1.190
		Stepdown	$Y= - 8.080 + 1.022 X_2$	0.520	7.782*
6.	Carpenter bee	Multiple	$Y= 2.039 - 0.016 X_1 + 0.002 X_2 + 0.011X_3 - 0.052 X_4 + 0.029 X_5 – 0.002 X_6$	0.579	1.834*
		Stepdown	$Y= 5.274 – 0.101 X_4$	0.341	6.724*
7.	Honey bee	Multiple	$Y= 8.097 - 0.210 X_1 + 0.289 X_2 + 0.169X_3 - 0.4070X_4 – 0.138X_5 + 0.130 X_6$	0.649	1.849*
		Stepdown	$Y= 7.429 - 0.163X_2$	0.397	7.233*
8.	Coccinellids	Multiple	$Y= 10.845 -0.360 X_1 + 0.333 X_2 + 0.078X_3 – 0.246 X_4 – 0.174 X_5 + 0.320 X_6$	0.619	1.621*
		Stepdown	$Y= 4.929 – 0.160 X_2$	0.373	7.743*
9.	Spiders	Multiple	$Y=1.160 + 0.105 X_1 - 0.019 X_2 + 0.036 X_3 – 0.152 X_4 + 0.00 X_5 + 0.477 X_6$	0.617	1.611*
		Stepdown	$Y= 11.059 - 0.193 X_2$	0.508	11.353**
10.	Damsel fly	Multiple	$Y= 1.178 + 0.007 X_1 - 0.016 X_2 + 0.011 X_3 - 0.034 X_4 + 0.005 X_5 - 0.063 X_6$	0.634	1.732*
		Stepdown	$Y= 0.481 + 0.140 X_3 - 0.031 X_4$	0.483	4.665*
11.	Chrysopids	Multiple	$Y= 1.183 - 0.011 X_1 + 0.023 X_2 + 0.014X_3 – 0.041 X_4 + 0.002 X_5 - 0.054 X_6$	0.550	1.222*
		Stepdown	$Y= 0.721 – 0.013 X_4$	0.210	2.916*

(at 5% level of significance, **at 1% level of significance) (X_1 = Maximum temperature, X_2 = Minimum temperature, X_3 = Morning RH%, X_4 = Evening RH, X_5 = Rainfall, X_6 = Bright sunshine hour)*

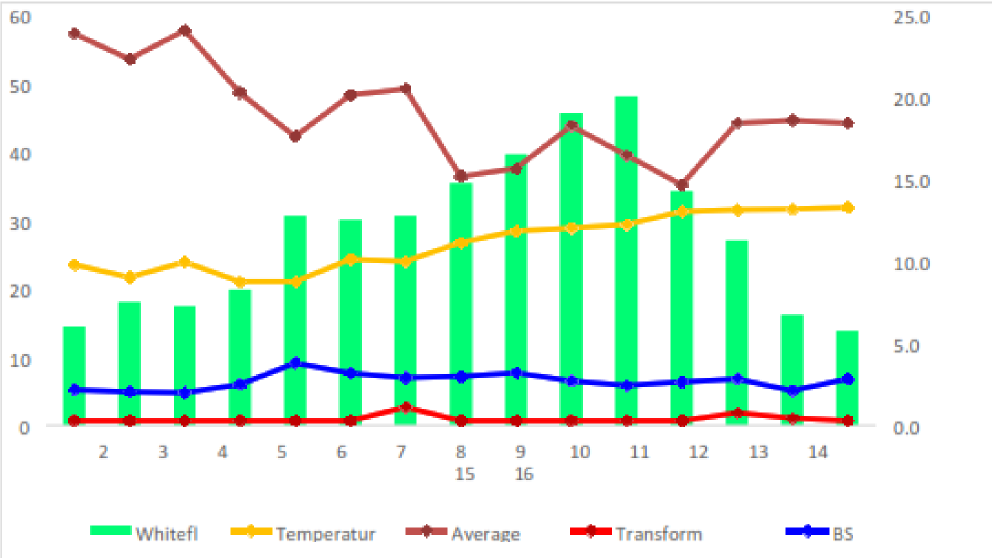

Fig. 1. Population fluctuation of whitefly in different SMW during 2020-21

temperature, morning, evening and mean relative humidity, transformed rainfall and BSH were 37.44°C, 21.23°C, 29.34°C, 48.71%, 30.14%, 39.43%, 0.71 mm and 5.84 hrs, respectively. The whitefly population had a significant negative correlation with morning, evening and mean relative humidity (r= -0.545, r = -0.780 and r = -0.664), while maximum and minimum temperature and B.S.H. had a positive but nonsignificant correlation (r= 0.30, r = 0.167, r = 0.233 and r = 0.442). Rainfall had a nonsignificant negative correlation (r= -0.003) (Table 3).

The results of present studies are in accordance with Ashfaq et al., Kaur et al. and Sarangdevot et al. [15-17] who reported that the *B. tabaci* population was positively correlated with mean temperature and negatively correlated with mean relative humidity. The positive correlation between the temperature and whitefly population can be attributed to the enhanced rate of development and reproduction of *B. tabaci* and it had been found that the oviposition activity of *B. tabaci* was maximum between 33 to 37ºC. The negative association between the whitefly population and relative humidity and rainfall was due to the *B. tabaci* adults which were largely controlled by rains particularly when there were regular heavy showers and strong winds. Cooler weather and high relative humidity and rainfall are detrimental to whitefly population and spread. Hence, a strategy should be planned to minimize the pest and disease attack either by manipulation in agronomic practices or chemical control. Muthukumar and Kalyanasundaram [18] found that *B. tabaci* observed from the first week after transplanting and persisted throughout the season. Hasan et al. [19] recorded *B. tabaci* peak population was seen on the 60 days old crop in 2005 and 2006, while the lowest was on the 30 days old crop. Regression analysis showed that all six weather parameters were responsible for 79.3% variation while in step-down regression analysis it was observed that only rainfall contributed to 39.6% variation in abundance of whitefly in brinjal ecosystem (Table 4).

3.1.2 Jassid

The activity of jassid *Amrasca bigutulla* was started from 2nd SMW and continued up to 16th SMW. The pest population ranged from 1.50 to 26.00 jassid/ 3 leaves per plant (Table 1). The peak population of *A. bigutulla* was (26 jassid/3 leaves/plant), during 9th SMW, when the maximum, minimum and mean temperature, morning, evening and mean relative humidity, transformed rainfall and B.S.H. were 36.96°C, 16.39°C, 26.67°C, 46.86%, 25.86%, 36.36%, 0.71 and 7.16, respectively.

Correlation studies revealed that the *A. bigutulla* population had a significant negative correlation with evening and mean relative humidity (r= -0.643, r = -0.572, respectively), but a significant positive correlation with B.S.H. (r = 0.577). It had

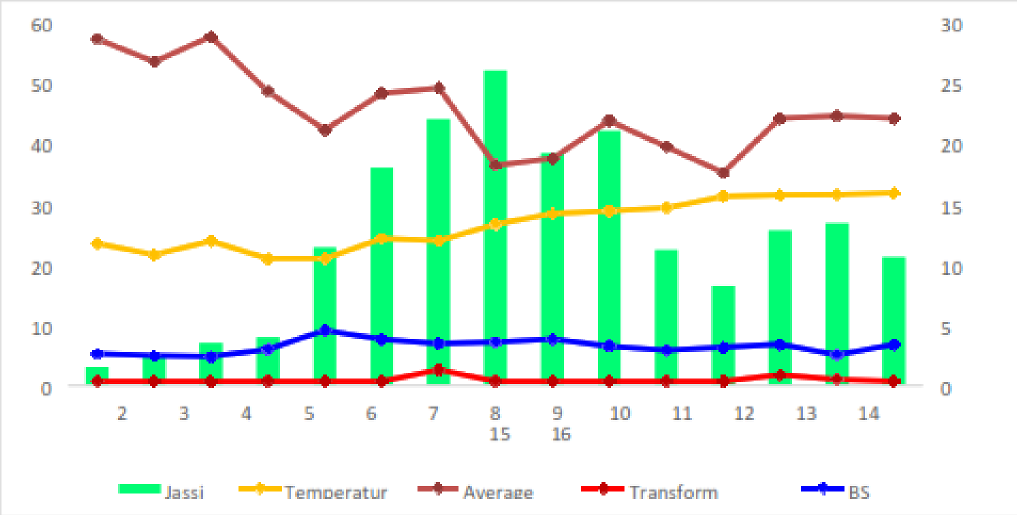

Fig. 2. Population fluctuation of jassid in different SMW during 2020-21

a nonsignificant but positive correlation with maximum, minimum and mean temperature and rainfall (r= 0.34, r = 0.25, r = 0.297 and r = 0.327, respectively). The morning relative humidity had a negative correlation (r= -0.487), but it was not significant (Table 3). Samal and Patnaik [20] reported that the aubergine leafhopper activity under Odisha condition peaked at 55-65 days and 40-50 days after planting during winter 2006-07 and summer 2007, respectively. Regression analysis showed that all six weather parameters are responsible for 60.0% variation while in step-down regression analysis it was observed that only rainfall contributed 39.6% variation in abundance of jassid in brinjal ecosystem (Table 4).

3.1.3 Epilachna Beetle

The brinjal hadda beetle *Epilachna vigintioctopunctata* was initially observed on the 2nd SMW up to 16th SMW. The average number of insects per plant ranged from 0.5 to 13.25. There was a gradual increase in the number of hadda beetle from January to April reaching at minimum during 2nd SMW. The highest population of 13.25 insects per plant was observed in 13th SMW (Table 1). It had a significant and positive correlation with maximum, minimum and mean temperature (r = 0.901, r = 0.917 and r = 0.929, respectively). While rainfall and BSH had positive but nonsignificant correlation (r= 0.172 and r = 0.073, respectively). It had significant negative correlation with morning, evening and mean relative humidity (r= - 0.750, r = -0.523 and r = -0.689, respectively) (Table 3).

The present findings are in close conformity with the findings of Muthukumar and Kalyansundaram, Shyamprasad and Logiswaran, Raghuraman and Veeraval, Ghosh and Senapati [18,21-23]. They found positive pest association with maximum temperature, while the negative association with morning and evening relative humidity. Sarvendra et al. [24] reported negative correlation between humidity and population of *H. vigintioctopunctata*. Temperature and relative humidity may directly affect insect herbivores through the regulation of dessication regimes and metabolic rates [25]. Suman and Swaminathan [26] recorded the peak infestation period of both adults and larvae of *Henosepilachna vigintioctopunctata* appeared in last week of February and continuing up to April, 2006. The atmospheric temperature had a significant positive correlation with the larvae and adults, while relative humidity had a negative correlation. Chen et al. [27] showed that temperature range of 24-32°C favoured the occurrence of *H. vigintioctopunctata*. Regression analysis showed that all six weather parameters were responsible for 96.9% variation, while in step-down regression analysis it was observed that only maximum relative humidity contributed to 71.9% variation in abundance of epiachna beetle in brinjal ecosystem (Table 4).

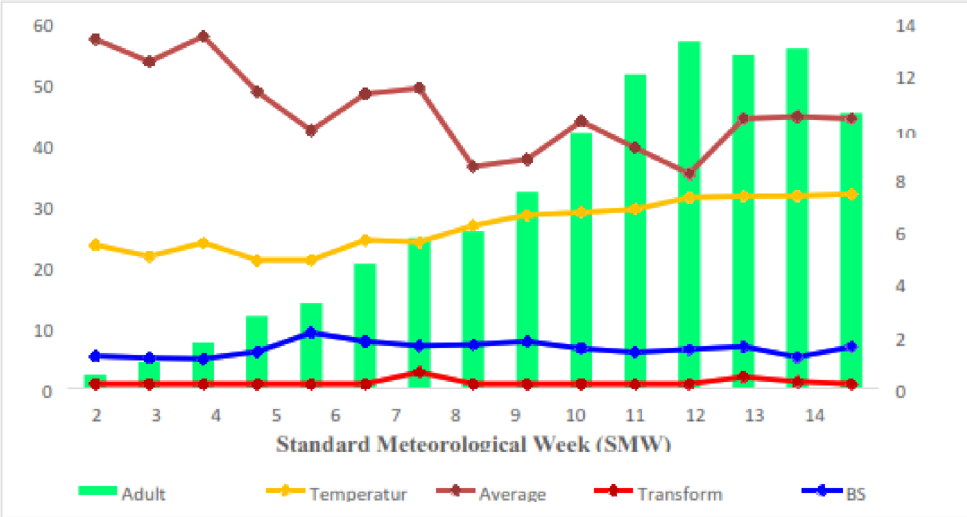

Fig. 3. Population fluctuation of epilachna beetle in different SMW during 2020-21

3.1.4 Shoot and fruit borer

The incidence of fruit and shoot borer *L. orbonalis* (BSFB) commenced from 4th SMW with a mean per cent shoot damage of 2.66 % and reached to a peak (20.00%) during 10th SMW. The incidence on fruit was noticed during 8th SMW (4.50 %) and reached maximum (18.30 %) during 12th SMW (Table 1). The per cent shoot damage was significantly and positively correlated with maximum temperature (r = 0.585). Minimum temperature, rainfall and B.S.H. had positive nonsignificant correlation (r= 0.421, r = 0.082 and r = 0.321 respectively) with population. It had significantly negative correlation with morning, evening and mean relative humidity (r= -0.688, r= -0.670 and r = -0.721, respectively). The incidence on fruit was significantly and positively correlated with maximum, minimum and mean temperature (r = 0.548, r = 0.725 and r = 0.693, respectively) and negatively correlated with rainfall (r = -0.596). While morning, mean relative humidity and B.S.H. had nonsignificant negative correlation (r= -0.312, r = -0.092 and r = -0.349, respectively), minimum relative humidity had positive nonsignificant correlation (r= 0.253) (Table 3).

The results of the present investigation are corroborative with the result of Muthukumar and Kalyansundaram [18] who reported that the maximum and minimum temperatures showed positive correlation with *L. orbonalis*, while relative humidity had negative correlation. Shaik [28] reported *L. orbonalis* population had positively significant relation with maximum and minimum temperatures. Devi [29] also reported brinjal *L. orbonalis* population had positively significant relation with maximum and minimum temperatures. Kumar et al. [30] also reported that the maximum and minimum temperatures showed positive correlation and evening relative humidity showed negative correlation on the incidence of *L. orbonalis*. Shyam Prasad and Logiswaran [21] reported that shoot damage showed significantly positive correlation with maximum temperature. The rainfall was found to be nonsignificant by Singh et al. and Naqvi et al. [31,32]. Singh and Guram [33] and Mall et al. [7] reported borer infestation on shoots a few weeks after transplanting in Punjab and Uttar Pradesh, respectively. Infestation of brinjal shoot and fruit borer occurred after 35 days of transplanting at Meerut [34]. Many of the workers have also reported that the incidence of shoot and fruit borer was observed throughout the year in different regions of South East Asia [35].

Regression analysis showed that all six weather parameters are responsible for 78.1% variation, while in step-down regression analysis it was observed that only rainfall contributed 52.0% variation in infestation of fruit in brinjal ecosystem (Table 4).

3.2 Natural Enemies

3.2.1 Coccinelid

The appearance of coccinellid beetles *Coccinella septempunctata*, *Menochilus sexmaculata* and *Coccinella novemnotata* was reported in the 4th

SMW with the population of 1.25 beetles/plant, which reached at its peak (3.75 beetles/plant), during 7th SMW. Beetle population was reached to its peak with the maximum and minimum temperature of 32.0 and 16.0°C and morning and evening RH of 60.86 and 35.57%, respectively (Table 2). The coccinellid showed a significant positive correlation with B.S.H. (r = 0.519) and non-significant positive correlation with rainfall (r = 0.069). It had a significant negative correlation with evening relative humidity (r = -0.505) while non-significant negative correlation with maximum, minimum and mean temperature and morning and mean relative humidity (r = -0.116, r = -0.179, r = -0.154, r = -0.166 and r = -0.309, respectively). Grubs and adults of ladybird beetle are predator. They feed on nymph and adult stages of soft bodied insect viz., aphid, jassid, and whitefly (Table 3). Regression analysis showed that all six weather parameters were responsible for 61.9% variation while in step-down regression analysis it was observed that only minimum temperature contributed 37.3% variation in abundance of coccinellids in brinjal ecosystem (Table 4).

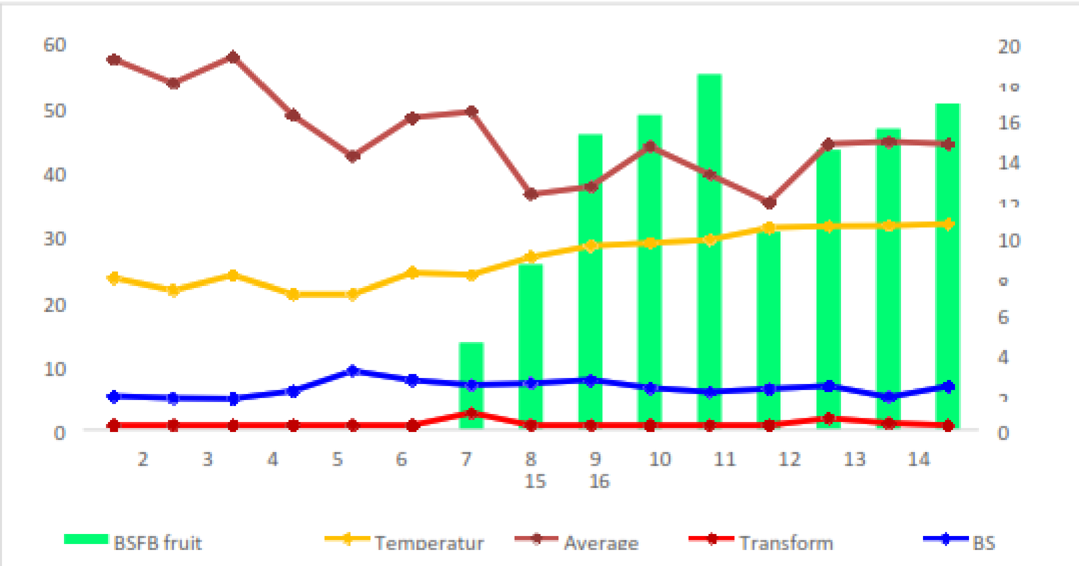

Fig. 4. Relationship of BSFB fruit infestation (%) with different SMW during 2020-21

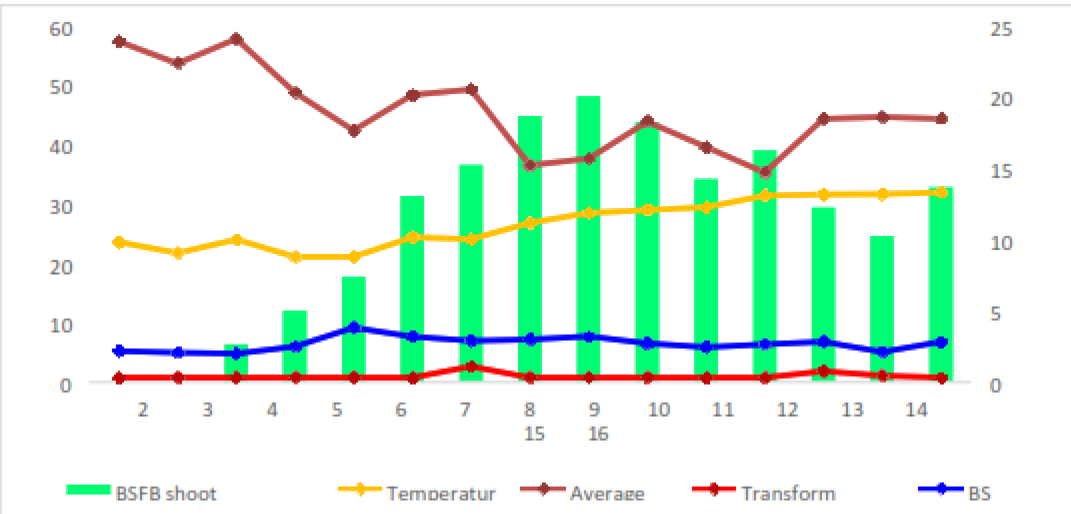

Fig. 5. Relationship of BSFB shoot infestation (%) in different SMW during 2020-21

3.2.2 Spider

The appearance of spiders lynx- *Oxyopes* sp., jumping- *Phiddipus* sp., wolf- *Marpissa* sp. were reported in the 4th SMW with the population of 3 spiders/plant, which reached at its peak (7.50/plant), during 10th SMW (Table 2). Spider population was appeared to its peak when the maximum and minimum temperature, morning and evening RH were 37.74 °C, 19.06 °C, 46.71% and 28.29%, respectively. The spiders showed a significant positive correlation with B.S.H. (r = 0.633) and non-significant positive correlation with maximum and mean temperature (r = 0.199 and r = 0.056, respectively) and a significant negative correlation with evening and mean relative humidity (r = -0.714 and r = -0.609, respectively) while non-significant negative correlation with minimum temperature and morning relative humidity and rainfall (r = -0.065, r = -0.494, r = -0.154 and r = -0.007, respectively) (Table 3). Regression analysis showed that all six weather parameters were responsible for 61.7% variation while in step-down regression analysis it was observed that only minimum temperature contributed 50.8% variation in abundance of spiders in brinjal ecosystem (Table 4).

3.2.3 Wood Ant

The appearance of wood ants was reported in the 4th SMW with the population of 2/plant, which reached at its peak (3.25 per plant), during 13th SMW (Table 2). Wood ant population was reached at its peak when the maximum and minimum temperature, morning and evening RH were 40.29°C, 22.20 °C, 44.00% and 26.29%, respectively. The wood ant showed a non-significant positive correlation with maximum, minimum, and mean temperature, BSH (r = 0.189, r = 0.079, r = 0.132 and r = 0.342, respectively) and non- significant negative correlation with morning, evening and mean relative humidity and Rainfall (r = -0.277, r = -0.219, r = -0.270 and r = -0.190, respectively) (Table 3).

3.2.4 Chrysopid

The appearance of chrysopids was reported in the 4th SMW with the population of 0.25/plant, which reached at its peak (0.5/plant), during 10th SMW (Table 2). Chrysopids population was reached at its peak when the maximum and minimum temperature, morning and evening RH were 37.74°C, 19.06°C, 46.71% and 26.29%, respectively. The chrysopids showed a non-significant positive correlation with maximum, minimum, and mean temperature and rainfall (r = 0.336, r = 0.256, r = 0.299 and r = 0.097, respectively) and non-significant negative correlation with maximum, minimum and mean relative humidity and BSH (r = -0.292, r = -0.457, r = -0.374 and r = -0.132, respectively) (Table 3). Regression analysis showed that all six weather parameters are responsible for 55.0% variation while in step-down regression analysis it was observed that only evening relative humidity contributed 21.0% variation in abundance of chrysopids in brinjal ecosystem (Table 4).

3.2.5 Damselfly

The appearance of damselfly was reported in the 4th SMW with the population of 0.25/plant, which reached at its peak (0.5/plant), during 10th SMW (Table 2). Damselfly population was reached when the maximum and minimum temperature, morning and evening RH were 37.74 °C, 19.06 °C, 46.71% and 26.29%, respectively. The damselfly showed a non-significant positive correlation with rainfall and B.S.H. (r = 0.024 and r = 0.099, respectively) and non-significant negative correlation with maximum, minimum and mean temperature and evening and mean relative humidity (r = - 0.239, r = -0.421, r = -0.347, r = -0.447 and r = -0.176, respectively) (Table 3). Regression analysis showed that all six weather parameters are responsible for 63.4% variation while in step-down regression analysis it was observed that only morning and evening RH together contributed 48.3% variation in abundance of damselfly in brinjal ecosystem (Table 3).

3.3 Pollinator

3.3.1 Carpenter bee

Abundance of flower visiting carpenter bees *Xylocopa* sp. was evaluated at flowering stage in brinjal crop. It was first appeared in the 3rd SMW with the population of 4/plot, which reached at its peak at (35/plot), during 12th SMW (Table 1). Its abundance was mainly in peak time of flowering. Regression analysis showed that all six weather parameters were responsible for 57.9% variation, while in step-down regression analysis it was observed that only maximum relative humidity contributed 34.1% variation in abundance of carpenter bee in brinjal ecosystem (Table 4).

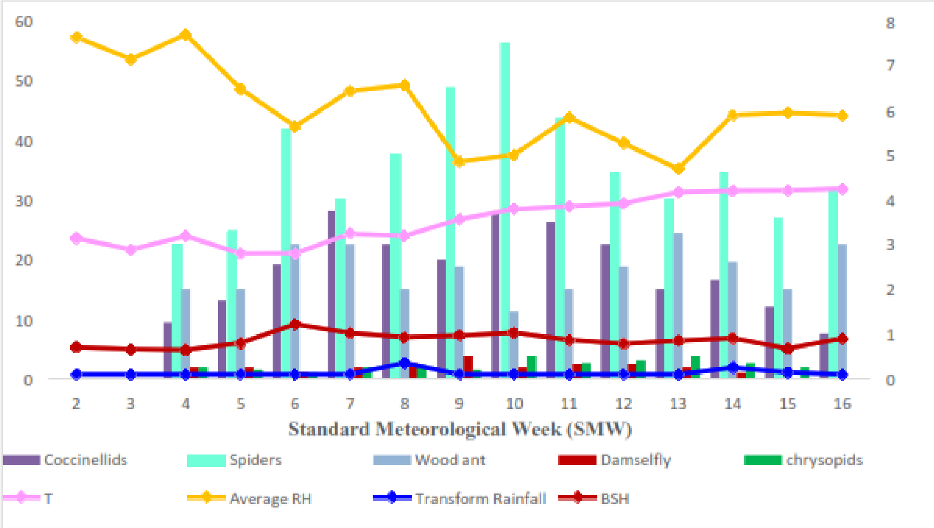

Fig. 6. Population fluctuation of natural enemies at different SMW during 2020-21

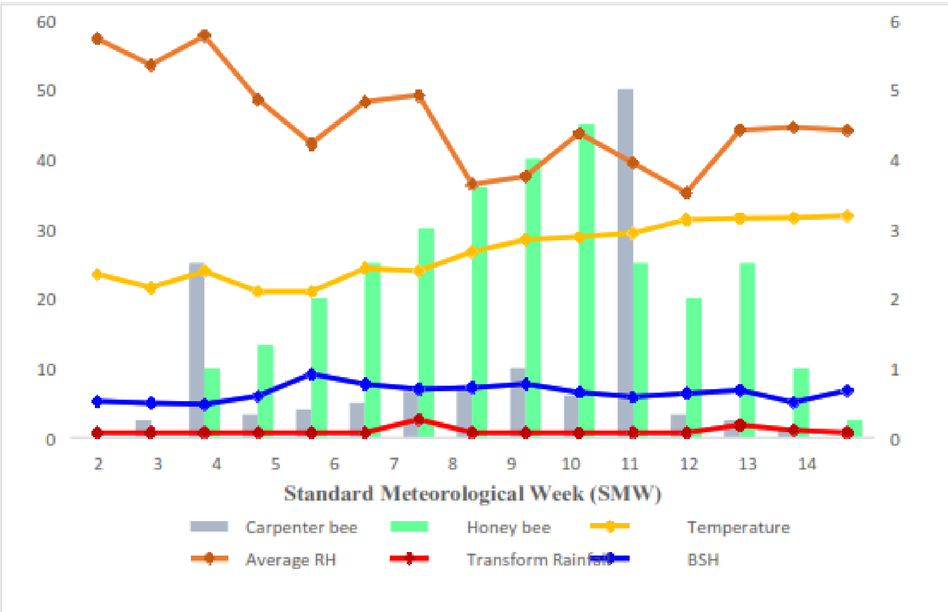

Fig. 7. Population fluctuation of pollinators, carpenter bee and honey bee, in different SMW during 2020-21

3.3.2 Honey bee

Abundance of flower visiting honey bees *A. mellifera*, *A. dorsata* and *A. cerena indica* were evaluated at flowering stage in brinjal. It was first appeared in the 3rd SMW with the population of 10/plot, which reached at its peak at (30/plot), during 11th SMW. Its abundance was mainly in peak time of flowering (Table 1). It was significantly negatively correlated with, evening relative humidity (r = -0.631) (Table 3). Regression analysis showed that all six weather parameters were responsible for 64.9% variation, while in step-down regression analysis it was observed that only minimum temperature contributed 39.7% variation in abundance of honey bee in brinjal ecosystem (Table 4).

4. CONCLUSION

Brinjal shoot and fruit borer, whitefly, and jassid were the most significant pests found in brinjal, while epilachna beetle was of minor importance because it was found in much lower numbers and caused less damage. Among the natural enemies, ladybird beetles *M. crocea*, *C. septempunctata*, *C. transversalis*, and *C. sexmaculata,* spiders *Phiddipus sp*., *Oxyopes sp*. and *Marpissa sp*. and black ant *C. compressus* were the dominating ones. Among the pollinators, *Xylocopa sp.* was the most dominant visitor of brinjal flower and was identified as potentially important in brinjal. *Xylocopa sp.* is known to provide effective fruit setting in brinjal. The pollinators appeared in higher numbers during the blooming period and was the dominant species found in the field.

ACKNOWLEDGEMENT

We are highly thankful to the head of K.V.K. Kalahandi, Bhawanipatna, Mr. Amitav Panda for providing necessary facilities for carrying out the work and helping and guiding me in the field for this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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