Spatio-temporal variation of insect pests of tomato with special reference to leaf miner, *Liriomyza trifolii* (Burgess)

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By

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APPROVAL OF THE EXAMINERS FOR THE AWARD OF THE DEGREE OF DOCTORATE OF PHILOSOPHY (AGRICULTURE)

IN

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We, the undersigned, have been satisfied with the performance of **Ngalaton Kasar,** a student of Ph.D. (Ag.) Department of Agricultural Entomology, in the *viva-voce* examination, conducted today, the ________________, 2020 and recommended that the thesis be accepted for the award of the degree of Doctorate of Philosophy (Agriculture) in Agricultural Entomology of Bidhan Chandra Krishi Viswavidyalaya.

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Certificate

This is to certify that the thesis entitled **"Spatio-temporal variation of insect pests of tomato with special reference to leaf miner, *Liriomyza trifolii* (Burgess)"** is an embodiment of the results of the research work carried out by **Miss Ngalaton Kasar** in partial fulfillment for the requirements of the **Degree of Doctor of Philosophy** in **Agricultural Entomology** of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, is a faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in this thesis have not so far been submitted for any other Degree or Diploma.

The assistance and help received during the courses of investigation have been duly acknowledged.

Dated: …………………..
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Acknowledgement

"I CAN DO ALL THINGS THROUGH HIM WHO STRENGTHENS ME".

PHILIPPIANS 4:13

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“Spatio-temporal variation of insect pests of tomato with special reference to leaf miner, *Liriomyza trifolii* (Burgess)”

ABSTRACT

Tomato (*Solanum lycopersicum*) is an intensely nutritious plant with an estimated global production of over 120 million metric tons (F.A.O. 2007). It is the world's largest vegetable crop after potato and sweet potato, and India ranks second in the area as well as in production. Because of its fleshy nature, tomato fruit is attacked by a number of insect pests and diseases from the time plants first emerge in the seed bed until harvest. In India leaf miner, *Liriomyza trifolii* (Burgess) is one of the recently introduced pest of tomato, whose infestation is increasing every year at an alarming rate.

The present investigation revealed that the population of the insect pests of tomato and their activities varied with the prevailing weather conditions, sowing and transplanting time and different growth stages of crop. Correlation studies with different weather parameters revealed that weather inputs had both significant and insignificant effects on the population build-up of the various insect pests of the crop. Weather indices-based prediction models were developed using Principal Component Multinomial Regression (PCMR) method. The models were found to be fitted for describing the insect population build-up of tomato leaf miner (*L. trifolii*), *Spodoptera litura* and *Helicoverpa armigera* and among the various weather factor inputs, temperature (maximum, minimum, day and night) was observed to have the most pronounced influence on them. From the biological studies of *L. trifolii* under different temperature regimes of 15°C, 20°C, 25°C and 30°C, it could be concluded that with gradual increase in temperature the developmental period of the different life stages also gradually decreased. Thus, temperature was found to have an inverse relationship with the developmental days of the leaf miner. Among the different insecticidal treatment schedules consisting of both chemical and non-chemical insecticides evaluated against the various insect pests of tomato, Emamectin benzoate 5% SG was the most effective treatment for leaf miner while Novaluron 5.25% + Indoxacarb 4.5% SC treatment recorded lowest population of aphid, whitefly, thrips, *S. litura* and *H. armigera*. For natural enemies’ populations consisting of spiders and coccinellids, treatments with botanicals and microbials were found to be relatively safer over the other treatments.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	: Percentage	RBD	: Randomized Block Design
/	: Per	RH	: Relative Humidity
@	: At the rate of	SD	: Standard deviation
–	: Negative or without	S.Em.	: Standard error of mean
+	: Positive or with	SMW	: Standard meteorological week
<	: Less than	Spp	: Species
>	: Greater than	sq.m.	: Square meter
^{0}C	: Degree Centigrade	t	: Tonnes
BCKV	: Bidhan Chandra Krishi Viswavidyalaya	T max	: Temperature Maximum
DAT	: Day after transplanting	T min	: Temperature Minimum
CD	: Critical difference	T day	: Temperature day
cm	: Centimetre (s)	T night	: Temperature night
et.al	: *Et alli* (and others)	*viz.*	: Videlicet (namely)
F.A.O.	: The Food and Agriculture Organization	V.P.	: Vapour pressure
Fig.	: Figure	WS	: Water soluble
g	: Gram (s)	CRD	: Completely Randomized Design
ha	: Hectare (s)	NSKE	: Neem seed kernel extract
hrs	: Hours	SG	: Water soluble granule
NS	: Non significant	SC	: Suspension concentrate
i.e.	: id est (= that is)	EC	: Emulsifiable concentrate
kg	: Kilogram (s)	WG	: Water dispersible granule
l	: Litre (s)	DAS	: Day after sowing
Ltd.	: Limited	DBS	: Day before spraying
m	: Metre (s)	IPM	: Integrated pest management
ml	: Millilitre	NHB	: National Horticulture Board
mm	: Millimetre	Av.	: Average
Mt	: Metric Tonnes	G	: Granules
MSL	: Mean sea level	oz	: Ounce (s)
µg	: Microgram	cv.	: Cultivar
No.	: Number (s)	C	: Concentrate
ppm	: Parts per million	SP	: Soluble powder
Pvt.	: Private	SL	: Soluble liquid/concentrate
q	: Quintal (s)	lb	: Pound
DS	: Powder for dry seed treatment	F	: Flowable
ETL	: Economic threshold level	EIL	: Economic Injury Level
NSKP	: Neem seed kernel powder	&	: and
ICBR	: Incremental Cost Benefit Ratio	IARI	: Indian Agricultural Research Institute

INTRODUCTION

Tomato (*Solanum lycopersicum*) is an intensely nutritious plant with an estimated global production of over 120 million metric tons (F.A.O. 2007). It belongs to the solenoid/ nightshade family of plants called the Solanaceae, native to Peruvian and Mexican region. It contains a full array of nutrients, including flavonoids, carotenoids, saponins, and fatty acid derivatives which helps in strengthening our cardiovascular system, musculoskeletal system, renal system (kidneys), hepatic system (liver), and integumentary system (skin). Tomato fruit is one of the most important “protective foods” both because of its special nutritive value and also due to its wide spread production and tops the list of canned vegetables. Tomato fights cancer and due to presence of various natural acids it is good for digestion. It is healthy, versatile, delicious and has zero cholesterol. It is a rich source of vitamins A, C, potassium, minerals and fibers. Tomatoes are also used in the preparation of soup, salad, pickles, ketchup, puree and sauces, and also consumed as a vegetable in many other ways.

Tomato is the world's largest vegetable crop after potato and sweet potato, and India ranks second in the area as well as in production of Tomato. The annual production of tomato in India is 196.97 lakh tonnes in an area of 8.09 lakh hectares. In different parts of West Bengal tomato is cultivated as rabi as well as spring summer crop. It is grown over an area of 57.35 thousand Ha with an annual production of 1233.16 thousand MT. The major tomato growing districts are Cooch Behar, North 24 Parganas, Nadia, Murshidabad, Alipurduar, South 24 Parganas (Anonymous, 2016-17).

There are several factors responsible for the low productivity of tomato in India. These include abiotic factors like weather parameters such as temperature, humidity, nutrient deficiency, water deficiency etc. Biotic factors include insect pests, pathogens and weed which limit the productivity of tomato crop. Like other vegetable crops tomato also more prone to insect pests and diseases mainly due to tenderness and softness as compared to other crops and virtual absence of resistance characters because of intensive hybrid cultivation. Because of its fleshy nature, tomato fruit is attacked by a number of insect pests and diseases from the time plants first emerge in the seed bed until harvest. A number of insect pests i.e., about 100 and 25 non insect pest species are reported to ravage the tomato fields (Lange and Bronson, 1981). Various insect pests such as fruit borer, *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera), whitefly

(*Bemesia tabaci* Genn.) (Homoptera: Aleyrodidae), jassids (*Amrasca biguttulla biguttulla* Ishida), thrips, (*Thrips tabaci* Lind.) serpentine leaf miner (*Liriomyza trifolii* Burgess) and two spotted spider mite, (*Tetranychus urticae*, Koch) (Acarinae: Tetranychidae) are responsible for low yield of tomato (Lal *et al*., 2008)., Nagamandla *et al*. (2017) reported that whitefly, aphid and leaf miner were most important insects in West Bengal damaging tomato during November to March under open conditions of field.

Aphid is a polyphagous pest belongs to the family Aphididae of the order Hemiptera. Different species of aphid e.g. *Aphis craccivora*, *Aphis gossypi* and *Myzus persicae* attack on tomato plant. Among them, *A. craccivora* is the major considered as major pest of tomato as its occurrence is common and irregular (Alam, 1969).

Among the various sucking insect-pests, whitefly (*B. tabaci* Genn.) is one of the destructive pests causing serious damage to tomato crop and is responsible for lowering its yield (De Barro *et al*., 2011). The destructive pest status of whiteflies is attributed to a number of factors like high degree of polyphagy, ingestion of phloem sap, massive honey dew secretions (which reduce both the cosmetic value of the tomato and the available leaf area for photosynthesis), uneven ripening and transmission of viruses like Tomato Yellow Leaf Curl Virus (Brown and Czosnek, 2002). Further, the honeydew (a sweet and sticky substance) is also secreted by the pest which supports the growth of sooty mould which in turn affects the yield in both quantitative and qualitative terms (Oliveira *et al*., 2001).

Thrips merit attention because they cause direct and indirect damage. Thrips feed on plant tissue by rasping and sucking sap, resulting in tissue scarification and depletion of the plant's resources (Welter *et al*., 1990; Shipp *et al*., 1998). The scarification reduces the photosynthetic capacity of leaves and causes blemishes on fruits. Indirectly, thrips transmit the tomato spotted wilt virus (TSWV) on tomato. The direct injury and the virus disease result in discoloration of fruits, thus lowering the quality of the fruits. Kagezi *et al*. (2001) found that thrips cause a tomato yield loss of 23.7%.

A major constraint in tomato production during fruiting is *Helicoverpa armigera* Hubner and *Spodoptera litura* Fabricus. In spite of all possible agronomical practices and use of high yielding varieties tomato yield is further reduced by the fruit borer, *H. armigera* and can caused 14 to 45 per cent loss to the fruit yield of tomato in different state of the country (Kurl and kumar, 2010). Leaf caterpillar, *S. litura* Fab. is also one of the predominant polyphagous pest and one of the most important horticultural pests. Its wide spread distribution and pest status has been attributed to its polyphagy and its ability to undergo both facultative diapause and seasonal migration (Devanand and Rani 2008). It is a noxious pest that damages crop extensively by skeletonizing the leaves and thus reducing the photosynthetic activity of the plant (Selvaraj *et al*., 2010). The larvae cause significant damage to the foliage and cause fruit damage ranging from 11.8 to 23.01 present in rainy season and 9.4 to 27.4 percent in winter (Patnaik, 1998).

Among the insect pests of tomato, the loss incurred by *L. trifolii* (Burgess) has become most important in recent years (Medeiros *et al.,* 2005). Leaf miner flies (Diptera: Agromyzidae) are a highly diverse group of exclusively phytophagous species and they comprise more than 3000 known species worldwide (Braun *et al*., 2008; Shahreki *et al*., 2012). The genus *Liriomyza* contains more than 300 species. These are distributed widely but most commonly found in temperate areas (Parella, 1987). Within this genus, 23 species are economically important, causing damage to agriculture and ornamental plants by their leaf mining activities and 5 species out of it are considered to be truly polyphagous (Spencer, 1965, 1973). Among them, *L. trifolii* (Burgess), the American serpentine leafminer, is known as one of the most serious pests of many vegetable and horticultural crops worldwide. It is a native of Florida in Southern United States and the Carribean Islands (Spencer, 1973). It was accidentally introduced into India from American sub continent along with chrysanthemum cuttings (Parrella, 1987). The first report of this invasive pest occurrence appeared in the proceedings of the annual castor research workers' group meeting held at Hyderabad (Anonymous 1991). During the following year, the pest was reported from Andhra Pradesh and Karnataka on several host plants including castor (Lakshminarayana *et al*. 1992) and has now spread to most of the states in India (Sujay *et al*. 2010). Srinivasan *et al*. (1995) mentioned that the leaf miner was fast spreading and was likely to be a major pest in India within a short time. *L. trifolii* was one of the recently introduced pests of tomato in India, whose infestation had been found to be increasing every year at an alarming rate (Rai *et al.,* 2013). It was first described as *Oscinis trifolii* (Comstock, 1880) and have been known by several common names like serpentine leafminer, American serpentine leaf miner, broad bean leaf miner, California leaf miner, celery leaf miner, chrysanthemum leaf miner (Malipatil and Ridland, 2008). In West-Bengal, it is locally known as 'Map poka'. Management of this insect is very difficult due to its wide host range, short life cycle and fast development of resistance to chemical insecticides. Hence, it has become a serious problem in tomato growing pockets. This pest significantly reduced the yield and fruit quality by direct feeding (Bethke and Parrella 1985; Parrella 1987). Leaves injured by leaf miners drop prematurely; heavily infested plants may lose most of their leaf surface area and are responsible for photosynthetic activity (Molla *et al*., 2011). Twisted and curled leaves are generally the first symptoms (Knapp *et al*., 1993). The mines are usually partially filled with frasses and are irregular in shape. Tissue death (necrosis) can occur around the mines and, during serious infestations, the leaves can become skeletonised. The estimated losses due to infestation of *L. trifolii* were 46-70% of tomato seedlings (Pohronenzy *et al*., 1986), 90% of tomato foliage (Johnson *et al*., 1983) and 70% of tomato yield (Zoebisch *et al*., 1984). In Karnataka state, the losses in summer season crops were reported to the extent of 35 % in tomato (Krishna Kumar, 1998).

Tomato production is highly dependent on the use of pesticides. Wide ranges of synthetic chemicals are being recommended from time to time against the pests of tomato. Indiscriminate use of these synthetic chemicals, incorrect timing of application and improper doses etc are causing serious problems, such as insecticide resistance development, increasing environmental pollution and health risks (Forget *et al*., 1993; Isman, 2006). These conventional insecticides also do not provide effective control and generally lead to pest resurgence as well as secondary pest outbreak. The important thing for any successful pest management programme is to develop a regular monitoring plan to study the dynamics of pest population that may be used to decide the right time and apply proper dose of suitable insecticides. The new generation insecticides generally work against a limited array of pest species than the older, broad spectrum pesticides. Therefore, it is essential to properly categorize the pest to be checked and to evaluate its prospective damage.

Any pest management programme requires the use of monitoring practices to be effective. It is, therefore, imperative to study the population fluctuation of the crop pest in relation to weather parameters that largely direct the activity of a given species of insect pest (Sharma *et al.,* 2013). Hence, the following objectives have been framed in order to,

1. To study the population dynamics of leaf miner, *Liriomyza trifolii* (Burgess) and other important insect pests of tomato.
2. To study the biology of *Liriomyza trifolii* (Burgess).
3. To establish relationship of population build-up of leaf miner and other important insect pests infesting tomato with different weather parameters and to develop predictive models.
4. To develop a management module of leaf miner and other important insect pests with botanicals and bio-rational pesticides.

REVIEW OF LITERATURE

The literature pertaining to important insect pests of tomato in relation to the present investigations has been compiled and presented here under the following heads:

2.1 Seasonal incidence and population dynamics of important insect pests of tomato.

Dhamdhere (1990) mentioned *Bemisia tabaci* and *Helicoverpa armigera* as regular pests.

Srinivasan (1993) reported white fly and fruit borers as major pests of tomato.

Gravena (1999) reported *Bemisia tabaci*, *Helicoverpa armigera* and *Liriomyza trifolii* as major pests of tomato crop.

Chaudhuri *et al*. (2001a) reported aphid (*A. gossypii*), whitefly (*B. tabaci*), leaf miner (*L. trifolii*), tingid bug (*Urentius hystricellus*) and fruit borer (*H. armigera*) to attack tomato crop.

Umeh *et al*. (2002) conducted a survey of some tomato producing areas of Nigeria and reported that the major insects attacking tomato included the fruit borer, *H. armigera*; whitefly, *B. tabaci* and various species of aphids, mostly *A. gossypii*.

Jandial and Kumar (2007) conducted field surveys in western Uttar Pradesh, India and reported fruit borer (*H. armigera*) as one of the most serious pest in tomato.

Kumar (2008) recorded five different species of insect on tomato under 3 orders and 5 families viz. whitefly, *B. tabaci*; aphid, *A. gossypii*; jassid, *Amrasca devastans*; serpentine leaf miner, *L. trifolii* and fruit borer, *H. armigera*.

Mandal (2012) reported that the fruit borer, *Helicoverpa armigera* (Hub.), aphid, *Aphis gossypii* Glov. and white fly, *Bemisia tabaci* are major insect pests of tomato.

Waluniba *et al*. (2014) reported eight insect pests associated with tomato which included the defoliators like Tobacco caterpillar, *Spotoptera litura* (Lepidoptera: Noctuidae), cabbage lopper, *Trichoplusia ni* (Lepidoptera: Noctuidae) and grasshopper *Heiroglyphus banian* (Orthoptera: Acrididae), sucking insects like aphid, *Aphis gossypii* (Hemiptera: Aphididae), whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae) and green stink bug, *Nezara viridula* (Hemiptera: Pentatomidae) and serpentine leaf miner, *Liriomyza trifolii* (Diptera: Agromyzeidae). Aphid and serpentine leaf miner were the most serious, as they persisted for longer durations with abundant numbers.

Nagamandla *et al*. (2017) reported that *Aphis gossypii*, *Bemisia tabaci*, *Thrips tabaci*, *Liriomyza trifolii*, *Spodoptera litura* and *Helicoverpa armigera* are the major insects causing severe losses under favorable weather condition.

2.1.1 Population dynamics of leaf miner, *L. trifolii* (Burgess) and other insect pests of tomato

Choudary and Rosaiah (2000) demonstrated that the leaf miner incidence commenced from the third week of November and reached a peak in fourth week of January. A second peak was observed in the second week of February.

Marcano and Issa (2000) observed that the larger number of larval populations of *L. trifolii* on tomato crop were present on the lower and middle stratum of plants and female preferred to oviposit on the first 5 leaflets of the plant.

Chaudhuri and Senapati (2004) reported in tomato higher incidence of leaf miner during late March to early May. They explained that the population densities slowly increased during early crop growing stages, but had gained momentum from flowering stage onwards.

Leaf miner (*L. trifolii*) infestation was highest during February second and third week on tomato as reported by Saradhi and Patnaik (2004) in a survey conducted in Orissa.

Reddy and Kumar (2005) carried out an experiment on the seasonal abundance of *L. trifolii* on tomato in Karnataka during the kharif season and observed that the peak incidence of *L. trifolii* during March-April, which coincided with the vegetative and reproductive stages of the crop. The population declined during November-December due to natural parasitization.

Kharpuse (2005) reported that maximum infestation due to leaf miner and maximum damage due to fruit borer on tomato occurred during middle of March and third week of March, respectively.

Galande and Ghorpade (2010) reported the incidence of *L. trifolii* (Burgess) throughout the year ranging from 3.53 to 7.73 live mines on eighteen terminal leaflets per plant. The lowest incidence (3.53 live mines per plant) was recorded on crop transplanted in the month of November, 1999 and the highest incidence (7.73 live mines per plant) was recorded on crop transplanted in the month of February, 2000. The peak activity of this pest was recorded during January to April with highest incidence in February, 2000.

Variya and Bhut (2014) during Rabi 2010-11 observed that the number of mines/leaf ranged between 2.52 and 10.26 with an average of 5.95. The infestation based on mines/leaf attained the highest peak (10.26 mines/leaf) during 3rd week of January. The number of larvae/leaf ranged between 0.24 and 2.24 with an average of 0.84. The larval population reached to the highest peak (2.24 per leaf) during 3rd week of January. Percent damaged leaves were in the range of 9.44 to 29.40 with an average of 15.99. Percent damaged leaves slightly increased as the crop became older and reached to the first peak (16.41%) during 4th week of November. Then after declined during next week and further increased up to the crop maturity. The infestation attained the highest peak (29.40%) during 1st week of January. Overall, the activity of leaf miner was higher during December-January.

Singh *et al*. (2018) reported that serpentine leaf miner was first observed on January 16, 2017 damaging tomato leaf i.e. during third standard week with 1.05 live mines/plant and remained active throughout the cropping period. The peak activity (31.25 live mines/plant) of the pest was recorded during fruiting stage of the crop in the last week of March, 2017.

High aphid population was observed in the first week of February and thereafter the population gradually decreased and lowest number was recorded in the month of April. The overall aphid population was highest at initial stage of crop and declined as crop grew towards maturity as reported by Shakeel *et al*. (2010)

Gosh (2017) observed that population of aphids was found throughout the seasons. The low level of population (0.19 to 0.50/leaf) was counted on 38th to 40th standard week of September to October, 52nd to 5th standard week of December to January and 18th to 22nd week that is 1st week May to 4th week of June when average temperature, relative humidity and weekly rainfall ranged from 15.71°C-28.86°C, 70.42%-92.93% and 0.00mm-240.20mm respectively. Persistent high population (0.62-2.69/leaf) was maintained on 41st standard week to 51st standard week that is during 2nd week of October to 3rd week of December and 6th to 17th week that is during 2nd week

February to 4th week of April when average temperature, relative humidity and weekly rainfall ranged from 18.33°C-27.83°C, 47.85%-92.39% and 0.00mm-63.40mm respectively.

Sarkar *et al*. (2018) reported that aphid (*Aphis gossypii* Glover) and whitefly (*Bemisia tabaci* Genn.) first appeared on the crop in third week of January and second week of February respectively. The peak populations of both the pest were observed in the third and fourth week of February.

Arnal *et al*. (1998) observed that the adult whiteflies (*B. tabaci*) were present throughout the growing period of tomato and also found that their population was higher at the end of the rainy season.

Chaudhuri *et al*. (2001b) reported that the highest population density of white fly was observed during mid-February on tomato crop. High infestation levels were maintained from mid-Febuary to mid-March when temperature, relative humidity, sunshine and rainfall were 17.07-22.13°C, 65.29-72 .78%, 7.79-8.9 hours per day and 5mm, respectively. Under laboratory conditions the pest was biologically more active during October-November.

Barde (2006) studied the seasonal incidence of whitefly on tomato and reported that it first appeared during the second week of January and remained active until the crop was harvested. Peak population was observed during the last week of February when maximum and minimum temperature was 30.5°C and 16.8°C, respectively, average relative humidity 61.5% and 162 mm rainfall.

Konar and Paul (2006) found that whitefly becomes active from October to March-April in gangetic plains of India. The population of whiteflies becomes low during late December to mid-January in eastern gangetic plains of West Bengal.

Lin *et al*. (2007) recorded at least 14 species of plants on which *B. tabaci* fed during the winter and spring. *L. esculentum* Mill, *Brassica alboglabra* Bailey, *Ficus carica* L., *Euphorbia pulcerrima* Wild, and *Hemelia patens* Haence were the main host plants. Further research on the population dynamics of *B. tabaci* on three major greenhouse hosts; tomato, cucumber, and melon, indicated that densities remained at a low level during the winter, but increased steadily from February to March until migration into field crops in April.

The population of *B. tabaci* came to notice in the 14th standard meteorological week and attained its peak during 22nd standard meteorological week as reported by Sarangdevot *et al*. (2010)

Shivanna *et al*. (2011) reported that maximum whitefly population was highest on the second fortnight of April with 29.50 per three leaves. Population declined from June first fortnight up to January. Population of 0.00 per three leaves were recorded during month of July and August. The whitefly population started increasing again from February onwards.

Chakraborty (2012) studied the population dynamics of whitefly, *B. tabaci* on tomato and reported that the population initiated at about 48th standard meteorological weeks (SW), increased slowly upto 1st SW then steadily upto 5th SW attaining the maximum at about 6th SW which was maintained up to about 9th SW.

Srinivasan *et al*. (2012) revealed that the peak incidence of whiteflies varied seasonally from year to year and in general, whitefly populations were not uniformly distributed.

There was a decrease in population of whitefly with decrease in temperature in January-February and the population increased with increase in temperature as observed by Salim *et al*. (2013)

Subba *et al*. (2017) studied the population dynamics of whitefly (*Bemisia tabaci* Genn.) on tomato (*L. esculentus* L.) and observed that maximum population level was maintained during 11th standard week to 18th standard week that is during 2nd week of March to 3rd week of March with peak population (0.47/leaf).

According to Eltez and Karsavuran (2006) the population level of *Thrips tabaci* was higher in the surveyed fields during 2003-04, with the value of 1-86 individuals per leaf, but decreased with the value of 1-20 individuals per leaf in 2005. Individuals were found abundant 2 weeks after the planting. *T. tabaci* became a widespread species on flowers of tomato with the value of 1-20 individuals per flower, but the population density has been found in a low number on leaves, in the surveyed fields during 2003-05.

According to Chavan *et al*. (2014) thrips started appearing on tomato plants during the first week of October, and the peak population was seen from the third week of October to the second week of November. The thrips population then progressively decreased from November third week onwards.

Subba and Ghosh (2016) assessed the population dynamics of thrips (*Thrips tabaci* L.) in relation to abiotic factors and its botanical management in tomato by Randomized Block Design for two consecutive seasons (2011-2013) at Uttar Banga Krishi Viswavidyalaya. They recorded minimum number of thrips (0.42-53/leaf) population during 38th to 44th standard week and observed maximum level of population during 45th to 2nd (1.05-1.89/leaf) and again during 6th to 20th (1.00-2.22/leaf) standard week.

Jamuna *et al.* (2019) studied the population dynamics of thrips on tomato crop during two consecutive kharif seasons (2016 and 2017). The results revealed that, thrips activity was found throughout the cropping period. The population of thrips increased gradually from first week after transplanting to flowering and fruit development stage and later it decreased as crop matures. During 2015-16 kharif crop, maximum thrips population (8.40 thrips/three leaves) was observed during the last week of November and first week of December. Similarly, during 2016-17 kharif crop, maximum thrips population (10.30 thrips/three leaves) was observed during third and last week of December.

Sharma *et al*. (2000) studied the seasonal incidence of pod borers on *Dolichos lablab* in Jabalpur, Madhya Pradesh, India. The peak population of *Helicoverpa armigera*, *Lampides boeticus*, *Sphenarches caffer*, *Anarsia ephippias*, *Spodoptera litura*, and *Maruca vitrata* was observed from the third week of November to the second week of December and from the last week of February to the second week of March. A temperature of more than 8°C during this period and the occurrence of rainfall during the first two weeks of November appeared to cause the population build up.

Monobrullah *et al*. (2007) stated that the larval activity of *S. litura* on tomato was recorded from the 14th standard week, but no larvae were found during that period on tomato. The larvae started appearing from the 17th standard week. A gradual increase in the larval population was recorded until the 25th standard week. Larval population declined gradually after the 27th standard week at the time of crop harvest. The peak population was observed during the 25th standard week.

Hanamant *et al*. (2013) conducted fixed plot survey during rabi/summer season at five locations of Dharwad district and also at the Main Agricultural Research Station, Dharwad to study the seasonal incidence of *Spodoptera litura* (F.) and leaf miner, *Aproaerima modicella* Deventer in summer groundnut crop. *Spodoptera* incidence started from 6th standard meteorological week (SMW) and reached its peak during the 11th SMW with 19.50 % leaf damage and declined thereafter. The peak incidence coincided with the reproductive and pod formation stage of the crop.

Shakya *et al*. (2015) revealed that the infestation of *Spodoptera litura* on tomato started from 15th January, 2014 with the peak infestation of 0.9 insects per plant noticed on 26th February, 2014. Declining trend in pest population was noticed with minimum infestation of 0.15 insects per plant on 23rd April, 2014.

Nadaf and Kulkarni (2006) recorded the peak incidence of *H. armigera* eggs during September second fortnight and incidence of larvae was peak during November first fortnight. During cropping period *H. armigera* egg load ranged from 1.63 to 2.22 eggs per plant whereas, larvae ranged from 1.45 to 2.02 larvae per plant. Peak incidence of *S. litura* eggs and larvae was recorded during October first fortnight. *S. litura* egg load ranges from 0.026 to 0.053 egg mass per plant whereas, larvae ranged from 0.162 to 0.573 larvae/plant.

Kurl and Kumar (2010) reported that the fruit borer, *H. armigera* (Hubner) larvae appeared on tomato crop in 2nd standard week (January) and continue till 21st standard week. The highest build-up of larvae was recorded in the 15th standard week. Thereafter, the larvae population decline. The average maximum temperature of 32.9°C, minimum temperature of 17.9°C, morning humidity of 74.2%, evening humidity of 30.1% coupled with rainfall of 6.0 mm prevailing during 10th standard week to 15th standard week were found most suitable for larval population build-up. Above and below of these ranges did not favour the development of larvae.

Singh *et al*. (2011) reported that the first appearance of *H. armigera* was recorded in 50th and 52nd standard week. The initial population gradually increased and remained confined to vegetative growth but it rapidly increased during fruiting stage and attained its peak in 15th standard week (2nd week of April). Thereafter, the pest population declined.

Chula *et al* (2017) showed that the activity of tomato fruit borer continued throughout the crop season with larval population peaking twice. Occurrence commenced from 8th standard week (February third week) with an average population of 2.04% infestation. The population increased and gradually reached its weak level of infestation 48.14% at 13th standard weak (March second weak) thereafter a declined trend was observed as temperature decreased gradually till the crop was matured in last week of April. The highest mean population of 7.05 larva/plant was observed during at 12th standard week in year.

Vikram *et al*. (2018) reported that incidence of *H. armigera* on tomato started in 8th standard meteorological week (third week of February) with an average population of 2.0 larvae per plant thereafter, larval population increased gradually and reached to its peak level (6.0 larvae per plant) in 12th standard meteorological week (third week of March).

Harshita *et al*. (2018) reported that peak infestation of *H. armigera* (6.06 and 6.30 larvae per plant) was recorded during March in 2015-16 and 2016-17, respectively. The first incidence of *H. armigera* during 2015-16 was observed on 12th December'2015 with a mean population of 0.46 larvae per plant and larval population gradually increased till the harvest of the crop. The larvae attained maximum population of 6.06 larvae per plant on 22nd March'2016. During 2016-17, the first incidence of fruit borer was noticed on 17th January'2016 with a mean population of 0.9 larvae per plant and larval population gradually increased till the harvest of the crop. The larvae attained maximum population of 6.3 larvae per plant on 20th March'2017.

Sapkal *et al*. (2018) conducted an investigation on the seasonal incidence of *Helicoverpa armigera* (Hubner) on tomato under protected cultivation in Parbhani during Kharif 2017-18 and reported that the population started during 35th SMW (0.5 larvae/plant) and there after the population reaches 2.8 larvae plant in the 47th SMW and the highest population recorded during fruiting stage of the crop in the range of 4.2 larvae per plant.

Mahapatra *et al*. (2018) noticed a maximum population of *H. armigera* during 5th Standard week of February 2017 (3.60 per plant) followed by 4th Standard week of January (3.10 per plant) whereas highest incidence of *S. litura* was observed in 5th standard week of February (2.0 per plant). As compared to *H. armigera*, the incidence of *S. litura* was found to be quite less during the period of observation (October 2016-March 2017).

Kharia *et al*. (2018) carried out an investigation during rabi season of 2014-15 in a farmer's field of an extensive tomato growing village Surajgarh, Haryana and reported that population of fruit borer, *Helicoverpa armigera* and whitefly, *Bemisia tabaci* were recorded starting from the 4th standard week at crop establishment stage and till 18th standard week at the crop maturity stage. The first appearance of the fruit borer was noticed during 11th standard week (12th - 18th March) and it reached maximum in 16th standard week (16th - 22nd April), while the population decreased up to crop maturity. A negligible population of whitefly was first observed during 16th standard week which remained below ETL ranging from 0.1 to 0.2 adults per plant till crop maturity (18th standard week).

Hath and Das (2004) observed the incidence of aphid (*A. gossypii*), leaf miner (*L.trifolii*) and fruit borer (*H. armigera*) at various intensities in late-planted tomato cultivars Pusa Ruby and Abinash-II under terai agroecology of West Bengal during 2000-01. Low population of aphid was noticed in the field from the third week of February up to the last week of March. At the peak, during the first week of March, the population was 4.47 and 6.66 aphids/5 leaves in Pusa Ruby and Abinash-II, respectively. A very non-significant level of leaf miner infestation (0.34%) was noticed during the third week of February. As the season and age of plant progressed the intensity of damage (in terms of percentage damaged leaves) also increased. The highest infestation was observed during the second week of April. The incidence of fruit borer was observed from the third week of March and second week of April, and the level of infestation was always high. The peak was recorded during the first week of April.

Kharpuse and Bajpai (2007) recorded maximum leaf miner infestation in tomato during March, while whitefly population peaked during first week of March and fruit borer population peaked in the third week of March, respectively.

Kumar (2008) reported that on tomato, whitefly appeared during the 2nd week of January, whereas aphid, jassid and leaf miner appeared in the 1st week of January, while fruit borer appeared during the last week of February. The peak activity of whitefly, jassid and winged aphid was recorded during last week of February. Highest leaf miner activity was recorded during the last week of March, while highest larval population of fruit borer was recorded during the 1st week of April at Jabalpur.

Chakrborty (2011) observed the incidence of *A. gossypii* population in tomato crop field at Alipurduar, West Bengal assessed by randomized block design during four consecutive kharif seasons. The population initiated at about 48th standard meteorological weeks (SMW), improved at first slowly up to 6^{th} SMW attaining the maximum at about 8^{th} SMW which was maintained up to about 11^{th} SMW. He also reported the seasonal incidence of *L. trifolii* on tomato and noticed that the population of *L. trifolii* was initiated at about 46^{th} standard meteorological weeks (SMW), improved at first slowly up to 1^{st} SMW and then steadily up to 6^{th} SMW attaining the maximum at about 8^{th} SMW which was maintained up to about 13^{th} SMW.

Waluniba and Ao (2014) conducted an experiment in the year 2010-2011 at experimental cum research farm, School of Agriculture Sciences and Rural Development, Nagaland University, and showed that the incidence of aphids (*A. gossypii*) was observed at 52^{nd}, 2^{nd} and 4^{th}, whitefly *(B. tabaci*) at 4^{th}, 7^{th} and 9^{th}, Serpentine leaf miner (*L. trifolii*) at 4^{th}, 7^{th} and 9^{th} and fruit borer (*H. armigera*) at 9^{th}, 11^{th} and 13^{th} standard week on D1, D2 and D3 respectively.

Mondal *et al*. (2019) revealed that the population of aphid initiated on second week of January while it disappeared from end of March. Population of white fly initiated on first week of February while the population disappeared from 15^{th} standard week onward. In case of tomato fruit borer, population initiated in the 7^{th} standard week and disappeared on 15^{th} standard week in the year.

2.2 Biology of leaf miner, *Liriomyza trifolii* (Burgess) on tomato

The adult *L. trifolii* (Diptera, Agromyzidae) is a small fly, up to 2 mm long. The head is yellow with plum-red eyes; the thorax and abdomen are greyish-black with a noticeable yellow patch at the hind end of the mesonotum. The underside and legs are mostly pale yellow. The eggs are oval, creamy or translucent and approx- imately 0.2 and 0.1 mm in length and breadth, respectively. The larva, which is initially colourless, darkens to yellow as it matures and the pupa is orange-yellow. Both the larva and pupa have a pair of distinctively shaped tricorn spiracles (Bartlett and Powell, 1981).

L. trifolii is about 2 mm long, with a yellow head and plum red eyes. A yellow patch is noticeable at the hind end of the mesonotum, leaving the rest of the thorax and abdomen grayish black. The legs and underside have a pale yellow shade (Minkenberg and van Lenteren, 1986).

Female flies use their ovipositor to puncture the leaves of the host plants causing wounds which serve as sites for feeding (by both male and female flies) or oviposition. Feeding punctures of *Liriomyza* species are rounded, usually about 0.2 mm in diameter, and appear as white speckles on the upper leaf surface. The eggs are inserted just below the leaf surface and hatch in 2-5 days according to temperature. Many eggs may be laid on a single leaf. The period of egg development varies with temperature and ranges from 2-8 days. There appears to be considerable variation in the relationship between temperature and development and in developmental threshold (6.2- 13.4°C). Larval development varies with temperature and host plant. The duration of the pupal stage varies inversely with temperature, but at least 50% of the total development time of a *Liriomyza* individual is spent in this stage. Total development time of the pupa at greenhouse/field temperatures is about 8-11 days. (Parrella, 1987).

Bethke and Parrella (1985) reported two types of leaf punctures caused by *L. trifolii* on tomato and chrysanthemum leaves, fan shaped punctures without eggs and tubular ones with or without eggs. However, all the leaf punctures were found to be as feeding punctures.

Feeding punctures and leaf mines are usually the first and most obvious sign of the presence of *Liriomyza*. Feeding punctures appear as white speckles between 0.13 and 0.15 mm in diameter. Oviposition punctures are usually smaller (0.05 mm) and are more uniformly round. The larval mine is on the upper surface of the leaf, in the leaf mesophyll tissue, and is linear, shallow, at first greenish, then later whitish, winding irregularly and frequently forming a secondary blotch. The trails of frass are distinctive in being deposited in black strips alternately at either side of the mine (like *L. sativae*), but becomes more granular towards the end of the mine (unlike *L. sativae*) (Spencer 1973). The duration of larval development also depends on temperature and probably host plant. Several generations can occur during the year, breeding only being restricted by the temperature and the availability of fresh plant growth in suitable hosts (Spencer, 1973). *L. trifolii* pupation occurs outside the leaf, in the soil beneath the plant. Pupa development will vary according to season and temperature. Adult emergence occurs 7-14 days after pupation at temperatures between 20°C and 30°C (Leibee, 1984). Peak emergence of adult *L. trifolii* occurs before midday (McGregor, 1914). Males usually emerge before females and mating takes place from 24 hours after emergence. Adults of *L. trifolii* live between 15 and 30 days. On average, females live longer than males. There are three larval stages that feed within the leaves. The larvae predominantly feed on the plant in which the eggs are laid. The larvae of *Liriomyza spp*. leave the plant to pupate (Parrella and Bethke, 1984) so pupae may be found in crop debris, in the soil or sometimes on the leaf surface. The rate of immature development of *L. trifolii* is dependent on temperature. At a uniform temperature of 28°C one generation cycle can be accomplished in 14-15 days, but at lower temperatures the time taken is progressively longer.

Eggs are 0.2 x 0.1 mm, translucent initially and turn creamy later. They are laid just below the epidermis (Minkenberg, 1988).

Eggs are oval in shape and small in size, measuring about 0.2–0.3 x 0.10–0.15 mm. Initially they are clear but soon become creamy-white. First-instar larvae are colourless on hatching, turning pale yellow-orange; later instars are yellow-orange. A headless maggot measures up to 3 mm in length when fully grown. Larvae (and puparia) have a pair of posterior spiracles shaped like a triple cone. Each posterior spiracle opens by three pores, one pore located toward the apex of each cone. The puparium is oval, slightly flattened ventrally, and measures 1.3–2.3 x 0.5–0.75 mm, with variable color, pale yellow-orange often darkening to golden brown. Adults are small flies, measuring less than 2 mm in length. The wings are transparent and measure 1.25–1.9 mm. Scutellum bright-yellow with inner setae usually standing on yellow ground; prescutum and scutum black with gray bloom. Thorax and abdomen are mostly gray and black, although the ventral surface and legs are yellow. Male and female *L. trifolii* are generally similar in appearance (Mujica *et al*., 2016).

L. trifolii was seen to inhabit and feed from both lower and middle tier of the plant (Zoebisch and Schuster 1990). The larvae prefer the palisade mesophyll in chrysanthemum (Parrella *et al*., 1985). Initially colourless, the larva gains a yellow color as it matures through three larval stages. The third instar cuts an opening at the end of the mine to exit (Minkenberg and van Lenteren, 1986). While leaf miners feed throughout the day, they oviposit during midday, and both larval and adult emergence is between 0900-1200 h. Most larvae that emerge from the leaves drop down to pupate in the soil while some do so in exposed places (Charlton and Allen, 1981).

Webb and Smith (1969) pointed out that duration of *L. munda* varies with temperature and host plant. They found that time for larval development on bean decreased as temperatures increased from 15.6°C to 26°C. At comparable temperatures larval development was more rapid in bean than in tomato or chrysanthemum. It has been reported that larvae of *L. trifolii* may aestivate at temperatures above 26°C

(McGregor, 1914; Webb and Smith, 1969) and that larval development above this temperature rapidly decelerates.

Beri (1974), reared *L. brassicae,* under laboratory conditions of 28° ± l°C and 84% ± 2% R.H. He reported that the egg was somewhat rounded anteriorly and posteriorly and about 0·28 mm long with average incubation period of 3 days, 7 hours and 51 minutes and average larval duration of 6·5 days. The average durations of the first, second and final instars were 51, 42·5 and 64 hours, respectively. The final instar larva was found to abandon the mine and pupate in the soil. The total pupal period was 9·17 days under constant temperature and humidity. The fly emerged from a slit formed at the anterior region of the pupa. The copulation period ranged from 22 to 45 min. The eggs were always laid singly. The larva, after hatching, feed on the mesophyll tissue of the leaf and with the result of extensive feeding, a linear serpentine mine is formed. The infestation is heavier in shady places.

The egg, larval and pupal stages on chrysanthemum averaged 4.1, 9.9 and 15 days, respectively, and the adult males and females lived for averages of 14.5 and 26.3 days, respectively. during which time the average temperature was 18 °C and the relative humidity averaged 82.7% (Prieto *et al*. 1982).

Leibee (1984) studied the influence of temperature on development and fecundity of *L. trifolii* on celery and observed that pupal survival was very low (9.4%) at 35°C as compared with lower temperature (>80 per cent survival). Maximum oviposition rate (38.67eggs/female) was attained at 30°C. Low oviposition rate and fecundity at 15°C indicated that this temperature was near to threshold activity for adult. The pre-pupal period varied from 2.67 ± 0.18 hrs at 35°C to 4.98 ± 0.73 hrs at 20°C on celery.

Leibee (1984) found that the incubation period of eggs of *L. trifolii* were 1.99 ± 0.03, 2.38 ± 0.05, 2.33 ± 0.04, 4.4 ± 0.04 and 9.97 ± 0.47 days at 35°C, 30°C, 25°C, 20°C and 15°C, respectively.

Parrella (1984) observed that maximum feeding by *L. trifolii* on chrysanthemum sp. occurred at 32.2°C, while significantly more oviposition (20.86 eggs/female/day) was found at 26.7°C temperature.

Schuster and Patel (1985) studied development time of *Liriomyza trifolii* larvae at temperatures of 15.6, 21.1 and 26.7 and 32.2°C and reported mean development time as 10.1, 7.1, 4.4 and 3.5 days respectively.

Mortality of *L. trifolii* decreases with increase in temperature from 11.5°C, to reach minimum at about 25°C and then increases again (Parrella *et al*., 1981, Miller and Isger 1985). The same temperature (25°C) was optimum for emergence of *L. trifolii,* while after 30°C a sharp increase in immature mortality was recorded (Minkenberg and van Lenteren 1986). The development time though, was seen to decrease from 15°C to 35°C (64d to 14d) (Leibee, 1982, 1984). With decrease in temperature from 35°C, female longevity increased and peaked at around 20°C and then dipped slightly (Leibee, 1982, 1984). Humidity was not found to play a major role, except in extreme cases of drought or moisture.

Chandler and Gilstrap (1987) studied the biology of *L. trifolii* on bell peppers (*Capsicum annum* L.) in laboratory at 24°C and reported that the females laid on an average 17.9 ± 28.8 eggs during their life span of 14.4 ± 5.8 days. Only 68.9 per cent of eggs were viable. Mean development time from oviposition to adulthood was 20.2 ± 0.4 days. The egg, larval and pupal stages lasted for 4.2 ± 0.1, 5.8 ± 0.2 and 10.2 ± 0.4 days, respectively. The life table analysis indicated that the egg and pupal stages of the agromyzid had highest levels of unexploited mortality.

Milkenburg (1988) studied the biology of *Liriomyza* with the effects of three constant (15°C, 20°C and 25°C) and one alternating (16-22°C, mean 19.5°C) temperatures on development, mortality, feeding, fecundity and longevity of *L. trifolii* on tomato plants cv. 'Moneydor' in the laboratory. Development rates and thresholds for each instar were estimated by mean of linear regression. No correlation was found between life history variables and pupal length. Generation time varied from 48 days at 15°C to 24 days at 25°C. Ninety percent oviposition occurred within the first 115 degree-days of adult life at both 20°C and 25°C. Fecundity and longevity were highly correlated with the number of feeding punctures. The data indicated that tomato is a suitable host plant allowing populations of *L. trifolii* to increase if temperatures are above 16°C.

Van Elferen and Yarhom, (1989) carried out a study was to determine the distribution of feeding and oviposition punctures made by *L. trifolii* Burgess on gypsophila *(Gypsophila paniculata)* and bean *(Phaseolus vulgaris)* leaves, and the development times of the immature stages on these plants. The larval period (±SE) observed at temperatures of 20, 25 and 30°C was 9.9 ± 0.2, 4.4 ± 0.1 and 3.7 ± 0.1, and 5.5 ± 0. l, 3.7 ± 0.1 and 2.4 ± 0.1 days, on gypsophila and bean, respectively. The pupal period at 17, 20, 25 and 30°C lasted 19.9 ± 0.2, 14.7 ± 0.1, 10.4 ± 0.1 and 7.8 ± 0.1 days, respectively.

Lakshminarayana *et al*. (1992) observed that the females of *L. trifolii* deposited hyaline eggs singly in the leaf tissue. The egg, larval and pupal period lasted for 2-3 days (Av. 2.5 days), 6-9 days (7.25) and 6-7 days (6.5), respectively. The maggots dropped on to the soil for pupation. Few numbers of maggots pupated on leaf surface. The adults lived for 3-6 days (4.75)

Chein and Ku (1996) studied the biology of *L. trifolii* and reported that emergence, oviposition and feeding of adults followed diurnal pattern. The observed lowest and highest temperatures for oviposition were 12°C and 40°C, respectively. Lower and upper development thresholds were 8.7°C and 38°G, respectively. Maximum population growth was predicted at 35°C with almost no increase at 15°C. Optimum temperature for oviposition ranged from 20°C to 25°C. At 25°C the development period and survival rate from egg to adult was 16.6 days and 81.6 per cent, respectively.

Nadagouda *et al*. (1996) evaluated the biology of *L. trifolii* on cotton, castor, cowpea and tomato at Raichur, Karnataka during 1995-96. They revealed that the egg, larval, prepupal and pupal period varied from 2.59 to 3.74 days, 3.93 to 4.05 days, 62 to 75 minutes and 9.82 to 10.65 days, respectively. Egg size varied from 190 to 196μ in length and 103 to 116μ in width while the size of puparia ranged from 1.46 to 1.69 mm in length and 0.59 to 0.81 mm in width on various hosts. The male and female longevity varied from 2.56 to 6.90 days and 4.69 to 9.80 days, respectively. The total life cycle ranged from 19.19 to 24.69 days for male and 21.32 to 27.59 days for female. Fecundity varied from 64.1 to 158 eggs and the ratio of ovipositional to feeding punctures varied from 1: 5.37 to 1: 8.55 on different host plants.

Nadagouda *et al*. (1997) noticed that life cycle of serpentine leaf miner varied with different hosts. They reported that cowpea was the most preferred host than others. The fecundity on cowpea was highest 158.6 ± 8.2, while it was found to be 110.8 ± 11.53, on 77.4 ± 7.69 and 64.1 ± 6.23 eggs on castor, cotton and tomato respectively.

Minkenberg and Helderman (1999) reported that optimum temperature for development and reproduction of *L. trifolii* on tomato was about 25°C.

Jeyakumar and Uthamasamy (2000) conducted biological studies on *L. trifolii* on cotton, *Gossypium hirsutum* L., tomato, *Lycopersicon esculentum* Mill., and cowpea, *Vigna sinensis* (L.) Walp. They revealed that its life cycle varied with different hosts. The duration of the pupal stage of *L. trifolii* was the longest in the leafminer's life cycle. *L. esculentum* was the preferred host - females of *L. trifolii* survived the longest and had the highest fecundity on this host. Sex discrimination was possible at the pupal stage, on the basis of size; female adults were found to emerge from larger-sized pupae and males from smaller ones.

Lanzoni *et al*. (2002) studied the influence of four constant temperatures (15, 20, 25, and 30°C) on development time and survivorship of *L. trifolii* (Burgess) and found that development time for egg ranged between, 6.3 ± 0.7 days, 3.6 ± 0.2 days, 2.1 ± 0.1 days and 1.6 ± 0.1 days at 15°C, 20°C, 25°C, and 30°C, respectively, larval period range from 14.3 ± 1.1 days, 6.7 ± 0.5 days, 4.6 ± 0.5 days and 3.6 ± 0.4 days at 15°C, 20°C, 25°C, and 30°C, respectively, pupal period 33.2 ± 2.3 days, 13.3 ± 0.6 days, 9.2 ± 0.4 days and 6.9 ± 0.3 days at 15, 20, 25, and 30°C, respectively. The total development of *L. trifolii* at 15°C, 20°C, 25°C, and 30°C was found to be 53.9 ± 2.5 days, 23.6 ± 0.8 days, 16.1 ± 0.7 days and 12.0 ± 0.5 days, respectively.

Pramod (2002) made observations on various life stages of serpentine leaf miner were made at a room temperature of 25 ± 1°C. The round shape eggs were laid singly in the leaf tissues with an incubation period of 2.52 ± 0.71 day. The hatching of the eggs was an average of 89.0 ± 7.387 per cent. The total larval period was on an average 4.96 ± 0.84 days. The average period of pre-pupal and pupal period was recorded as 3.48 ± 0.91and 8.8 ± 0.91 days, respectively. The average longevity of adult male and female fly was observed to be 4.96 ± 1.05 and 6.04 ± 1.09 days, respectively. And total life span of male was 20.50 ± 0.87 and for female 23.0 ± 1.12, days. The number of eggs produced by a single female varied from 135 to 452 with an average of 315.4 ± 96.47 eggs/female.

Saradhi and Patnaik (2003) reported that in tomato, the serpentine leafminer, *L. trifolii* (Diptera: Agromyzidae), completed one generation in 15-21 days with a mean of 17.9 days. The egg, larva, pre-puparium and pupal stages lasted for 4.4 ± 0.68, 3.6 ± 0.50, 0.20 ± -0.05 and 9.7 ± 1.12 days, respectively. The percentage of pupation and adult emergence was 58 and 72, respectively. The average fecundity was 23 and the maximum number of eggs (8.8/female) was laid on the 3rd day of adult captivity. The oviposition period lasted for 6 days. The sex ratio (female:male) was 1:0.78. The ratio of oviposition:feeding puncture was 1:8.03.

Choudhury and Senapati (2004) reported that the duration of the life cycle of leaf miner, *Liriomyza trifolii* was longer (22.22 days) during February-March and shorter (15.68 days) during the relatively warmer month (April) of the cropping season. The developmental stages and life cycle of the pest were negatively correlated with temperature and relative humidity. The relatively higher temperature and relative humidity that prevailed during April favoured the rapid multiplication and shortened the life cycle of the pest, which resulted in higher level of infestation during the period under field conditions.

Costa-Lima *et al*. (2010) evaluated the influence of temperature and relative humidity on the survival and reproductive parameters of *L. sativae* in cowpeas (*Vigna unguiculata* L. WaLp.) (Fabales: Fabaceae). under temperatures of 18, 20, 22, 25, 28, 30, and 32 ± 1°C (50 ±10% RH) and relative humidity values of 30, 50, 70, and 90 ± 10% (25 ± 1°C) under a 14 L:10 D photoperiod. Adult longevity decreased as temperature and relative humidity increased and was greater, in general, for females. The preoviposition and oviposition periods also decreased as temperature increased, whereas relative humidity only caused reductions in the oviposition period at higher levels. Fecundity was similar in the range from 18 to 30°C but decreased at 32°C with respect to relative humidity; the best performances of *L. sativae* occurred at lower levels. The pattern of oviposition rate changed with temperature and relative humidity. Regardless of temperature and relative humidity, *L. sativae* laid between 75 and 92% of its eggs on the adaxial surface of the cowpea leaves. This information will be highly useful to design a leafminer production system aimed at the multiplication of natural enemies, as well as for pest management in the field.

Ganapathy *et al*. (2010) reported that in life cycle of serpentine leaf miner, egg period lasted for 96.2 ± 10.3 hrs. Larval and pupal periods were 7.5 ± 2.2 and 9.5 ± 0.9 days, respectively. Females lived longer (6.7 days) and laid about 92.2 ± 8.6 eggs whereas, males survived only for 4.1 days. Sex ratio was nearly unity (1.0: 0.9), and total life cycle was completed in 23-29 days.

Owino (2014) studied the effect of temperature on the life history of *L. trifolii* Burgess (Diptera: Agromyzidae) at seven constant temperatures of 10, 15, 18, 20, 25, 30 and 35°C. Egg, larval and pupal development did not take place at 100C, development time was shortest at 35°C (Egg 1.27 ± 0.00: larvae 2.43 ± 0.00 and pupa 6.82 ± 0.01 days), longest at 15°C (Eggs11.4 ± 0.0014 days while larvae and pupa development did not take place), lowest mortality was at 25°C (0.070, 0.449, 0.384 for egg, larvae and pupa respectively) and highest total oviposition was recorded at 27°C at 60 eggs per female. Development rate was inversely proportional to temperature; male senescence was highest at 30°C (0.56 1/days) while female senescence was highest at 35°C (8.66 1/days).

Mujica *et al*. (2016) studied the development of *L. trifolii* completed from egg to adult at temperatures of 15º–35ºC and pointed out that development time decreased with increasing temperature and was shortest with 8.4 days at 35ºC. Mortality was lowest at 25ºC for eggs and larvae (11% for both stages) and at 20ºC for pupae (9%). The highest mortality was observed at 15ºC for eggs (60%) and at 35ºC for larvae (72%) and pupae (67%). Significant differences were observed in the longevity between male and female adults, with female longevity twice as long as males at all temperatures. The lowest senescence rate was observed within the temperature range of 20º–25ºC. Oviposition peaked at 25ºC with 215 eggs per female; at 15º and 35ºC, 12 and 52 eggs were laid on average, respectively.

Okram *et al*. (2017) carried out laboratory experiments on biology of *L. trifolii* on tomato. The results of the laboratory experiments revealed that the duration of various developmental stages i.e. oviposition, incubation, larval and pupal periods were recorded with a mean of 2.41 ± 0.63, 3.39 ± 0.62, 2.87 ± 0.33 and 12.29 ± 1.13 days respectively and the adult stages lasted for 8- 13 days with a mean of 10.02 ± 1.25 days. The fecundity ranged from 13 to 23 eggs per female with a mean of 17.5 ± 3.28 and egg hatching per cent ranged from 84.21 to 100%. The length and breadth of various developmental stages i.e. egg, larva, pupa, adult male and female were found to 0.18 ± 0.02, 0.10 ± 0.01; 0.10 ± 0.01, 0.53 ± 0.06; 1.60 ± 0.08, 0.74 ± 0.03; 1.62 ± 0.07, 0.77 ± 0.03 and 1.78 ± 0.05, 0.81 ± 0.03 mm respectively.

Capinera (2017) pointed out that the female deposits the eggs on the lower surface of the leaf, but they are inserted just below the epidermis. Eggs are oval in shape and small in size, measuring about 1.0 mm long and 0.2 mm wide. Initially they are clear but soon become creamy white in color. The larva is colorless in the initial stage but becomes yellowish as it matures. The mean and range of body lengths of the first instar are 0.39 (0.33–0.53) mm. For the second instar, the body measurements are 1.00 (0.55–1.21) mm. For the third instar, the body measurements are 1.99 (1.26–2.62) mm. The larva normally leaves the leaf mine and drops to the soil to pupate (or more technically, pupariate). The puparium is initially yellowish, then golden brown, but turns darker brown with time. This is oval and slightly flattened ventrally. It measures about 1.3 to 2.3 mm long and 0.5 to 0.75 mm wide. Adults are small, measuring less than 2 mm in length, with a wing length of 1.25 to 1.9 mm. The head is yellow with red eyes. The thorax and abdomen are mostly gray and black although the ventral surface and legs are yellow. The wings are transparent. Key characters that serve to differentiate this species from the vegetable leafminer, *Liriomyza sativae* Blanchard, are the matte, grayish black mesonotum, and the (mostly to entirely) yellow hind margins of the eyes.

2.3 Relationship of population build up of leaf miner and other insect pests infesting tomato with weather parameters and development of prediction models

Jagannatha (1994) found that the population of *L. trifolii* was negatively correlated with relative humidity, wind velocity and rainfall and positively correlated with minimum temperature.

Bagmare *et al*. (1995) studied the effect of weather parameters on the populations of different species of agromyzids on various host plants at Jabalpur. Correlation analysis of the variables showed that mean temperature and sunshine hours had a positive correlation however, with the population of *L. trifolii*. Rainfall and relative humidity had a negative correlation. In case of *L. trifolii,* linear equations $Y = -1.82 + 0.08 X_1 - 0.00049 X_3$ ($R^2 = 0.55$) and $Y = 1.48 + 0.06 X_1 + 0.06 X_2 - 0.03 X_4$ ($R^2 = 0.75$) were selected as the best fit for predicting its population on soyabean and tomato, respectively.

Singh *et al*. (1996) studied the role of abiotic factors in seasonal abundance of the pest and reported that 84 - 92 per cent variability in the population of *L. trifolii,* could be accounted by weather factors especially sunshine hours and rainfall at Hissar.

Choudary and Rosaiah (2000) reported that the influence of weather parameters on the leaf miner incidence revealed that minimum temperature and evening relative humidity had negative correlation while wind velocity and sunshine hours showed positive correlation. The step-down regression analysis showed that minimum temperature, morning relative humidity and wind velocity together influenced the damage by the pest.

Asalatha, (2002) reported that leaf infestation by leaf miner and its population on tomato were positively correlated with maximum temperature and sunshine hours and negatively correlated with relative humidity and minimum temperature, respectively.

Choudhury and Senapati (2004) conducted a field experiment in Pundibari, West Bengal, India, during 1997-99, and observed higher level of leaf miner (*L. trifolii*) infestation in tomato (cv. Abinash-II) from late March to late May when the average temperature, relative humidity, sunshine hours per day, and total rainfall reached 21.60-27.23 degrees C, 65.39-80.25%, 3.39-8.49 h per day, and 375.30 mm, respectively. Leaf miner incidence was significantly and positively correlated with temperature, minimum relative humidity, and rainfall, but was non-significantly and positively correlated with the average relative humidity. Temperature and relative humidity gradient showed significantly negative correlation with leaf miner incidence.

Reddy and Kumar (2005) observed a highly significant negative correlation between the seasonal abundance of *L. trifolii* and mean rainfall (-0.6481 and -0.5863), total rainfall (-0.7206 and -0.6976) and number of rainy days (-0.7001 and -0.7114). A positive non-significant correlation between the seasonal abundance of the pest, and the maximum and minimum temperatures (0.1172 and 0.2648; 0.1193 and 0.2398, respectively) and negative non-significant correlation between morning and evening relative humidity (-0.2510 and -0.3258; -0.2601 and -0.3187, respectively) was observed.

Galande and Ghorpade (2010) recorded peak activity of leaf miner when the maximum temperature and morning relative humidity was at 34.14 °C to 35.23 °C and 70.75 to 77.32 per cent respectively. The maximum temperature showed significant and positive correlation (r=0.872**), whereas morning relative humidity showed significant but negative correlation (r=-0.578*) with *L. trifolii* incidence. In case of *L. trifolii*, linear equation Y=7.8155+0.5187 Tmax-0.2587 MRH (R2=0.88) was found to be the best fit for predicting the leaf miner incidence in tomato crop based on weather parameters.

Chakraborty (2011a) reported that abiotic conditions such as maximum temperature, minimum temperature, temperature gradient, average temperature, maximum relative humidity, minimum relative humidity and sunshine hours had significant negative influence on *L. trifolii* population. In case of relative humidity gradient, a positive influence was observed. In addition, other factors such as average relative humidity, number of rainy days, rainfall expressed insignificant positive effect on population development.

Variya and Bhut (2014) revealed that correlation studies indicated number of mines, larvae as well as percent damaged leaves had significant negative correlation with maximum temperature (-0.68162**, -0.71533** and -0.71308**), minimum temperature (-0.78761**, -0.82541** and -0.82630**), mean temperature (-0.77091**, -0.80886** and -0.80795**), morning vapour pressure (-0.73098**, -0.77537** and -0.77992**), evening vapour pressure (-0.71101**, -0.77414** and -0.74275**), mean vapour pressure (-0.73715**, -0.79196** and -0.77982**) and mean vapour pressure deficit (-0.62057**, -0.60331** and -0.57694**), respectively. Moreover, mines and larvae significantly and negatively correlated with morning vapour pressure deficit (-0.48046*) and evening relative humidity (-0.43393*).

Singh *et al*. (2018) reported that the population of serpentine leaf miner was found significantly and positively correlated with maximum temperature (r = 0.57) but significant negative correlation was evaluated with morning (r = -0.62) and evening (r = -0.67) relative humidity.

Prasad *et al*. (1984) reported that maximum, mean and minimum temperatures exiting one or two weeks preceding the aphid population at any time showed a significant and negative correlation with the prevailing population, but with a lower value of determination factor (R2). When the aphid population along with mean and minimum temperature, all existing one week before the prevailing aphid population, were involved in regression analysis, the interaction explained nearly 72 % of the variation.

Chakraborty (2011b) reported that abiotic conditions such as maximum temperature, minimum temperature, temperature gradient, average temperature, minimum relative humidity and sunshine hours had significant negative influence on *A. gossypii* population. In case of maximum relative humidity and relative humidity gradient a positive influenced was observed. Other factors such as average relative humidity, number of rainy days, rainfall expressed insignificant positive effects on population development.

Shukla (2014) reported that aphids showed positive correlation with rainfall (r = 0.261) and negative correlation with both maximum and minimum temperature. Aphids showed positive correlation with relative humidity.

Shakeel *et al*. (2014) reported that aphid population had significant negative correlation with minimum and maximum temperature, whereas significant positive correlation with relative humidity, and non-significant negative correlation with rainfall.

Ghosh (2017) concluded that the weather parameter such as temperature (maximum, minimum and average) had a non-significant positive influence on aphid population while non-significant negative influence found with weekly total rainfall. Average relative humidity express significant positive effect on population development.

Gupta *et al*. (1997) studied on impact of abiotic factors on population build-up of whitefly on cotton crop in IARI, New Delhi reported negative correlation of relative humidity and rainfall on population build-up of whitefly who reported a non-significant correlation with regard to the functional relationship between pest population and biotic factors.

Abdel *et al*. (1998) reported that temperature had a significant effect on both egg and nymphal population of white fly on tomato while relative humidity had no significant effect.

Chaudhuri *et al*. (2001a) reported that temperature, relative humidity and rainfall were found negatively correlated with white fly population.

The correlation among whitefly population and weather factors showed that temperature, relative humidity and precipitation affected negatively to whitefly population (Umar *et al*., 2003).

Lanunocheta and Pankaj (2012) found that whitefly population was positively correlated with temperature whereas relative humidity showed negative non significant correlation with pest population.

Chakraborty (2012) revealed that abiotic conditions had significant negative influence on *B. tabaci* population. In case of relative humidity gradient, a positive influence was observed.

Subba *et al*. (2017) reported that weekly population counts on white fly showed non-significant negative correlation (p=0.05) with temperature and weekly total rainfall where as significant negative correlation with relative humidity.

Subba and Ghosh (2016) reported that correlation coefficient values revealed that temperature difference had significant positive influence on thrips while significant negative correlation with temperature (minimum and average), relative humidity (minimum, average) and weekly total rainfall. In case of maximum relative humidity and maximum temperature non-significant negative influence was observed.

According to Jamuna *et al.* (2019) correlation studies indicated that, minimum temperature, rainfall, rainy days and evening relative humidity were found significant negative correlation with the thrips population, while sunshine hours and morning relative humidity found significant positive correlation with the thrips population.

Prashant et al. (2007) conducted a study at Meerut, Uttar Pradesh, India, in the spring season, to determine the population intensity of insect pests on cabbage at weekly intervals. *Spodoptera litura* population was first recorded on the last week of January in late season cabbage. Thereafter, it gradually reached its maximum level (4.2 larvae/ plant). The population was positively correlated with the mean temperature but negatively correlated with relative humidity.

Satyanarayana *et al*. (2010) concluded that the incidence of *Spodoptera litura* in terms of larval population showed non-significant relationship with maximum temperature, relative humidity, wind speed, spiders and coccinellid predatory beetles, but significant relationship with minimum temperature.

Selvaraj *et al*. (2010) reported that build-up of *S. litura* population showed a positive correlation with relative humidity, sunshine hours and dewfall, whereas negatively correlated with wind velocity. The determination of the effects of different weather factors on population and incidence of *S. litura* in cotton is essential for effective pest management. This study will be very helpful not only in forecasting outbreaks of *S. litura* but also in formulating effective pest management strategies.

Shakya *et al*. (2015) studied the incidence of cutworm, *Spodoptera litura* on tomato and observed that correlation with weather parameters revealed significant negative correlation with maximum temperature (r=-0.5698) and minimum temperature (r=-0.5684) and significant positive correlation with maximum relative humidity (r=0.6813), minimum relative humidity (r=0.4397) and rainfall (r= 0.1800).

Kadu *et al*. (1987) reported that the activity of *Helicoverpa armigera* on tomato increased with the rise in temperature.

Kakati *et al*. (2005) reported that the population build-up of the tomato fruit borer pest had significant negative correlation with minimum temperature and non-significant correlation with maximum temperature.

Waqas *et al*. (2010) studied the population dynamics of *H. armigera* (Hubner) on tomato in Punjab province of Pakistan. They reported that temperature was positively while relative humidity was negatively correlated with larval population and fruit infestation, respectively.

Rainfall and relative humidity were negatively correlated with the *H. armigera* activity, whereas, maximum and minimum temperature were positive correlation with relative humidity. Likewise, maximum and minimum temperature were positively associated in enhancing the pest populations build up. The maximum temperature demonstrated negative impact with relative humidity in the build-up of larval population of *H. armigera* (Singh *et al*., 2011).

Chakraborty *et al*. (2011) studied the population dynamics of *H. armigera* were studied in Uttar Dinajpur, West Bengal, India, during 2007-09. The maximum temperature and minimum temperature showed a significant positive correlation with larval population. The correlation of sunshine hours, rainfall and number of rainy days on pest incidence was negative.

Hameed *et al*. (2015) proposed pests forecasting model on the basis of past 5 years pest abundance data. Population data was taken from different locations of Multan district from 2006-2010 by Pests Warning Wing of Agriculture Department, Govt. of Punjab, Pakistan. Weather in relation to *Helicoverpa armigera* (Hub.) abundance was summarized on the basis of multivariate regression and correlation tactics. Results revealed that maximum temperature had negative impact on American bollworm population while relative humidity had highly significant positive effect on *Helicoverpa armigera* population. ARIMA model forecast American bollworm percent hot spots will decrease with minimum value -1.4 to maximum value 1.05.

Chula *et al* (2017) reported that maximum and minimum temperatures showed significantly positive correlation whereas, the relative humidity revealed negative significant correlation with fruit borer population, respectively. The rainfall showed significantly negative correlation with fruit borer population. The wind velocity and sunshine showed significantly positive correlation with fruit borer population on tomato.

Kumar *et al*. (2017) revealed that correlation between fruit borer population and mean atmospheric temperature was positive and significant in with and without marigold (r= 0.633 and 0.677, respectively). The significantly positive correlation was found between *H. armigera* larvae and damaged fruits in tomato with and without marigold (r = 0.878 and 0.929, respectively).

Vikram *et al*. (2018) reported that weather parameters, temperature [maximum (r = 0.625) and minimum (r = 0.668)], wind velocity (r=0.527) and sunshine hours (r=0.722) showed significant positive correlation with larval population of *H. armigera*. Relative humidity [morning (r=-0.160) and evening (r=-0.388)] had nonsignificant negative correlation while, rainfall had non-significant positive correlation (r=0.091) with larval population.

Mahapatra *et al*. (2018) reported that the borers i.e. *H. armigera* and *S. litura* were negatively correlated to mean maximum temperature (-0.13 and -0.10), mean minimum temperature (- 0.47 and -0.43), evening RH (-0.52 and -0.49) and rainfall (-0.36 and -0.32) while a positive correlation was witnessed so far morning R.H (0.31 and 0.28).

Sharma *et al*. (2013) reported that fruit borer population exhibited significant positive correlation with the temperature but positive and non-significant with sunshine hours. Relative humidity and rainfall had non-significant negative effect on borer population. Aphid population was positively but non-significantly correlated with the maximum, minimum temperatures and sunshine hours and negative non-significantly with relative humidity and rainfall. The leaf miner population was positively but non-significantly correlated with maximum temperature and sunshine hours. However, minimum temperature and rainfall had positive and significant effected on leaf miner population. Relative humidity was negatively correlated with leaf miner. The correlation studies between whitefly and abiotic factors showed positive correlation for temperature and sunshine hours, while the correlation was negative relative humidity and rainfall. The multiple linear regression analysis showed that all the weather parameters together were responsible for 96.3, 69.7, 97.1, 77.3 and 89.0 % (R2 value) of total variation of fruit borer, aphid, mealy bug, leaf miner and whitefly population, respectively.

Waluniba and Ao (2014) reported that the incidence of aphid correlating with abiotic factors showed negative significant influence by maximum temperature at 4^{th} December planting date, whitefly showed negative significant influence on 4^{th} December planting date, leaf miner showed positive significant effect with maximum and minimum temperature in all the planting dates and also minimum relative humidity on 19^{th} December planting showed positive significant effect and in case of tomato fruit borer it showed a positive significant effect with maximum temperature and minimum relative humidity at 19^{th} November and 19^{th} December planting respectively.

Kharia *et al*. (2018) reported that the fruit borer population had a significant positive correlation with maximum temperature, minimum temperature and bright sunshine while significant negative correlation with morning and evening relative humidity. Similarly, whitefly population had a significant positive correlation with temperature, while significant negative correlation with relative humidity although the population was far below ETL.

Mondal *et al*. (2019) reported that among abiotic factors rainfall (r= -0.104) showed negatively non-significant effect on aphid population build up. Correlation of weather parameter with white fly population revealed non-significant effect against maximum temperature (r=-0.010) and rainfall (r=0.007). However, rain fall (r= -0.208) showed negatively non-significant correlation with *H. armigera* population build up. The percentage contribution of all the weather parameters over *H. armigera* population was 18.6% (R2= 0.186). The higher natural enemy population were found simultaneously with higher insect pest population recorded in field i.e. during February to March.

2.4 Development of management module with Botanical and bio-rational pesticides options

2.4.1 Impact of insecticides on leaf miner and other major insect pests of tomato

Vikraktamath *et al*. (1993) and Jagannatha (1994) reported that application of 4% neem seed kernel extract was effective in controlling *L. trifolii* on tomato.

Jayakumar and Uthamasamy (1997) reported on application of some botanicals like neem oil (3%) to cause 93.3 per cent larval mortality, neem seed kernel extract

(5%) and mahua oil (3%) (*Madhuca longifolia*) to cause 90 per cent and 90 per cent larval mortality of *L. trifolii*, respectively.

Morale (1997) studied the effect of plant products against *H. armigera* and reported that neem oil, karanj oil and NSKP 5% affected the larval mortality, fecundity and adult emergence in tomato.

Pawar *et al*., (1997) conducted field studies during kharif 1992-94 in Maharashtra, India, to evaluate the efficacy of neem seed kernel extracts (5%), 0.01% cypermethrin 25 EC, 0.07% endosulfan 35 EC, 0.03% dimethoate 30 EC, 0.07% dichlorvos 76 EC, 0.001% deltamethrin 2.8 EC, 0.05% malathion 50 EC and Phorate 10 G at 1 kg/ha to control *L. trifolii* on tomatoes (cv. Dhanashree). The best pest control was by neem seed extract, and cypermethrin, endosulfan and dimethoate. The best cost:benefit ratio was found with neem seed extract (1:14), followed by cypermethrin (1:12), dimethoate and endosulfan (both 1:10).

Thiamethoxam, a new generation neonicotinoid insecticide, was found to be effective in preventing transmission of tomato yellow leaf curl geminivirus (TYLCV) by the whitefly, *B. tabaci* reported by Mason *et al*. (2000)

Praveen (2000) reported that microbials and neem formulations have been reported to reduce the *H. armigera* and fruit damage in tomato.

Sridevi *et al*. (2004) reported that application of *B. bassiana* ($1.6x10^5$ to $2.5x10^5$ spores/ml) resulted in 60.4 to 75.3 percent larval mortality of *H. armigera* on tomato crop.

Choudhary and Rosaiah (2001) evaluated different insecticides and plant products against *L. trifolii* on tomato. NSKE 5 % and Neemazol 0.5 % were effective and produced significantly higher yields.

Choudhury and Senpati (2001) carried out field evaluation of synthetic (0.05% malathion, 0.05% DDVP (dichlorvos), and 0.01% *avermectin* (abamectin) and biological (1500 ppm azadirachtin, 1g *B. thuringiensis*/ml at $5x10^7$ spores, *B. bassiana* at 10^7 conidia/ml, and *nuclear polyhedrosis virus* or NPV) pesticides against the key pests of tomato, viz. leaf miner (*L. trifolii*) and fruit borer (*H. armigera*), during late season (1996-99) in terai region of West Bengal, India, and revealed that the biologically originated pesticides were more effective over synthetic pesticides. Avermectin at 0.01% a.i. and NPV at 250 LE/ha were most effective against the pest complex. Avermectin suppressed 44.18% leaf miner infestation and 49.95% and 52.03% fruit damage in number and weight, respectively. Higher level of pest suppression by avermectin resulted in higher tomato yield (59.74 t/ha). Pesticides from biological origin had no adverse effect on health, environment, and natural enemies of cop pests, making them compatible with future integrated pest management programme.

Asalatha (2002) reported that nine eco-friendly insecticides against leaf miner on tomato and found that neem seed kernel extract 4% gave the best results since it caused 80.42 per cent larval mortality. The next effective insecticide was multi neem 5% recording 74.56 per cent larval mortality, followed by neem seed kernel 10% (71.65%).

Seal *et al*. (2002) carried out experiments both in laboratory and in field to be observed the effectiveness of indoxacarb 15 SC, abamectin 0.15 EC and thiamethoxam 2 SC in controlling leafminers on beans and tomatoes. The result revealed that abamectin 0.15 EC @ 8 oz/acre recorded highest larval and pupal mortality of leafminer, *L. trifolii* in beans. However, thiamethoxam applied at the rates of 4 and 8 oz/acre provided significant reduction of leafminers on tomatoes followed by indoxacarb @ 0.065 Ib/acre + surfactant Agri Dex @ 0.5% which was equally effective to the first, second and third instars of leafminers.

Emamectin benzoate showed a rapid action against the leaf miner with 100% mortality even a-day after application, while acephate and cyromazine exhibited slow action in laboratory condition at yokohama in Japan (Ishida *et al*., 2002).

Schuster and Morris (2002) conducted experiments at Florida during 2000 and 2001 to compare the efficacy of imidacloprid 1.6 F and thiamethoxam 25 WG. They found that soil application and foliar spray of either imidacloprid @ 3.75 oz/acre or thiamethoxam @ 4 oz/acre resulted in reduced leaf mining by *L. trifolii* on tomato, however, the best performance and more consistent was with thiamethoxam.

Walunj *et al*. (2002) conducted a field experiment was during rabi 1999/2000 in Maharashtra, India to evaluate the efficacy of the new insecticide, abamectin (Vertimec 1.8 EC), at 5.0, 7.0 and 10.0 g a.i./ha, against the serpentine leaf miner, *L. trifolii*, on tomato (Namdhari Hybrid-815). The following treatments were used for comparison: fluvalinate 25 EC at 37.5 g a.i./ha, profenofos 50 EC at 500 g a.i./ha, Polytrin C 44 EC [cypermethrin + profenofos] at 440 g a.i./ha, *B. thuringiensis* 50 WP at 500 g a.i./ha and untreated control. All insecticide treatments were significantly superior to the untreated control in minimizing the incidence of the leaf miner. Abamectin was superior over the rest of the treatments. Abamectin at 10.0 g a.i./ha recorded the lowest percentage of affected leaflets (17.78%), followed by abamectin at 7.0 g a.i./ha (21.11%) and Polytrin C at 440 g a.i./ha (22.22%), at 7 days after treatment. Efficacy was reduced at 14 days after treatment in each treatment. The highest yield (150.00 q/ha) was recorded in the plot treated with abamectin at 10.0 g a.i./ha, which was at par with abamectin at 7.0 g a.i./ha and Polytrin C at 440 g a.i./ha with yields of 138.78 and 137.00 q/ha, respectively.

Thiamethoxam 70 WS was tested as seed treatment @ 2.85 g, 4.28 g and 10g/kg seed along with imidacloprid 70 WS @ 10 g/kg seed, carbosulfan 25 DS @ 50 g/kg seed and soil application of phorate 10 G @ 20 kg/ha against leaf miner and sucking pests of cotton i.e., leafhopper, thrips, aphid and whitefly. All the insecticidal treatments effectively checked the pest population up to 40 days. Among the seed treatments, thiamethoxam at higher dose (10 g/kg) was highly effective against leafhopper up to 50 days. However, at lower doses (2.85 and 4.28g), it gave good control of sucking pests up to 40 days after treatment. Treatment of cotton seeds with thiamethoxam at 2.85g/ kg appeared to be optimum for the control of early sucking pests. (Prasanna *et al*., 2004)

Wadnekar *et al*. (2004) reported that mean number of aphid was found to be significantly low in thiamethoxam 25 WG @ 150 g a.i/ha with 0.4, 0.83 and 1.17 aphids/ leaf after 2, 7 and 14 DAS, respectively Thiamethoxam 25 WG @ 100 g and thiamethoxam 25 WG @ 75 g a.i./ha, 4.95 and 5.9 aphids per leaf, respectively

Seed treatment with thiamethoxam @ 5 g a.i./ha followed by alphamethrin 0.05% spray was the most effective treatment in reducing whitefly populations in okra as reported by Kale *et al*. (2005)

Mayoral *et al*. (2006) studied the efficacy of *B. bassiana* based bioinsecticide, applied at different doses, in controlling whiteflies on protected tomato. All the *B. bassiana* treatments significantly reduced the whitefly infestation compared to the untreated control and a significant dose-response effect was recorded.

Murugraj *et al*. (2006) conducted studies against tomato fruit borer *H. armigera* (Hubner), and reported the superiority of emamectin benzoate over lambda cyhalothrin and spinosad.

Both the neem products tested (neem oil and NSKE) were found to reduce more than 50 % of whitefly population by Jat and Jeyakumar (2006).

Saad *et al*. (2006) conducted field trials to observe the performance of three different sequences as a unique solution for the control of the leaf miner, *L. trifolii* infesting garden beans during 2004 and 2005. They found that the comparative performance of pesticides alone showed abamectin 1.9% EC 58.48% most effective followed by azadirachtin (56.24%) in reducing the larval population of leafminer.

Hossain and Poehling (2006) studied the effect of neem-based formulation on serpentine leaf miner *L. satviea* on tomato crop in Bangkok, Thailand and reported that the effect on oviposition was not significant but drastic increase in 1^{st} and 2^{nd} instar larval mortility was seen and found more effective in green house condition.

An experiment was conducted to evaluate different insecticides against *L. trifolii* in tomato at Nagpur in Maharashtra by Wankhede *et al*. (2007). Neem oil 1% gave the lowest (4.37%) leaf miner infestation at 14 days after second spray followed by 0.01% spinosad and 5% Neem Seed Extract. Spinosad 0.01% registered the highest yield (20.36 t/ha) while, 5% Neem Seed Extract exhibited the highest ICBR of 1:47.08.

Sabbour and Sahab (2007) evaluated three entomopathogenic fungi *B. bassiana*, *Metarhizium anisopliae* and *Verticillium lecanii* against fruit borer *H. armigera*. *B. bassiana* was found to be most effective than other two bioinsecticides.

Thiamethoxam was the most effective insecticides against cotton aphids under green house condition reported by Dhawan *et al*. (2008).

Prasad and Syed (2010) reported that when four different concentrations (0.1, 0.125, 0.2 and 0.25 x 10^8 conidia per ml) of fungus *B. bassiana* (Balsamo), vuillemin were used against III larval instar of *H. armigera* (Hubner), 86.7 percent mortality was observed at highest dose level against 23.20 percent in control.

Hernandaz *et al*. (2010) evaluated the efficacy of novaluron 0.83 EC, abamectin 0.15 EC, spinetoram 120 SC, lambda-cyhalothrin 5 EC agaisnt *Liriomyza* on pepper and found that the most effective insecticide was novaluron as it caused lowest leafminer larval density per plant followed by spinoteram and abamectin at 25 and 35 days after the second application, whereas plants treated with lambda-cyhalothrin increased leafminer density.

Al-Kherb (2011) reported that the population of whitefly, *B. tabaci* on tomato plants significantly reduced by neonicotinoid insecticides whereas acetamiprid 20 SP reduced insect adults at an average of 63.6% while imidcloprid 20 SL caused 71.5% reduction and that of thiamethoxam 25 WG proved to be the most effective compound (reduction percentage of 82.0%). Thiomethoxam 25 WG was more toxic against whitefly than other tested insecticides which may be due to its conversion to another neonicotinoid insecticide, clothianidin which are known by its long persistence and high level of toxicity on insect pests (Nauen *et al*., 2003).

Bihari *et al*. (2011) reported that lowest fruit borer infestation (5.84%) was recorded in NSKE. Highest infestation (27.49%) was observed in control. Minimum fruit damage (7.73%) was recorded in NSKE while maximum (29.05%) in control. Plant vigor was also found to be influenced by botanicals application. Plant height, number of branches per plant, number of flower clusters per plant and number of fruit set per plant were recorded maximum (62.39 cm, 12.43, 83.45, 32.47) in NSKE while minimum (52.39 cm, 8.44, 69.43, 20.84) in control respectively.

Gacemi and Guenaoui (2012) conducted an experiment at Algeria during 2009-10 to evaluate the efficacy of emamectin benzoate 5 SG against larvae of the tomato leaf miner and reported that a dose of 0.6 gm/l of this insecticide gave excellent performance to control tomato leafminer, *Tuta absoluta* larvae with a mortality reaching 87%. The persistence of the product according to the firm varied between 7 and 14 days.

Patel *et al*. (2012) evaluated the field efficacy of nine different insecticides (Thiamethoxam 0.0125%, Spinosad 0.015%, Diafenthiuron 0.05%, Emmamectin 0.025%, Fipronil 0.08%, Clothianidin 0.05%, Imidacloprid 0.035%, Methyl-o-demeton 0.025% and Dimethoate 0.03%) against leaf miner (Liriomyza trifolii Burgess) and reported diafenthiuron, emmamectin, thiamethoxam and spinosad as highly effective; clothianidin, dimethoate and fipronil as mediocre; whereas methyl-o-demeton and imidacloprid as least effective.

According to Naik *et al.* (2012) Neemazol @ 3.5% recorded 1.67 and 3.17 aphids/3 leaves and 2.00 and 2.63 whitefly/3 leaves, Neem oil @ 2% recorded 1.93 and 4.33 aphids /3 leaves and 2.17 and 3.40 whitefly /3 leaves and NSKE @ 5% recorded 2.00 and 6.00 aphids /3 leaves and 3.00 and 4.00 whitefly /3 leaves at 10 DAS on the first and the second spray respectively and these were found superior among botanicals.

Yldrm and Baspnar (2012) conducted a study to develop some alternative methods for controlling *L. trifolii* (Burgess) in tomato during 2008-2009. Effects of two different doses of Neem (Neem Azal T/S) on *L. trifolii* larvae and their important parasitoids were examined under laboratory and greenhouse conditions. It was resulted that Neem could control *L. trifolii* larvae efficiently. In addition, Neem also has shown less impact on parasitoids of the pest than cyromazine, used as a comparative agent with a percentage of parasitism close to that of control.

Shah *et al*. (2013) recorded that the minimum number of larvae/plant of *H. armigera* (0.40 and 0.46) was recorded in neem seed extract and emamectin benzoate and maximum number of 1.00 larvae /plant was recorded in control. Maximum yield (7540 kg ha-1) was recorded in neem seed extract (2.5%) and percent infestation of larvae of tomato fruit worm was minimum (0.40) in emamectin benzoate whereas maximum (1.00) in control plot.

Devi *et al.* (2014) studied the bioefficacy of seven different biorational insecticides against tomato fruit borer *H. armigera* infestation under West Bengal condition tested on the basis of percentage of fruit damage and percentage increased/decreased on yield under field condition. All the seven insecticides were significantly superior over control and out of seven insecticides, Spinetoram (Spinosad 45% SC) 50 gm a.i/ha provided the highest fruit yield of (33.7 q/ha) as compared to untreated control (18.65q/ha).The study revealed that Spinetoram was the paramount effective biorational insecticide against fruit borer of tomato. Results showed that among the six biorational insecticides, Spinetoram recorded the overall best control (6.39%) followed by Emamectin benzoate (7.41%), *B. thuringiensis* (10.43%), Neem (10.56%), *B. bassiana* (11.01%), Chlorfenapyr (11.30%), *V. lecanii* (11.41%), respectively providing highest fruit protection over control.

NSKE 5% @ 2 kg/ha, neem oil @ 2.5 lit/ha and azadirachtin 3000 ppm @ 2.5 lit/ha 20 days after transplanting were most effective against whitefly and serpentine leaf miner of tomato reported by Chavan *et al*. (2015).

Maurya *et al*. (2015) evaluated the effectiveness of thiamethoxam against the sucking insects of tomato. The seed treatment with thiamethoxam protected tomato seedlings from aphids and thrips at the early season from the onset of seed planting. There was a fast initial effect against the pests then gradually decreased to reach a moderate effect. Data revealed that Thiamethoxam 70% WS @ 4.2 g a.i./kg of seed showed the significant pest reduction followed by Thiamethoxam 70% WS @ 3.85 g a.i./kg of seed.

Tarate *et al*. (2016) conducted insecticides application at 25, 45 and 65 days after transplanting and showed that efficacy of emamectin benzoate 5 SG @ 9.5 g a.i/ha was most effective against leaf miner, *L. trifolii* Burgess. followed by spinosad 45 SC @ 75 g a.i/ha and lambda cyhalothrin 5 EC @ 50 g a.i./ha. The highest yield was recorded in spinosad 45 SC @ 75 g a.i/ha (220.41 q/ha) which was found significantly superior over rest of the treatments. The second best treatment in respect of fruit yield was emamectin benzoate 5 SG @ 9.5 g a.i/ha (213.74 q/ha).

Ghosal *et al*. (2016) conducted an investigation during rabi season 2009 and 2010 to test the effectiveness of recently developed new ready mix insecticide Plethora (Novaluron 5.25 %+ Indoxacarb 4.5% SC) along with other insecticides against *Helicoverpa armigera* Hub and *Spodoptera litura* Fab. infesting tomato. It was observed that Plethora @ 875 ml/ha recorded only 3.75% fruit damage, while in control plot it was 45.6%. Though highest cost benefit ratio (1:6.17) was obtained when Plethora was applied at 825 ml/ha. Independently novaluron performed well specially against *S. litura* and indoxacarb showed better performance against *H. armigera* but lamda-cyhalothrin expressed comparatively lower performance than other selected insecticides which received 28.30% fruit infestation.

Babar *et al*. (2016) evaluated six insecticides from the new chemistries Radiant 12%SC (spintoram), Tracer 240SC (spinosad), Emamectin benzoate 5%SG (emamectin), Lufenuron 5%EC (lufenuron), Coragen 20SC (chlorantraniliprole) and Challenger 36%SC (chlorofenapyr) which are relatively safer to human and environment were tested on tomato crop heavily infested by *H. armigera*. The percentage mortality was compared after 03, 05 and 07 days of spray and all the treatments were compared with control as well as with one another. The results reveal that among the bioinsecticides Radiant 12%SC (spintoram) and Tracer 240SC (spinosad) proved to be most effective by exhibiting average maximum percentage mortality of the pest up to seven days after treatment where as among the chemical insecticides Lufenuron 5%EC (lufenuron) proved to be most effective.

2.4.2 Impact of insecticides on natural enemies.

Kaethner (1999) reported that the neem extract and and neem oil were harmless to the egg and larvae of *Chrysoperla carnea* and *Coccinella sepempunctata*.

Chakraborti (2001) found that that the neem based treatments like NSKE and neem oil were found safe to natural enemies during his field trial.

Smitha (2002) reported that neem cake and vermicompost were safe to the coccinellid predatory beetles in chilli ecosystem.

Ecofreindly chemicals namely imidacloprid, novaluron etc were found relatively less toxic to coccinellids when compared to conventional insecticides like dichlorovos (Sunitha *et al*., 2004)

Seal *et al*. (2007) reported that predatory spider population was considerably lowered immediately following application of insecticides such as metaflumiazone, indoxacarb, novaluron, spinetoram and spinosad but the populations treated with indoxacarb and spinosad had fully recovered by the seven days after treatment.

Ghosh *et al*. (2010) studied that spinosad is safe to 3 important predators viz., *M. sexmaculatus*, *S. corollae* and *C. carnea* in tomato field.

Al-Kherb (2011) reported that neonicotionids groups of thiamethoxam 20 WG showed slightly higher toxic effect where it reduced the population of *C. carnea, C. undecempuntata, Orius sp* and *Paederus alferii* by an average of 24.9, 30.2, 38.4 and 32.3 per cent, respectively on tomato crop. Similarly, acetamiprid 20 SP and imidacloprid 17.8 SL also reduced the *C. carnea*, *C. undecempuntata*, *Orius sp* and *P. alferii* population by the average of 20.2, 23.5, 32.3 and 28.4 per cent and they were 22.4, 24.2, 36.1 and 29.81 per cent, respectively.

Biological origin and neem-based pesticides were relatively less harmful to various natural enemies in brinjal ecosystem. However synthetic chemicals had higher mortality than that of the biopesticides as reported by Tiwari *et al*. (2011).

Hikal *et al*. (2017) pointed out that botanical insecticides affect only target insects, not destroy beneficial natural enemies and provide residue-free food and safe environment. Botanical insecticides are therefore recommended as an integrated insect management program which can greatly reduce the use of synthetic insecticides.

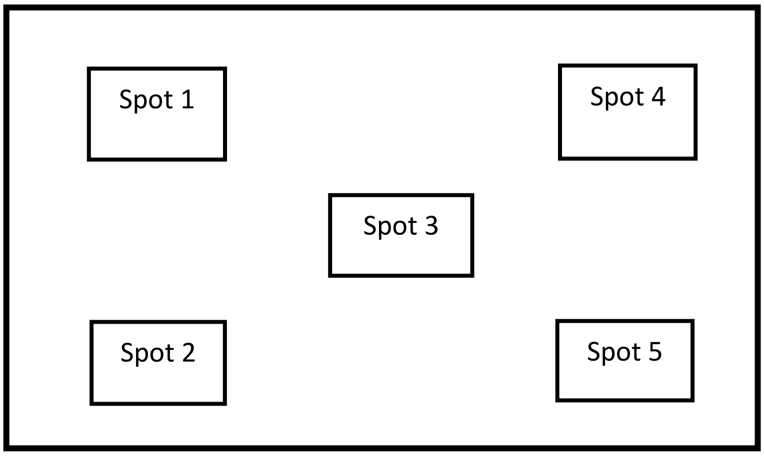
The details of the materials used and methods adopted throughout the course of present investigations are described here systematically:

3.1 To study the population dynamics of important insect pests of tomato

3.1.1 Survey and surveillance of insect pests of tomato under Gangetic region of West Bengal

Field experiments on tomato were conducted at C-Block farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, West Bengal and ten farmers' field at ten different villages under three districts viz., Nadia, 24 Parganas (North) and Hooghly during rabi (Table 1) and summer season (Table 2). Periodical field observations of insect pests of tomato viz., aphid (*Myzus persicae*, *Aphis gossypii*), whitefly (*Bemisia tabaci*), thrips (*Thrips tabaci*, *Frankliniella sp.*), leaf miner (*Liriomyza trifolii*) and tobacco caterpillar (*Spodoptera litura*) and fruit borer (*Helicoverpa armigera*) were conducted as fixed survey basis at seven days interval.

Observations in the fields were taken following the procedure given in the manual by NICRA (National Innovations on Climate Resilient Agriculture) ICAR, New Delhi, for surveillance of insect pests of tomato. In each field five spots were selected randomly (four in the corners, at least five feet inside of the field borders, and one in the centre) and from each spot five plants were again selected randomly for recording the population of insects as shown below.



Experimental field

Observations recorded on:

- **Leaf miner** : No. of live mines/five random leaves
- **Aphids** : No. of adults/five young leaves
- **White fly** : No. of adults/five leaves (2 top+1 middle+ 2 bottom)
- **Thrips** : No. of adults/five terminal leaves
- **Tobacco caterpillar (*S. litura*) & gram pod borer (*H. armigera*) larvae** : Whole plant basis

3.1.2 Population dynamics of leaf miner, *L. trifolii* (Burgess) and other important insect pests of tomato conducted at experimental plot in C-Block farm, BCKV, Kalyani, West Bengal

Field experiments were conducted at C-Block farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, West Bengal during rabi and summer season. The field was at medium highland with sandy loam soil having good water holding capacity. The pH of the soil was almost neutral in the fields. The climatic condition of the site of experiments was typical to new alluvial zone of West Bengal. The experimental plots were of 250 square feet with plant to plant spacing of 45 cm and row to row distance of 60 cm. All the recommended agronomical practices were followed but no plant protection measures were used to facilitate natural build-up of insect population. Observations were recorded at weekly basis following the same procedure given in the NICRA manual.

Tomato crops were raised for seven years i.e. 2011-2012 to 2017-2018 during rabi season and 2012-2018 during summer season. Tomato seedlings were transplanted at 36th SMW (i.e. second week of September) in the year 2011-12, 39th SMW (i.e. fifth week of November) in 2012-13, 44th SMW (i.e. fourth week of October) in 2013-14, 43rd SMW (i.e. third week of October) in 2014-15, 42nd SMW (i.e. second week of October) in 2015-16, 41st SMW (i.e. first week of October) in 2016-17 and lastly 44th SMW (i.e. fourth week of October) in 2017-18 during the rabi cropping season. While the seedlings for summer season were transplanted at 3rd SMW (i.e. third week of January) in the year 2012, 10th SMW (i.e. second week of March) in 2013, 4th SMW (i.e. fourth week of January) in 2014, 9th SMW (i.e. fourth week of February) in 2015, 6th SMW (i.e. second week of February) in 2016 and 5th SMW (i.e. second week of February) in both 2017 and 2018.

3.2 To study the biology of *L. trifolii* (Burgess) and other important pests.

The present investigation on the biology of *L. trifolii* was carried out in the Plant Protection Laboratory of Department of Agricultural Entomology, BCKV.

3.2.1 Rearing for conducting biological studies

A stock culture was first established in the laboratory. Infested tomato leaves with live mines from the field were collected. These were initially collected in polythene bags from the fields and transferred to glass containers lined with blotting paper and wet cotton to maintain the turgidity of the leaves and covered with fine muslin cloth tied with a rubber band. After few days the pupae were collected in petridishes (10 cm diameter) and placed inside a rearing cage of size 1ft × 1ft for adult emergence. Then freshly emerged male and female adults had been chosen for pairing and placed in glass jar to facilitate incubation studies.

3.2.2 Biology

The developmental periods of the different life stages of *L. trifolii* were studied in the laboratory at four controlled temperature of 15 ± 1°C, 20 ± 1°C, 25 ± 1°C and 30 ± 1°C. They were conducted on freshly collected tomato leaves introduce in petridishes and glass jars and incubation period up to adult emergence were studied and recorded. Such biological study had been conducted at four different temperature regimes to record the changes in the developmental periods with the changes in temperature the insects were exposed to.

Incubation period

The period from egg laying to the hatching was recorded and considered as incubation period study. Ten fresh egg laying punctures were marked and kept under close investigation. The incubation periods of the egg were observed and recorded at four different temperature regimes.

Larval period

Ten freshly hatched larvae were picked up to study the different instars and their developmental periods. The period between egg hatching and pupation was observed as larval period. Total larval periods were then worked out at four different temperature regimes.

Pupal period

To record the pupal period, ten freshly formed pupae were kept individually in plastic vial under observation till emergence of adults and on this basis, the average pupal period was worked out. The periods between formation of pupa till the adult eclosion were noted at four different temperature regimes as pupal period.

Adult longevity

The adults emerged from the pupa were introduced individually into a glass jar to study the fecundity and longevity. Fresh tomato leaves were provided with 10% honey solution for feeding and oviposition. The leaves were changed regularly after 24 hours interval and the older leaves transferred to another glass jar for emergence of the progenies. The longevities of ten males and females were recorded by observing the duration between emergence to death of adult.

Total life cycle

The total period for the completion of life cycle was worked out based on the durations of egg, larval, pupal and adult stages respectively at four different temperature regimes.

3.2.3 Morphemetrics

The length and width of ten eggs, larvae, pupae and adults were observed separately under the microscope and recorded.

3.3 Relationship of population build-up of leaf miner and other insect pests infesting tomato with weather parameters and development of prediction models.

The meteorological parameters constituting maximum and minimum temperature (°C), rainfall (mm), maximum and minimum relative humidity (%) and total sunshine hours (hr) were collected from the AICRP on Meteorology, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal (Table 3 & 4). These parameters were used for correlation and prediction model development.

3.3.1 Development of prediction models based on weather variables

3.3.1.1 Principal Component Analysis

Principal Component Analysis (PCA) is a multivariate technique that transforms a number of correlated variables into a (smaller) number of uncorrelated variables with maximum variance, called Principal Components (PC). The first principal component accounts for as much of the variability in the data as possible and each succeeding component accounts for as much of the remaining variability as possible.

Let $X = [x_1, x_2, ..., x_p]$ be a set of p quantitative independent variables, y a categorical response variable with more than two categories. The aim of PCA is to find a set of uncorrelated latent variables $Z = [z_1, z_2, ..., z_p]$ which are linear combinations of the original variables Z = XV. The weight matrix $V = [v_1, v_2, ..., v_p]$ is built by the eigenvectors of the covariance or correlation matrix. These matrices can be calculated from the data matrix X. The covariance matrix contains scaled sums of squares and cross products. The correlation matrix is similar to the covariance matrix but first the variables, i.e., the columns, have been standardized. For the reasons which are beyond the scope of this study, it is often preferable to perform the analysis on correlation matrix R, whose elements are the correlation coefficients among the independent variables. The basic proprieties of the analysis are:

• The PC's are orthogonal

• The weights used to determine the PC's maximize the variance among the x variables, so, the first a<p PC's lead to a good approximated reconstruction of original matrix $X=ZV^T$

3.3.1.2 Multinomial Logistic Regression

Multinomial Logistic Regression is the simplest model in discrete choice analysis when more than two alternatives are in a choice set. It is derived from utility-maximizing theory that states that consumer chooses the alternative which maximizes his utility. Obviously not all the attributes of the alternatives will be observed and for this reason the utility is divided in two parts:

• D_{ib} is the systematic part of the utility that the individual i received by a generic alternative b

• ε_{ib} is the random part and summarizes the contribution of unobserved variables (Ben-Akiva and Lerman, 1985). The probability to select a specific alternative c for the individual i is then:

$$\pi_i (c) = \Pr (D_{ic} + \varepsilon_{ic} \geq D_{ib} + \varepsilon_{ib}) \square \; c \neq b; \; b = l, ... ,s \qquad (1)$$

where, D_{ic} is the systematic part of the utility that the individual i receives by the alternative c, ε_{ic} is the disturbance and s is the number of alternatives. If we assume that the disturbances are independent and identically extreme value distributed (Marschak, 1960) we obtain the multinomial logistic model. The probability can be then expressed as follows:

$$\boldsymbol{\pi}_{\mathbf{i}}\ \mathbf{(c)} = \frac{\exp(\mu D_{ic})}{\sum_{b=1}^{s} \exp(\mu D_{ic})} \tag{2}$$

The term μ is a scale parameter and it can be normalized to 1; furthermore, if the systematic part of the utility is linear in the parameters, we have:

$$\boldsymbol{\pi}_{\mathbf{i}}\ \mathbf{(c)} = \frac{\exp(X_{ij}\beta_{jc})}{\sum_{b=1}^{s} \exp(X_{ij}\beta_{jc})} \tag{3}$$

where, x_{ij} (i = 1,..,n,; j = 1,..,p) are the elements of the X matrix and β_{jb} are the parameters to be estimated (Train, 2003).

3.3.1.3 Principal Component Multinomial Regression

At this point, we can present the new approach: Principal Component Multinomial Regression (PCMR). At first step, PCMR creates the PC's of the regressions as described above. At second step the multinomial model is carried out on the set of p PC's. The probability, for the individual i, to choose the alternative c can be expressed in terms of all PC's as:

$$\boldsymbol{\pi}_{\mathbf{i}}\ \mathbf{(c)} = \frac{\exp\left\{\sum_{j=1}^{p}\sum_{k=1}^{p} Z_{ik}V_{kj}\beta_{jc}\right\}}{\left\{\sum_{b=1}^{s}\exp\sum_{j=1}^{p}\sum_{k=1}^{s} Z_{ik}V_{kj}\beta_{jb}\right\}} = \frac{\exp\left\{\sum_{k=1}^{s} Z_{ik}\,\gamma_{kc}\right\}}{\left\{\sum_{b=1}^{s}\exp\sum_{k=1}^{s} Z_{ik}\gamma_{kc}\right\}} \tag{4}$$

Where:

z_{ik}, (i = 1,..,n; k = 1,..,p) = The elements of the PC matrix

v_{kj}, (j = 1,..,p) =The elements of the transposed matrix V^T

$\gamma_{kb} = \sum_{j=1}^{p} V_{kj}\beta_{jb}$(b=l,…,s) = The coefficients to be estimated

β_{jb} = The parameters expressed in function of original variables and

S = The number of alternatives of the data set

At third step, the number of PC's a<p, to be retained in the model, is chosen. The next paragraph discusses about the different tools for selecting the number of PC's. At fourth step, the multinomial model is carried out on the subset of a<p PC's. The probability, for the individual i, to choose the alternative c can be expressed in terms of a PC's as:

$$\boldsymbol{\pi}_{\mathbf{i}}^{(\mathbf{a})}\ (\mathbf{c}) = \frac{\exp\left\{\sum_{j=1}^{p}\sum_{k=1}^{s} Z_{ik} V_{kj} \beta_{jc}^{(a)}\right\}}{\left\{\sum_{b=1}^{s}\exp\sum_{j=1}^{p}\sum_{k=1}^{s} Z_{ik} V_{kj} \beta_{jc}^{(a)}\right\}} = \frac{\exp\left\{\sum_{k=1}^{s} Z_{ik}\gamma_{kc}^{(a)}\right\}}{\left\{\sum_{b=1}^{s}\exp\sum_{k=1}^{s} Z_{ik}\gamma_{kb}^{(a)}\right\}} \tag{5}$$

Where:

$\gamma_{kb}^{(a)} = \sum_{j=1}^{p} V_{kj}\, \beta_{jb}^{(a)}$= The coefficients to be estimated on the subset of a PC's

$\beta_{jb}^{(a)}$= The PCMR parameters obtained after the extraction of the a components

Finally, the multinomial model parameters can be expressed in function of original variables (X matrix).

$$Z^{(a)}\,\gamma^{(a)} = XV^{(a)}\,\gamma^{(a)} = X\beta^{(a)} \tag{6}$$

where, $\beta^{(a)} = V^{(a)}\,\gamma^{(a)}$; $Z^{(a)}$ is the matrix of a PC's; $\gamma^{(a)}$ is the matrix of parameters on a PC's for the s alternatives; $V^{(a)}$ is the matrix of a eigenvectors; $\beta^{(a)}$ is the matrix of parameters expressed in function of original variables. An interesting result which has been obtained is , $\beta^{(p)}=\beta$, that is, if we retain all PC's in the model, the matrix of parameters expressed in function of original variables, $\beta^{(p)}$ is equal to the matrix of classical multinomial parameters, β.

However, the most important result is that the PCMR leads to lower variance estimates of model parameters comparing to classical multinomial model. We calculate the variance of the estimated parameters of the multinomial model by bootstrap resampling. Let, $\hat{\beta}_{jbl}^{(a)}$ be the bootstrap estimate of the parameter $\beta_{jb}^{(a)}$ for the $\boldsymbol{l}$-th sample, let $\hat{\beta}_{jb}^{(a)}$ be the estimated parameter, the bootstrap estimate of variance of $\hat{\beta}_{jb}^{(a)}$ is the empirical estimate calculated from m bootstrap values:

$$S^2\left(\hat{\beta}_{jb}^{(a)}\right) = \frac{1}{m}\sum_{1}^{m}\left(\hat{\beta}_{jbl}^{(a)} - \overline{\beta}_{jb}^{(a)}\right)^2 \tag{7}$$

where, $\overline{\beta}_{jb}^{(a)} = \frac{1}{m}\sum_{j}^{m}\hat{\beta}_{jbl}^{(a)}$ is the bootstrap mean of the estimations of the j-th parameter.

3.3.1.4 Model Calibration and Validation

The number of PC's, a, is bounded from above by p, the number of x variables. Hence, the number of components should be chosen in the range 1≤a≤p. The number of PC's, a, to be retained in the model can be selected according to different tools. The first possibility is to retain all the components, but the most used criteria are:

- To consider the PC's in their natural order and stop when explained variability is about 75%
- To consider the PC's that correspond to eigenvalues bigger than one

However, the dependence relationship between the response and the predictor variables is not taken into account. For this reason we propose the criterion of considering in the model all the PC's that influence in statistical significant manner the response variable. A forward stepwise procedure is applied for selecting the significant components. To determine the goodness of the different criteria, we develop a bootstrap procedure and we use the bootstrap samples to estimate the parameters, both for the original matrix and for the PC matrix. We propose two accuracy measures:

• The Root Mean Squared Error (RMSE) of bootstrap estimates for $\hat{\beta}_{jb}^{(a)}$.

• The BIAS for $\hat{\beta}_{jb}^{(a)}$, calculated as the differences, in absolute value, between the bootstrap mean of the parameter estimations and the true values of the parameters

They are defined as follows:

$$\mathrm{RMSE}\left(\hat{\beta}_{jb}^{(a)}\right)=\frac{1}{m}\sum_{1}^{m}\left(\hat{\beta}_{jbl}^{(a)}-\beta_{jb}\right)^{2} \text{ and } \mathrm{BIAS}\left(\hat{\beta}_{jb}^{(a)}\right)=\left|\bar{\beta}_{jb}^{(a)}-\beta_{jb}\right| \qquad (8)$$

The simulation study and the accuracy measures show the best results are obtained, when the criterion of significant components (the third above-written-criterion) is used.

3.4 To develop a management module of leaf miner and other important insect pests with botanicals and biorational pesticides.

Field experiment was conducted at C-Block Farm of BCKV, Kalyani, West Bengal for two consecutive tomato growing seasons during 2016-17 and 2017-18 to evaluate the effectiveness of seven different treatment schedules consisting of both botanicals and biorational pesticides against some important insect pests of tomato.

Lay out of the proposed experiment for Tomato in fixed plot

- Variety : Local
- Season : Rabi
- Plot size : 3m × 2m
- Treatments : 7
- Replication : 3

- Design : RBD
- Spacing : 60cm X 45cm

Seed treatment with thiamethoxam 70% WS @ 3g/kg seed was followed by foliar spray of different concentrations of the treatments (Table 1) applied at 45 and 60 DAT at an interval of 15 days.

Table 5: Details of treatments used in management module of important insect pests of tomato

Treatment	Chemical name	Trade name	Dose for field application (ml/ha, g a.i/ha)	Formulation (ml/l, g/liter of water)
T1	*Bacillus thuringiensis var. kurstaki*	-	1000 g/ha	2 ml
T2	*Beauveria bassiana*	-	1500 g/ha	3 ml
T3	NSKE 5%	-	1000 ml/ha	2 ml
T4	Azadirachtin 1%	Neemazal T/S	1000 ml/ha	2 ml
T5	Emamectin benzoate 5% SG	Missile	10g ai/ha	0.3 g
T6	Novaluron 5.25% + Indoxacarb 4.5% SC	Plethora	850 ml/ha	1.5 ml
T7	Untreated Control	-	-	-

Observations to be recorded:

Observations had been recorded at weekly interval after spraying. The population of aphids had been recorded as no. of adults/five young leaves, for whitefly it was no. of adults/five leaves (2 top+1 middle+2 bottom), in thrips it was no. of adults /5 terminal leaves, in leaf miner it was recorded as number of live mines from five random leaves, for *S. litura, H. armigera* larvae and natural enemies viz., spiders and coccinellids numbers were recorded from whole plant.

Statistical analysis

The computation of analysis of variance of data collected from field experiment were done by using Randomized Block Design (RBD), while the data from laboratory studies were analyzed by Completely Randomized Design (CRD) and Critical difference values were computed. The data regarding different insect populations were subjected to square root transformation. After determination of significance of difference between the treatment means at (0.05) percent probability, critical difference was calculated in order to compare the treatment means.

RESULTS AND DISCUSSION

This chapter deals with the experimental findings obtained during course of investigation. The data has been analysed statistically, duly supported by tables and graphs. The results are presented experiment wise, along with the discussion.

4.1. Pest complex and relative abundance of major insect-pests of tomato during 2011-12 to 2017-18

The pest complex of tomato crop observed during the study revealed the incidence of six major species of insect pests belonging to four categories viz., defoliators, borers, miner and sap suckers. They are enumerated below as mentioned in Table: 4.

Table 6: Enumeration of Major insect pest complex of tomato (*L. esculentum* L.)

Common name	Scientific name	Family	order
Leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Aphid	*Myzus persicae* (Sulzer) *Aphis gossypii* (Glover)	Aphididae	Hemiptera
White fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Thrips	*Thrips tabaci* (Hendel) *Frankliniella sp.* (Pergande)	Thripidae	Thysanoptera
Tobacco caterpillar	*Spodoptera litura* Fabricius	Noctuidae	Lepidoptera
Fruit borer	*Helicoverpa armigera* (Hubner)	Noctuidae	Lepidoptera

Misra (2010) reported six insect pests from West Bengal attacking tomato in various stages of crop growth. Of these, three insect pests (fruit borer, whitefly and leafminer) were identified as major pests in India. Also, Nagamandla *et al*. (2017) reported that *Aphis gossypii*, *Bemisia tabaci*, *Thrips tabaci*, *Liriomyza trifolii*, *Spodoptera litura* and *Helicoverpa armigera* are the major important insects of tomato in West Bengal.

4.1.1 Survey and surveillance of insect pests of tomato under Gangetic region of West Bengal (Initiation and Peak periods of the insect pests during rabi and summer seasons)

4.1.1.1 Periods of distribution of Leaf miner, *L. trifolii* (Burgess) on tomato in Rabi season (Table 7)

In the first year of study i.e. 2011-12, initiation of leaf miner attack could be recorded at villages of Hooghly from 41st – 44th SMW. While in the villages of 24 PGS (N) the appearance could be recorded from 43rd – 44th SMW. At Nadia district the attack started from 42nd – 45th SMW while specifically at C-block Farm of BCKV, Kalyani i.e. experimental plot, the attack started from 40th SMW. Peak of leaf miner was observed earlier at experimental plot of BCKV than Hooghly, 24 PGS (N) and other parts of Nadia district. Peak of leaf miner could be noted from 49th – 1st SMW, 5th – 6th SMW, 51st – 3rd SMW and 46th SMW at districts of Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2012-13, initiation of leaf miner attack at Hooghly could be recorded from 46th – 49th SMW. At 24 PGS (N), the appearance could be noted from 47th – 48th SMW. At Nadia attack started from 47th – 50th SMW while in experimental plot of BCKV the attack started from 47 SMW. Peak of leaf miner could be observed from 6th – 9th SMW at Hooghly. At 24 PGS (N) district, it was observed from 6th – 8th while it was found from 2nd – 6th SMW and 5th SMW at Nadia and at experimental plot of BCKV, respectively.

In 2013-14, initiation of leaf miner attack could be recorded from 50th – 51st SMW at Hooghly. At 24 PGS (N), the pest appeared from 51st SMW, while at Nadia, it was from 49th SMW. In experimental plot of BCKV the attack was found from 51st SMW. Peaks of leaf miner were observed on 5th – 8th SMW, 8th – 9th SMW, 6th – 10th SMW and 8th SMW at districts of Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2014-15, initiation of leaf miner could be recorded from 42nd SMW at villages of Hooghly. While at 24 PGS (N) the appearance could be recorded from 42nd – 45th SMW. At Nadia the attack started from 41st SMW and at experimental plot of BCKV it was from 46th SMW. Peaks of leaf miner could be found from 2nd – 4th SMW, 4th – 8th SMW, 2nd – 4th SMW and 6th SMW at districts of Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of leaf miner could be recorded from 42^{nd} – 45^{th} SMW at Hooghly. While at 24 PGS (N) the appearance could be recorded from 46^{th} – 47^{th} SMW. At Nadia the attack started from 44^{th} – 45^{th} SMW and at experimental plot it was from 44^{th} SMW. Peaks of leaf miner could be observed from 5^{th} – 6^{th} SMW, 4^{th} – 6^{th} SMW, 6^{th} SMW and 5^{th} SMW at Hooghly, 24 PGS (N), Nadia districts and experimental plot of BCKV, respectively.

In 2016-17, initiation of leaf miner could be recorded from 45^{th} – 47^{th} SMW at Hooghly. While at the 24 PGS (N) the appearance could be recorded from 46^{th} – 51^{st} SMW. At Nadia the attack started from 48^{th} – 59^{th} SMW and at experimental plot of BCKV, it was from 44^{th} SMW. Peaks of leaf miner could be noted from 4^{th} – 5^{th} SMW, 6^{th} – 8^{th} SMW, 5^{th} – 6^{th} SMW and 52^{nd} SMW at Hooghly, 24 PGS (N), Nadia districts and experimental plot of BCKV, respectively.

In 2017-18, initiation of leaf miner could be recorded from 42^{nd} – 46^{th} SMW at Hooghly. While at 24 PGS (N), the appearance of the pest could be recorded from 42^{nd} – 48^{th} SMW. At Nadia the attack started from 46^{th} SMW while at experimental plot of BCKV it was from 45^{th} SMW. Peaks of leaf miner could be observed from 1^{st} – 8^{th} SMW, 7^{th} – 9^{th} SMW, 4^{th} SMW and 7^{th} SMW at Hooghly, 24 PGS (N), Nadia districts and experimental plot of BCKV, respectively.

4.1.1.2 Periods of distribution of Leaf miner, *L. trifolii* (Burgess) on tomato in Summer season (Table 7)

In 2012, initiation of leaf miner attack in *summer* season could be recorded from 4^{th} – 8^{th} SMW and 5^{th} SMW at 24 PGS (N) and experimental plot of BCKV, respectively. In 2013, at 24 PGS (N) and experimental plot of BCKV, the initiation of the pest population could be noted from 2^{nd} – 6^{th} SMW and 10^{th} SMW respectively, in 2014, those were from 4^{th} – 6^{th} SMW and 6^{th} SMW, while in 2015 from 4^{th} – 7^{th} SMW and 10^{th} SMW and in 2016, from 4^{th} – 6^{th} SMW and 7^{th} SMW respectively. In 2017, initiation of leaf miner could be recorded from 3^{rd} – 6^{th} SMW and 6^{th} SMW at 24 PGS (N) and experimental plot respectively while in 2018, it was found from 2^{nd} – 8^{th} SMW and 6^{th} SMW at 24 PGS (N) and experimental plot of BCKV, respectively.

Peaks of pest population at 24 PGS (N) could be recorded from 15^{th} – 18^{th} SMW, 12^{th} – 13^{th} SMW, 8^{th} – 10^{th} SMW, 11^{th} – 17^{th} SMW, 12^{th} – 17^{th} SMW, 10^{th} – 16^{th} SMW and 10^{th} – 18^{th} SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. While at experimental plot of BCKV, peaks were found at 22nd SMW, 23rd SMW, 16th SMW, 22nd SMW, 17th SMW, 11th SMW and 11th SMW in 2012, 2013, 2014, 2015 and 2016, 2017 and 2018, respectively.

4.1.1.3 Periods of distribution of aphids on tomato in Rabi season (Table 8)

During 2011-12, initiation of aphid attack in villages of Hooghly could be recorded from 39th – 42nd SMW. While at 24 PGS (North) the pest appearance could be recorded from 42nd – 43rd SMW. At Nadia the attack started from 41st – 45th SMW while at experimental plot of BCKV, it was from 40th SMW. Peaks of aphid population could be on 51st – 1st SMW, 45th – 7th SMW, 2nd – 6th SMW and 40th SMW at districts of Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2012-13, initiation of aphid attack could be recorded from 42nd – 47th SMW at Hooghly. At 24 PGS (N), the appearance could be noted from 44th – 46th SMW. At Nadia, the attack started from 43rd – 47th SMW. And in the experimental plot of BCKV the attack started from 42nd SMW. Peaks of aphid population could be on 48th – 50th SMW at Hooghly and 47th – 50th SMW at 24 PGS (N) while it was from 48th – 50th SMW and 50th SMW and at Nadia and experimental plot of BCKV, respectively.

In 2013-14, initiation of aphid attack could be recorded from 44th – 46th SMW at Hooghly. While, at 24 PGS the appearance could be noted from 46th – 47th SMW. At Nadia and experimental plot of BCKV, the attack started from 43rd – 47th SMW and 47th SMW, respectively. Peaks of aphid population could be on 47th – 48th SMW, 48th – 4th SMW, 47th – 52nd SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2014-15, initiation of aphid attack at Hooghly could be recorded from 40th – 42nd SMW. While at the 24 PGS (N) the appearance could be recorded from 40th – 45th SMW. At Nadia, the attack started from 40th – 41st SMW and at experimental plot of BCKV it was from 44 SMW. Peaks of aphid population could be on 44th – 45th SMW, 45th – 47th SMW, 46th SMW and 48th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of aphid attack at Hooghly could be recorded from 42nd – 45th SMW. While at the 24 PGS (N) the appearance could be recorded from 44th – 46th SMW. At Nadia, the attack started from 43rd – 44th SMW and at experimental plot of BCKV it was noted from 44th SMW. Peaks of aphid population could be observed from

46th – 49th SMW, 47th – 50th SMW, 47th – 49th SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2016-17, initiation of aphid attack at Hooghly could be recorded from 45th – 46th SMW. While at the 24 PGS (N) the appearance could be recorded from 46th – 50th SMW. At Nadia the attack started from 47th – 48th SMW and at experimental plot from 42nd SMW. Peaks of aphid population could be on 51st – 1st SMW, 52nd – 3rd SMW, 51st – 1st SMW and 48th SMW at Hooghly, 24 PGS (N), Nadia and at experimental plot of BCKV, respectively.

In 2017-18, initiation of aphid could be recorded from 39th – 45th SMW at Hooghly. While at the 24 PGS (N), the appearance of the pest could be recorded from 40th – 45th SMW. At Nadia the attack started from 43rd SMW while at experimental plot of BCKV it was from 45th SMW onwards. Peaks of aphid population was observed from 44th – 47th SMW, 46th – 52nd SMW, 45th SMW and 50th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

4.1.1.4 Periods of distribution of aphids on tomato in Summer season (Table 8)

In summer 2012, initiation of aphid attack at 24 PGS (N) and experimental plot of BCKV could be recorded from 4th – 8th SMW and 4th SMW, respectively. In 2013, pest incidence could be noted from 2nd – 6th SMW at 24 PGS (N), while at the experimental plot of BCKV it was from 10th SMW. In 2014, the pest incidence could be observed from 4th – 6th SMW at 24 PGS (N) and 5th SMW at experimental plot of BCKV. In 2015 it was from 4th – 7th SMW at 24 PGS (N) and 8th SMW at experimental plot of BCKV. While in 2016, the pest initiation could be recorded from 4th – 5th SMW at 24 PGS (N) and 6th SMW at experimental plot of BCKV. In 2017, initiation of aphid population could be recorded from 2nd – 5th SMW and 6th SMW at 24 PGS (N) and experimental plot of BCKV, respectively, while in 2018, it was recorded from 2nd – 8th SMW and 6th SMW at 24 PGS (N) and experimental plot of BCKV, respectively.

Peaks of pest population at 24 PGS (N) could be found from 15th – 18th SMW, 12th – 13th SMW, 8th – 10th SMW, 11th – 17th SMW, 8th – 15th SMW, 10th – 15th SMW and 7th – 14th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. While at experimental plot of BCKV it was noted from 12th SMW, 13th SMW, 11th SMW, 14th SMW, 11th SMW and 13th SMW and 11 SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively.

4.1.1.5 Periods of distribution of whitefly on tomato in Rabi season (Table 9)

In 2011-12, initiation of whitefly attack could be recorded from 39^{th} – 42^{nd} SMW at Hooghly. While at 24 PGS (N), the appearance could be recorded from 39^{th} – 43^{rd} SMW. While at Nadia attack started from 41^{st} – 44^{th} SMW and at experimental plot of BCKV it was from 37^{th} SMW. Peak of whitefly population could be on 49^{th} – 52^{nd} SMW, 44 SMW, 50^{th} – 3^{rd} SMW and 46^{th} SMW at Hooghly, 24 PGS (N), Nadia district and experimental plot of BCKV.

In second year i.e. 2012-13, initiation of whitefly attack at Hooghly and 24 PGS (N) villages could be recorded from 41^{st} – 44^{th} SMW. At Nadia, the appearance could be noted from 40^{th} – 45^{th} SMW and at experimental plot of BCKV it was from 40^{th} SMW. Peak of whitefly population could be on 45^{th} – 47^{th} SMW at Hooghly and 47^{th} SMW at 24 PGS (N) while it was from 46^{th} – 49^{th} SMW at Nadia and 45^{th} SMW at experimental plot of BCKV.

In third year of study i.e. in 2013-14, initiation of whitefly attack at Hooghly could be recorded from 41^{st} – 43^{rd} SMW. At 24 PGS the appearance could be from 42^{nd} – 44^{th} SMW, while at Nadia the attack started from 42^{nd} – 46^{th} SMW. In experimental plot of BCKV the attack was from 45^{th} SMW. Peak of whitefly population could be on 44^{th} – 46^{th} SMW, 46^{th} – 47^{th} SMW, 45^{th} – 52^{nd} SMW and 47^{th} SMW at Hooghly, 24 PGS (N), Nadia district and experimental plot of BCKV, respectively.

In 2014-15, initiation of attack at Hooghly could be recorded from 37^{th} – 38^{th} SMW. While at the 24 PGS (N) the appearance could be recorded from 37^{th} – 44^{th} SMW. At Nadia the attack started from 38^{th} SMW and at experimental plot of BCKV it was from 43^{rd} SMW. Peak of whitefly population could be on 39^{th} – 44^{th} SMW, 43^{rd} – 47^{th} SMW, 44^{th} SMW and 48^{th} SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of whitefly attack could be recorded from 38^{th} – 44^{th} SMW at Hooghly. While at 24 PGS (N) the appearance could be recorded from 44^{th} – 46^{th} SMW. At Nadia the attack started from 41^{st} – 42^{nd} SMW and at experimental plot of BCKV it was from 42^{nd} SMW. Peaks could be noted on 46^{th} – 49^{th} SMW, 46^{th} – 48^{th} SMW, 45^{th} – 47^{th} SMW and 46^{th} SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2016-17, initiation of whitefly attack could be recorded from 45th – 46th SMW at Hooghly. While at the 24 PGS (N) the appearance could be recorded from 46th – 50th SMW. At Nadia the attack started from 47th – 48th SMW and at experimental plot of BCKV it was from 42nd SMW. Peaks could be observed on 51st – 1st SMW, 52nd – 3rd SMW, 52nd – 1st SMW and 48th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2017-18, initiation of whitefly could be recorded from 39th – 46th SMW at Hooghly. While at 24 PGS (N), the appearance of the pest could be recorded from 40th – 45th SMW. At Nadia the attack started from 43rd SMW while at experimental plot of BCKV it was from 45th SMW onwards. Peak of whitefly could be seen on 44th – 49th SMW, 52nd SMW, 44th SMW and 50th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

4.1.1.6 Periods of distribution of whitefly on tomato in Summer season (Table 9)

In 2012, initiation of whitefly attack in *summer* season could be recorded from 4th – 7th SMW and 4th SMW at 24 PGS (N) and experimental plot respectively. In 2013, it was noted from 3rd – 6th SMW and 10th SMW at 24 PGS (N) and experimental plot, respectively, while in 2014, incidence was noted from 3rd – 5th SMW at 24 PGS (N) and 5th SMW at experimental plot, while in 2015 and 2016, it was observed from 2nd – 7th SMW and 4th – 6th SMW, 8th SMW and 6th SMW at 24 PGS (N) and experimental plot, respectively. And in 2017 it was recorded from 2nd – 6th SMW at 24 PGS (N) and on 6th SMW at experimental plot of BCKV. However, during 2018 it was recorded from 2nd – 8th SMW in 24 PGS (N) and on 6th SMW at experimental plot of BCKV.

Peak incidence of pest at 24 PGS (N) could be found from 14th – 17th SMW, 12th – 15th SMW, 8th – 12th SMW, 12th – 15th SMW, 8th – 15th SMW, 10th – 15th SMW and 6th – 12th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. While in experimental plot of BCKV it was seen on 15th SMW, 14th SMW, 11th SMW, 15th SMW, 12th SMW, 13th SMW and 9th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively.

4.1.1.7 Periods of distribution of thrips on tomato in Rabi season (Table 10)

In 2011-12, initiation of thrips attack could be recorded from 39th – 42nd SMW at Hooghly. While at 24 PGS (N) the pest appearance could be recorded from 39th – 44th SMW. At Nadia, attack started from 41st – 44th SMW and at experimental plot of

BCKV it was from 37th SMW. Peak of thrips population could be seen on 51st – 1st SMW, 5th – 7th SMW, 49th – 3rd SMW and 46th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2012-13, initiation of thrips attack at Hooghly district could be recorded from 43rd - 46th SMW. At 24 PGS (N), the appearance could be noted from 46th SMW. At Nadia district, attack started from 42nd – 47th SMW and at experimental plot of BCKV it was from 43rd SMW. Peak of thrips population could be observed on 50th SMW at Hooghly, 24 PGS (N) district and experimental plot of BCKV while it was from 47th – 50th SMW at Nadia district.

In third year of study i.e. in 2013-14, initiation of thrips attack at Hooghly could be recorded from 43rd – 46th SMW. At 24 PGS the appearance could be from 47th – 48th SMW while at Nadia, the attack started from 46th – 50th SMW. At experimental plot it was observed from 47th SMW. Peak of thrips population could be seen on 46th – 47th SMW, 1st – 5th SMW, 52nd – 2nd SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2014-15, initiation of thrips attack at Hooghly could be recorded from 41st – 42nd SMW. While at 24 PGS (N) the appearance could be recorded from 42nd – 44th SMW. At Nadia and experimental plot of BCKV, the attack started from 42nd SMW and 46th SMW respectively. Peak population could be found on 45th – 48th SMW, 47th – 48th SMW, 47th SMW and 50th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of thrips attack at Hooghly could be recorded from 42nd – 45th SMW. While at 24 PGS (N) the appearance could be recorded from 46th – 47th SMW. At Nadia and experimental plot of BCKV, the attack started from 45th – 46th SMW and 45th SMW respectively. Peak population could be observed on 49th – 50th SMW, 50th – 51st SMW, 50th – 51st SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2016-17, initiation of thrips attack at Hooghly could be recorded from 45-46th SMW. While at 24 PGS (N) the appearance could be recorded from 45th – 50th SMW. At Nadia and experimental plot of BCKV, the attack started from 48th SMW and 42nd SMW respectively. Peak population could be seen on 51st – 52nd SMW, 51st – 3rd SMW, 52nd – 1st SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2017-18, initiation of thrips could be recorded from 42nd – 47th SMW at Hooghly district. While at 24 PGS (N), the appearance of the pest could be recorded from 41st – 47th SMW. At Nadia the attack started from 46th SMW while at experimental plot of BCKV it was from 48th SMW onwards. Peaks could be observed on 48th – 4th SMW, 52nd – 1st SMW, 52nd SMW and 52nd SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

4.1.1.8 Periods of distribution of thrips on tomato in Summer season (Table 10)

In 2012, at 24 PGS (N), initiation of thrips attack in *summer* season could be recorded from 4th – 8th SMW. In 2013, pest could be noted from 2nd – 7th SMW while in 2014, it was from 5th – 8th SMW. In 2015 and 2016, its incidence was observed from 4th – 8th SMW and 4th – 6th SMW, respectively. And in 2017 and 2018 it was recorded from 3rd – 5th and 2nd – 8th, respectively. Peak population could be found from 13th – 16th SMW, 12th – 15th SMW, 11th – 15th SMW, 12th – 18th SMW, 9th – 15th SMW, 9th – 14th SMW and 6th – 12th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively in 24 PGS (N).

In the experimental plot of BCKV, the pest initiation started from 5th SMW, 10th SMW, 7th SMW, 9th SMW, 7th SMW, 6th SMW and 6th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. While peak incidence was observed on 12th SMW, 19th SMW, 15th SMW, 16th SMW, 9th SMW, 10th SMW and 11th SMW in 2012, 2013, 2014, 2015 and 2016, 2017 and 2018, respectively.

4.1.1.9 Periods of distribution of *S. litura* on tomato in Rabi season (Table 11)

In 2011-12, initiation of *S. litura* attack at Hooghly could be recorded from 40th – 42nd SMW. While at 24 PGS (N) it could be recorded from 41st – 43rd SMW. At Nadia and experimental plot of BCKV the attack started from 42nd – 46th SMW and 38th SMW, respectively. Peak of pest population could be observed at Hooghly on 51st – 52nd SMW, at 24 PGS (N) on 47th – 49th SMW, at Nadia district on 51st – 4th SMW and at experimental plot attack of BCKV peak was observed on 46th SMW.

In 2012-13, initiation of *S. litura* attack at Hooghly was recorded from 41st – 45th SMW. At 24 PGS (N) and Nadia initiation of pest was both observed from 43rd – 46th SMW. While at experimental plot of BCKV, attack started from 41st SMW. Peak of the pest was on 44th – 48th SMW at Hooghly and at 24 PGS (N) on 42nd – 47th while at Nadia district it was on 48th SMW and at experimental plot of BCKV it was seen on 44th SMW.

In 2013-14, initiation of *S. litura* attack at Hooghly could be recorded from 42nd – 45th SMW. At 24 PGS (N) the pest could be observed from 45th SMW, while at Nadia the attack started from 43rd - 47th SMW. However, at experimental plot of BCKV incidence started from 46th SMW. Peak of the pest population were observed on 46th – 47th SMW, 46th – 48th SMW, 43rd – 47th SMW and 47th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2014-15, initiation of *S. litura* population at Hooghly could be recorded from 38th – 40th SMW. While at the 24 PGS (N) attack could be recorded from 38th – 45th SMW. At Nadia and experimental plot of BCKV, attack started from 38th SMW and 45th SMW, respectively. Peak of the pest could be seen on 42nd – 45th SMW, 44th – 50th SMW, 43rd – 44th SMW and 48th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of *S. litura* population at Hooghly district could be recorded from 39th – 44th SMW. While at 24 PGS (N) the pest could be recorded from 44th – 46th SMW. At Nadia and experimental plot of BCKV, attack started from 42nd - 44th SMW and 43rd SMW, respectively. Peak of the pest could be found on 46th – 49th SMW, 47th SMW, 47th – 49th SMW and 47th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2016-17, initiation of *S. litura* population at Hooghly could be recorded from 45th – 46th SMW. While at 24 PGS (N) the pest appearance could be recorded from 46th – 51st SMW. At Nadia and experimental plot of BCKV, attack started from 48th SMW and 44th SMW, respectively. Peak of the pest could be seen on 50th – 52nd SMW, 50th – 54th SMW, 52nd – 2nd SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2017-18, initiation of *S. litura* could be recorded from 39th – 47th SMW at Hooghly. While at 24 PGS (N), the appearance of the pest could be recorded from 42nd – 49th SMW. At Nadia the attack started from 46th SMW while at experimental plot of BCKV, it was 45th SMW onwards. Peaks could be observed on 42nd – 4th SMW, 50th – 2nd SMW, 50th SMW and 5th SMW at Hooghly, 24 PGS (N), Nadia district and experimental plot of BCKV, respectively.

4.1.1.10 Periods of distribution of *S. litura* on tomato in Summer season (Table 11)

In 2012, at 24 PGS (N), initiation of *S. litura* attack in *summer* season could be recorded from 7^{th} – 9^{th} SMW. In 2013, pest could be noted from 3^{rd} – 6^{th} SMW while in 2014 it was from 6^{th} – 8^{th} SMW. In 2015 and 2016 pest initiation was both observed from 4^{th} – 7^{th} SMW. And in 2017 and 2018 it was recorded from 3^{rd} – 6^{th} SMW and 2^{nd} – 8^{th} SMW, respectively. Peak of pest population could be found from 15^{th} – 16^{th} SMW, 18^{th} – 21^{st} SMW, 15^{th} – 19^{th} SMW, 16^{th} – 20^{th} SMW, 9^{th} – 12^{th} SMW, 12^{th} – 16^{th} SMW and 10^{th} – 18^{th} SMW in 2012, 2013, 2013-14, 2015, 2016, 2017 and 2018, respectively.

At experimental plot of BCKV, the pest initiation started from 6^{th} SMW, 10^{th} SMW, 5^{th} SMW, 9^{th} SMW, 8^{th} SMW, 6^{th} SMW and 6^{th} SMW in 2012, 2013, 2014, 2015 and 2016, 2017 and 2018 respectively. While peak population was observed on 13^{th} SMW, 18^{th} SMW, 10^{th} SMW, 13^{th} SMW, 12^{th} SMW, 13^{th} SMW, and 12^{th} SMW in 2012, 2013, 2014, 2015 and 2016, 2017 and 2018, respectively.

4.1.1.11 Periods of distribution of *H. armigera* on tomato in Rabi season (Table 12)

In 2011-12, initiation of *H. armigera* attack at Hooghly could be recorded from 40^{th} – 42^{nd} SMW. While at 24 PGS (N) the appearance could be recorded from 41^{st} – 43^{rd} SMW. At Nadia district and experimental plot of BCKV, attack started from 42^{nd} – 46^{th} SMW and 38^{th} SMW, respectively. Peak of pest population could be observed on 51^{st} – 52^{nd} SMW at Hooghly, 47^{th} – 49^{th} SMW at 24 PGS (N), 51^{st} – 4^{th} SMW at Nadia and 46^{th} SMW at experimental plot of BCKV.

In 2012-13, initiation of *H. armigera* attack at Hooghly was recorded from 41^{st} – 45^{th} SMW. At 24 PGS (N) and Nadia initiation of pest was observed from 43^{rd} -46^{th} SMW. While at experimental plot attack started from 41^{st} SMW. Peak could be observed on 44^{th} – 48^{th} SMW at Hooghly and from 42^{nd} – 47^{th} at 24 PGS (N), while at experimental plot of BCKV it was noted on 48^{th} SMW and on 44^{th} SMW at Nadia.

In 2013-14, initiation of *H. armigera* attack at Hooghly could be recorded from 42^{nd} – 45^{th} SMW. At 24 PGS (N) the appearance could be observed from 45^{th} SMW, while at Nadia the attack started from 43^{rd} – 47^{th} SMW. In experimental plot of BCKV however, incidence started from 46^{th} SMW. Peak population were observed on 46^{th} – 47^{th} SMW, 46^{th} – 48^{th} SMW, 43^{rd} – 47^{th} SMW and 47^{th} SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2014-15, initiation of pest population at Hooghly could be recorded from 38th – 40th SMW. While at 24 PGS (N) the appearance could be recorded from 38th – 45th SMW. At Nadia and experimental plot attack started from 38th SMW and 45th SMW, respectively. Peak of the pest could be noted from 42nd – 45th SMW, 44th – 50th SMW, 43rd – 44th SMW and 48th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2015-16, initiation of *H. armigera* population at Hooghly could be recorded from 39th – 44th SMW. While at 24 PGS (N) the appearance could be recorded from 44th – 46th SMW. At Nadia and experimental plot of BCKV, attack started from 42nd – 44th SMW and 43rd SMW, respectively. Peak of the pest could be observed on 46th – 49th SMW, 47th SMW, 47th – 49th SMW and 47th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2016-17, initiation of *H. armigera* population could be recorded from 45th – 46th SMW at Hooghly. While at 24 PGS (N), the appearance could be recorded from 46th – 51st SMW. At Nadia and experimental plot of BCKV, attack started from 48th SMW and 44th SMW, respectively. Peak of the pest could be observed from 50th – 52nd SMW, 50th – 54th SMW, 52nd – 2nd SMW and 49th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

In 2017-18, initiation of pest population could be recorded from 39th – 46th SMW at Hooghly. While at 24 PGS (N), pest appearance could be recorded from 42nd – 47th SMW. At Nadia the attack started from 45th SMW while at experimental plot of BCKV it was from 45th SMW onwards. While its peak was observed from 48th – 8th SMW, 52nd – 7th SMW, 5th SMW and 7th SMW at Hooghly, 24 PGS (N), Nadia and experimental plot of BCKV, respectively.

4.1.1.12 Periods of distribution of *H. armigera* on tomato in Summer season (Table 12)

In 2012, at 24 PGS (N) initiation of *H. armigera* attack in *summer* season could be recorded from 4th - 8th SMW. In 2013, it could be noted from 2nd –06th SMW while in 2014 could be from 4th – 6th SMW. In 2015 and 2016 its incidence could be observed from 4th – 7th and 4th – 5th SMW, while it was noted from 5th – 8th and 5th – 9th SMW during 2017 and 2018, respectively. Peaks of pest population could be found from 15th - 18th SMW, 12th – 13th SMW, 8th - 10th SMW, 11th – 17th SMW, 8th – 15th SMW, 14th –

11th SMW, and 15th – 18th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018 respectively.

At experimental plot of BCKV, pest initiation started from 12th SMW, 17th SMW, 13th SMW, 17th SMW, 13th SMW, 10th SMW and 7th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. While peak incidence was observed on 17th SMW, 22nd SMW, 17th SMW, 20th SMW, 16th SMW, 20th SMW & 19th SMW in 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively.

4.1.2 Population dynamics of leaf miner, *L. trifolii* (Burgess) and other important insect pests of tomato at experimental plot of C-Block farm, Kalyani

The results presented here include the occurrence of important insect pests of tomato. A large number of insect pests were found to infest the crop throughout the course of investigation. Among these, some were important as they were prevalent at regular interval and caused a considerable damage to the crop, while the others were sporadic in nature. All the major pests of tomato which were observed in this locality are mentioned in the Table 6. These insect pests were observed to infest the tomato crop under field conditions and it was clear that these pests were prevalent in the field throughout the entire period in the present investigation, but their population was not uniform throughout the season.

4.1.2.1 Population dynamics of leaf miner (*L. trifolii*) in rabi season

The data regarding incidence of leaf miner on tomato crop during all the seven years of investigation i.e. from 2011-12 to 2017-18 is presented in Fig. 1 and Table 13. It could be revealed that in the year 2011-12, the pest was present on the crop for 19 weeks and the first incidence could be recorded on 40th SMW i.e., in the first week of October with an incidence load of 0.36 leaf miner/plant. During this period, the average of T max was 34.18 °C and T min was 25.80°C with an average RH max of 92.14 % and RH min of 65 % and average weekly rainfall was found to be 29.20 mm. Population of leaf miner during the period continued to increase and highest population was recorded during 3rd week of November (46th SMW) with a population load of 1.52 leaf miner/plant. During this period, the average of T max was 30.16 °C and T min was 19.91°C with an average RH max of 94.14 % and RH min of 62.43 % and average weekly rainfall found to be 8.00 mm. Later the leaf miner population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of leaf miner population load was found to be 0.84 leaf miner/plant during 6th SMW (2nd week of February).

In 2012-13, the incidence of the pest could be recorded for 11 weeks with its initiation in the third week of November with a population load of 0.2 leaf miner/ plant. During this period, the average of T max was 30.40°C and T min was 18.11°C with an average RH max of 88.29 % and RH min of 49.29 % with no rainfall during the period. Population of leaf miner during the period continued to increase and highest population was recorded during last week of January (5th SMW) with a population load of 1.20 leaf miner/plant. During this period, the average of T max was 27.73°C and T min was 10.29°C with an average RH max of 91.86 % and RH min of 47.57 % and with no rainfall.

In 2013-14, the pest was present on the crop for 10 weeks with its initiation in third week of December (0.48 leaf miner/plant). During this period, the average of T max was 28.19°C and T min was 12.54°C with an average RH max of 83.71 % and RH min of 62.14 % with no rainfall. And highest population was recorded during 3rd week of February (8th SMW) with a population load of 1.72 leaf miner/plant. During this period, the average of T max was 29.17 °C and T min was 14.09°C with an average RH max of 85.14 % and RH min of 54.43 % with no rainfall.

In 2014-15, the pest had been found to be present in the crop for 16 weeks with its first appearance on 2nd week of November with incidence load of 0.48 leaf miner/plant and during the period the average of T max was 33.47°C and T min was 19.71°C with an average RH max of 81.29 % and RH min of 56.57 % with no rainfall. And highest population was recorded during 3rd week of February (8th SMW) with a population load of 3.00 leaf miner/plant. During this period, the average of T max was 34.19°C and T min was 19.67°C with an average RH max of 85.86 % and RH min of 50.14 % with an average weekly rainfall found of 5.30 mm.

During 2015-16 and 2016-17 the incidences of the pest were recorded for 14 weeks with their arrival on the crop during last week of the October with population loads of 0.40 and 0.32 leaf miner/plant respectively. During 2015-16 period, the average of T max was 31.37°C and T min was 21.36°C with an average RH max of 94 % and RH min of 63.57 % with no rainfall whereas, during 2016-17 the average of T max found to be31.57°C and T min was 23.87°C with an average RH max of 95.71 % and RH min of 72.29 % with an average rainfall of 1.10 mm rainfall during the period.

And highest population was recorded during last week of January (5^{th} SMW) with a population load of 3.68 leaf miner/plant and 2.96 leaf miner/plant during the year 2015-16 and 2016-17 respectively.

In 2017-18, the pest incidence was recorded for 15 weeks on the crop with its first onset during 2^{nd} week of November with a population load of 0.12 leaf miner/plant. And during the period the average of T max was 31.83°C and T min was 19.89°C with an average RH max of 94.00 % and RH min of 53.86 % with no rainfall. And highest population was recorded during 3^{rd} week of February (7^{th} SMW) with a population load of 1.52 leaf miner/plant. During this period, the average of T max was 29.41°C and T min was 13.96°C with an average RH max of 88.14 % and RH min of 43.43 % without any rainfall.

The Overall data for seven years i.e. 2011-12 to 2017-18 during rabi season revealed that leaf miner first appeared on tomato crop from first week of October to third week of December (i.e. from 40^{th} to 51^{st} SMW). The peak population of leaf miner during the period of study i.e. 2011-12 to 2017-18, was observed towards the end of the crop duration i.e. from last week of January to third week of February (5^{th} – 8^{th} SMW) with the exception in 2011-12, where peak population was recorded during third week of November (46^{th} SMW). And the highest population load of leaf miner (3.68 leaf miner/plant) was observed at 5^{th} SMW i.e. first week of February, in 2015-16, during which the average T max was 28.14 °C, T min was 14.90°C, RH max was 92.43 % and RH min of 48.57 % with no rainfall.

Chaudhuri and Senapati (2004) reported that in tomato, the population densities of leaf miner slowly increased during early crop growing stages, but had gained momentum from flowering stage onwards. Chakraborty (2011) recorded the leaf miner population at about 46^{th} SMW, improved at first slowly up to 1^{st} SMW and then steadily up to 6^{th} SMW attaining the maximum at about 8^{th} SMW which was maintained up to about 13^{th} SMW. While Choudary and Rosaiah (2000) reported that the leaf miner incidence commenced from the third week of November and reached a peak in fourth week of January. A second peak was observed in the second week of February. Similar findings were also reported by Variya and Bhut (2014), Saradhi and Patnaik (2004) and Galande and Ghorpade (2010) where peak leaf miner infestation took place in third week of January and in February month. Thus, the above reports are more or less in support with the present findings.

4.1.2.1.1 Correlation studies between leaf miner and weather parameters during rabi season

Perusal of the data presented in Table 13.1 indicated that during first year of study (2011-12), T max (r = -0.478*), T min (r = -0.653**), T day (r = -0.585**), T night (r = -0.616**), RH min (r = -0.634**) and rainfall (r = -0.658**) showed negative and significant correlations with leaf miner population while, RH max showed non-significant negative correlation. During the second year of study (2012-13), T max (r = -0.8306**), T min (r = -0.872**), T day (r = -0.874**) and T night (r = -0.878**) showed high significantly negative correlation with leaf miner. RH min (r = -0.329) and rainfall (r = -0.437) showed non-significant negative correlation while, RH max (r = 0.1721) showed non-significant positive correlation with leaf miner. In the third year of study (2013-14), T min (r = -0.522*), T day (r = -0.497*), T night (r = -0.512*), showed significantly negative correlation while T max (r = -0.445) was found to have non-significant negative correlation and RH max (r = 0.167), RH min (r = 0.002), rainfall (r = 0.333) showed non-significant positive correlation. In 2014-15, T max, T min, T day and T night showed significantly negative correlation with leaf miner while RH max and Rainfall showed non-significant positive correlation and RH min (r= -0.296) revealed non-significant negative correlation. In the year 2015-16 also, T max and T min showed highly significant negative correlation with leaf miner while RH max and RH min showed non-significant negative correlation and Rainfall (r= 0.031) revealed non-significant positive correlation with the leaf miner in the above table. In 2016-17, correlation between leaf miner and weather factors showed a highly significant negative correlation with T max and T min, T day and T night and also significant and negative correlation with RH (max, min), and rainfall. And during the last year of study i.e. in 2017-18, T (min and night), RH (max, min) were found to be negatively significantly correlated and T (max and day) and rainfall were found have non-significant negative correlation with leaf miner population.

The overall seven years data i.e. 2011-12 to 2017-18, revealed that temperature (maximum, minimum, day and night) had significant negative correlation with leaf miner population, and in 2016-17 and 2017-18, maximum and minimum relative humidity also showed significant negative correlation with the pest population.

Table 13.1: Correlation between leaf miner and weather parameters during rabi season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.478*	-0.653**	-0.585**	-0.616**	-0.146	-0.634**	-0.658**
2012-13	-0.830**	-0.872**	-0.874**	-0.878**	0.172	-0.329	-0.437
2013-14	-0.445	-0.522*	-0.497*	-0.512*	0.167	0.002	0.333
2014-15	-0.490*	-0.580*	-0.561*	-0.576*	0.146	-0.296	0.365
2015-16	-0.751**	-0.794**	-0.786**	-0.793**	-0.268	-0.415	0.031
2016-17	-0.932**	-0.947**	-0.958**	-0.957**	-0.599*	-0.577*	-0.522*
2017-18	-0.240	-0.658**	-0.482	-0.562*	-0.708**	-0.689**	-0.231

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.2 Population dynamics of leaf miner (*L. trifolii*) in *summer* season

The incidence of leaf miner population during 2012 to 2018 is presented in Table 14 and Fig. 2. It is revealed that in the year 2012, leaf miner made its first appearance on the crop on first week of February with a population load of 0.28 leaf miner/plant and remained on the crop for 18 weeks. During this period, the average of T max was 24.97°C and T min was 10.47°C with an average RH max of 91.29 % and RH min of 41.72 % with no rainfall. Population of leaf miner during the period continued to increase and highest population was recorded during last week of May (22nd SMW) with a population load of 3.40 leaf miner/plant.

During 2013, the pest was found to be present on the crop for 15 weeks with its initiation on first week of March with population load of 0.2 leaf miner/plant. In this period, the average of T max was 33.59°C and T min was 14.54°C while average RH max was 89.43 % and RH min was 30.57 % and no rainfall was recorded. Population of leaf miner during the period continued to increase and highest population was recorded during second week of June (23rd SMW) with a population load of 3.40 leaf miner/plant. The average of T max was 35.20°C and T min was 25.51°C with an average RH max of 93.14 % and RH min of 68.86 % with an average weekly rainfall of 47.10 mm was recorded during the period.

During 2014, pest initiation was recorded on first week of February (0.72 leaf miner/ plant) and it remained on the crop for 15 weeks. In this period, the average of T max was 27.01°C and T min was 9.61°C with an average RH max of 85.00 % and RH min of 54.57 % with no rainfall was recorded. Population of leaf miner during the period continued to increase and highest population was recorded during second week of May (19th SMW) with a population load of 3.32 leaf miner/plant. The weekly average of T max was 35.03°C and T min was 24.03°C with an average RH max of 87.57 % and RH min of 59.43 % with an average weekly rainfall of 24.90 mm was recorded during the period. Later the leaf miner population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of leaf miner population load was found to be 3.12 leaf miner/plant during 20th SMW (3rd week of May).

During the year 2015, first incidence of the pest was found in 2nd week of March (0.6 leaf miner/ plant) and it thrived on the crop for 14 weeks. During the period the weekly average of T max was 33.69°C and T min was 15.90°C with an average RH max of 77.43 % and RH min of 35.14 % and an average weekly rainfall of 2.30 mm was recorded. Population of leaf miner during the period continued to increase and highest population was recorded during last week of May (22nd SMW) with a population load of 3.12 leaf miner/plant.

In the year 2016, the pest could be recorded for 11 weeks with its arrival in 3rd week of February and a population 1.68 leaf miner/plant was observed. During the period, weekly average of T max was 31.46°C and T min was 19.79°C with an average RH max of 94.86 % and RH min of 56.14 % with no rainfall recorded was recorded. Population of leaf miner during the period continued to increase and highest population was recorded during last week of April (17th SMW) with a population load of 4.72 leaf miner/plant. During the period the weekly average of T max was 40.10°C and T min was 27.49°C with an average RH max of 88.14 % and RH min of 45.29 % with no rainfall was recorded during the period.

In both the year 2017 and 2018 the pest made its first appearance on the crop on second week of February with a population load of 0.76 and 1.28 leaf miner per plant respectively and it remained on the crop for 16 weeks and 14 weeks, respectively. The weekly average of T max was 29.64°C and T min was 11.79°C with an average RH max of 91.71 % and RH min of 53.00 % with no rainfall was recorded in the year 2017. While in 2018, weekly average of T max was 29.39°C and T min was 15.73°C with an average RH max of 89.00 % and RH min of 43.71 % with an average rainfall of 0.04 mm was recorded. In both the year population of leaf miner during the period continued to increase and highest population was recorded during third week of March (11th

SMW) with a population load of 4.96 and 5.12 leaf miner/plant respectively. The weekly average of T max was 32.21°C and T min was 16.73°C with an average RH max of 86.71 % and RH min of 34.14 % with no rainfall recorded was recorded in the year 2017. Whereas, in 2018 the weekly average of T max was 35.26°C and T min was 20.94°C with an average RH max of 88.71 % and RH min of 39.57 % with an average rainfall of 0.04 mm was recorded. Later the leaf miner population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of leaf miner population load was found to be 0.84 leaf miner/plant during 21st SMW (last week of May) in the year 2017 and in 2018 it was recorded at 1.32 leaf miner/plant during 19th SMW (second week of May). Highest pest attack had been found to take place from third week of March during 2017 & 2018 with a pest load of 4.96 and 5.12 leaf miner/plant. And from 2012 to 2016 it varies from fourth week of April to second week of June.

The Overall data for seven years i.e. 2012 to 2018 during summer season revealed that the first appearance of leaf miner on tomato crop was recorded from first week of February to first week of March (i.e. from 5th to 10th SMW). While peak periods were noticed from second week of March to second week of June (11th to 23rd SMW) and highest infestation of 5.12 leaf miner/plant was found on 11th SMW (second week of March) in 2018.

The present findings are more or less in conformity with Chaudhuri and Senapati (2004) reported that in tomato higher incidence of leaf miner was observed during late March to early May. They explained that the population densities slowly increased during early crop growing stages, but had gained momentum from flowering stage onwards. Similar findings were reported by Reddy and Kumar (2005) who observed that the peak incidence of *L. trifolii* occurred during March-April, which coincided with the vegetative and reproductive stages of the crop. Kharpuse (2005) also recorded maximum infestation of leaf miner on tomato during middle of March. The present findings are also in allignment with Singh *et al*. (2018) who reported that serpentine leaf miner was first observed damaging tomato leaf on 16th January i.e. during third standard week with 1.05 live mines/plant and remained active throughout the cropping period. The peak activity (31.25 live mines/plant) of the pest was recorded during fruiting stage of the crop in the last week of March.

4.1.2.2.1 Correlation studies between leaf miner and weather parameters during summer season

Correlation among different weather factors and leaf miner during summer season is presented in Table 14.1. From the results of first year of investigation (2012) it was found that T max (r = 0.955**), T min (r = 0.972**), T day (r = 0.975**) and T night (r = 0.977**) showed highly significant positive correlation with leaf miner population. While, RH max (r = -0.340) showed negative non-significant correlation and RH min (r = 0.331) and rainfall showed non-significant positive correlation. In 2013, T min (r = 0.804**), T night (r = 0.626*), RH min (r = 0.797**) and rainfall (r = 0.523*) showed positive significant correlation while T max (r = -0.170) showed negative correlation and T day (r = 0.420), RH max (r = 0.344) showed non-significant positive relation. In 2014, T max (r = 0.910**), T min (r = 0.916**), T day (r = 0.922**) and T night (r = 0.923**) were found to be highly significant and positively correlated whereas, RH min (r = -0.679**) revealed highly significant and negatively correlation with leaf miner. RH max and rainfall (r = 0.152) showed non-significant positive correlation. Similarly, in 2015 and 2016, Temperatures (max, min, day and night) were found to be significant & positively correlated with leaf miner population. RH min showed significant & positively correlation in 2015 whereas, in 2016, RH min revealed significant negative correlation. In 2015, RH max and rainfall showed positive non-significant correlation but in 2016, RH max and rainfall showed negative non-significant correlation with the leaf miner population. Lastly, in 2017 & 2018, Temperatures (max, min, day and night) were found to have non-significant positive correlation and RH max in 2017 was also found to be the same. RH min and rainfall in 2017 and RH max, RH min, and rainfall in 2018 were revealed to be non-significant and negatively correlated with the pest population.

The overall seven years data indicated that temperature (maximum, minimum, day and night) had significant and highly positive correlation with leaf miner population in 2012 to 2016, while in 2013 and 2014, minimum relative humidity revealed a significant positive and negative correlation with the pest population, respectively.

Choudary and Rosaiah (2000) reported that minimum temperature and evening relative humidity had negative correlation while wind velocity and sunshine hours showed positive correlation with leaf miner incidence. Chakraborty (2011a) also reported that maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity and sunshine hours had significant negative influence on *L. trifolii* population. But number of rainy days rainfall expressed insignificant positive effect on population development. Similarly, Variya and Bhut (2014) revealed that number of mines and larvae had significant negative correlation with maximum temperature, minimum temperature, mean temperature and evening relative humidity. Reddy and Kumar (2005) however, observed a highly significant negative correlation between the seasonal abundance of *L. trifolii* and rainfall but a positive non-significant correlation with maximum and minimum temperatures and negative non-significant correlation between morning and evening relative humidity was revealed. Asalatha, (2002) on the other hand stated that leaf infestation by leaf miner and its population on tomato were positively correlated with maximum temperature and sunshine hours and negatively correlated with relative humidity and minimum temperature. While Chaudhuri and Senapati (2004) revealed leaf miner incidence had significant and positive correlation with temperature, minimum relative humidity, and rainfall, but was non-significantly and positively correlated with the average relative humidity. Galande and Ghorpade (2010) also revealed that maximum temperature showed significant and positive correlation, whereas morning relative humidity showed significant but negative correlation with *L. trifolii* incidence. Singh *et al*. (2018) also reported that the population of serpentine leaf miner was found to be significantly and positively correlated with maximum temperature (r = 0.57) but significant negative correlation was evaluated with morning (r = -0.62) and evening (r = -0.67) relative humidity. Thus, the above reports are more or less in corroboration with the present findings.

Table: 14.1 Correlation between leaf miner and weather parameters during *summer* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Max	Min	Day	Night	Max	Min	
2012	0.955**	0.972**	0.975**	0.977**	-0.340	0.331	0.353
2013	-0.170	0.804**	0.420	0.626*	0.344	0.797**	0.523*
2014	0.910**	0.916**	0.922**	0.923**	0.059	-0.679**	0.152
2015	0.597*	0.768**	0.757**	0.770**	0.482	0.572*	0.264
2016	0.896**	0.953**	0.931**	0.943**	-0.556	-0.601*	-0.122
2017	0.209	0.153	0.182	0.171	0.181	-0.309	-0.305
2018	0.504	0.221	0.371	0.313	-0.106	-0.500	-0.183

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.3 Population dynamics of aphid in *rabi* season

The data regarding population dynamics of aphid on tomato crop during all the year of investigation i.e. 2011-12 to 2017-18 presented in Table 15, Fig. 3. From the table & figure mentioned it could be revealed that in the year 2011-12, the pest made its first appearance on the crop on first week of October with population load of 2.76 aphid/leaf and it remained on the crop for 19 weeks. During this period, the average of T max was 34.18 °C and T min was 25.80°C with an average RH max of 92.14 % and RH min of 65 % and average weekly rainfall was found to be 29.20 mm. Population of aphid during the period continued to increase and highest population was recorded during 2nd week of November (46th SMW) with a population load of 3.52 leaf aphid/leaf. During this period, the average of T max was 30.16 °C and T min was 19.91°C with an average RH max of 94.14 % and RH min of 62.43 % and average weekly rainfall found to be 8.00 mm. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.96 aphid/leaf during 6th SMW (2nd week of February).

During 2012-13 and 2016-17 it was third week of October with a population of 1.22 and 1.00 aphid/leaf respectively. The pest remained on the crop for 16 weeks in both years and during 2012-13, the average of T max was 33.74 °C and T min was 22.01°C with an average RH max of 93.14 % and RH min of 55.43 % and average weekly rainfall was found to be nil. While, in 2016-17, the average of T max was 33.77°C and T min was 22.57°C with an average RH max of 94.29 % and RH min of 56.14 % with no rainfall was recorded. Population of aphid during 2012-13 period continued to increase and highest population was recorded during 2nd week of December (50th SMW) with a population load of 5.92 leaf aphid/leaf. During this period, the average of T max was 27.79°C and T min was 15.20°C with an average RH max of 95.43 % and RH min of 64.29 % and average weekly rainfall found to be 7.30 mm. However, Population of aphid during 2016-17 period continued to increase and highest population was recorded during last week of November (48th SMW) with a population load of 6.32 leaf aphid/leaf. During this period, the average of T max was 29.36 °C and T min was 16.57°C with an average RH max of 93.00 % and RH min of 58.29 % and no rainfall was recorded. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of leaf miner population load was found to be 1.20 aphid/leaf during 5th SMW (last week of January). Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.20 and 1.04 aphid/leaf during 5th SMW (last week of January) in both the year i.e., 2012-13 and 2016-17, respectively.

In 2013-14, the pest could be recorded for 14 weeks with its arrival in the third week of November (2.08 aphid/leaf). During this period, the average of T max was 28.93°C and T min was 14.63°C with an average RH max of 79.71 % and RH min of 53.43 % and no rainfall was recorded. Population of aphid continued to increase and highest population was recorded during 2nd week of December (50th SMW) with a population load of 2.68 leaf aphid/leaf. During this period, the average of T max was 27.29°C and T min was 11.63°C with an average RH max of 83.43 % and RH min of 55.14 % and no rainfall was recorded. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.40 aphid/leaf during 8th SMW (3rdweek of February).

In 2014-15 and 2015-16, the pest first appeared to be in first week of November with population load of 2.16 and 1.60 aphid/leaf respectively and it remained on the crop for 17 and 14 weeks respectively. During 2014-15, the average of T max was 32.44°C and T min was 19.76°C with an average RH max of 83.71 % and RH min of 59.71 % and no rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during last week of November (48th SMW) with a population load of 7.04 aphid/leaf. During this period, the average of T max was 30.66 °C and T min was 12.43°C with an average RH max of 82.71 % and RH min of 49.29 % and no rainfall was recorded. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.20 aphid/leaf during 8th SMW (i.e. 3rd week of February). However, during 2015-16, the average of T max was 31.37°C and T min was 21.36°C with an average RH max of 94.00 % and RH min of 63.57 % and no rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during 1st week of December (49th SMW) with a population load of 7.00 aphid/leaf. During this period, the average of T max was 28.74°C and T min was 17.19°C with an average RH max of 93.71% and RH min of 59.57% and no rainfall was recorded. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.84 aphid/leaf during 5th SMW (last week of January).

During the year 2017-2018, the incidence of aphid population was recorded during second week of November (45th SMW) with a population load of 0.24 aphid/leaf and it remained on the crop for 15 weeks. The average of T max was 31.83°C and T min was 19.89°C with an average RH max of 94.00 % and RH min of 53.86 % and no rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during 2ndweek of December (50th SMW) with a population load of 3.36 aphid/leaf. During this period, the average of T max was 27.50°C and T min was 17.41°C with an average RH max of 95.57% and RH min of 68.71% and with an average rainfall of 1.83 mm was recorded during the period. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.20 aphid/leaf during 5th SMW (2nd week of February).

The overall results of seven years data from 2011-12 to 2017-18, revealed that infestation of aphids on tomato crop during rabi season started from first week of October to third week of November (40th to 47th SMW) Thereafter, the population increased and attained its peak during the third week of November to second week of December (46th to 50th SMW) and highest population load of 7.04 aphid/leaf was recorded during last week of November (48th SMW) in 2015-16. Then its trend was decreasing due to the ageing of crop.

The present findings are in close proximity with the findings of Singh *et al*. (2005) who reported that aphid (*Aphis gossypii*) was recorded on the crop from 3rd week of August and reached maximum during 3rd week of November with an intensity of 4.28 aphids/ leaf. While Chakraborty (2011b) reported that population of aphid initiated at about 48th standard meteorological weeks (SMW) and it slowly increased up to 52nd SMW then steadily up to 6th SMW attaining the maximum at about 8th SMW which was maintained up to about 11th SMW. Gosh (2017) on the other hand, observed that population of aphids could be found throughout the seasons. Low level of population (0.19 to 0.50/leaf) was counted on 38th to 40th standard week of September to October, 52nd to 5th standard week of December to January and 18th to 22nd week of

May to June. While persistent high population (0.62-2.69/leaf) was maintained on 41st standard week to 51st standard week during 2nd week of October to 3rd week of December and 6th to 17th week during 2nd week February to 4th week of April.

4.1.2.3.1 Correlation studies between aphid and weather parameters during *rabi* season

From the data presented in Table 15.1, it is revealed that during the first year of study (2011-12), the aphid population was non-significant and negatively correlated with T max (r = -0.208), T day (-0.324), T night (-0.364) and with RH max (r = -0.227) whereas, T min (r = -0.418*), RH min (r = -0.570**) and rainfall (r= -0.724**) showed significant but negative correlation. During the second year of study i.e., 2012-13, T max (r = -0.463*), T min (r = -0.502*) T day (-0.492*) and T night (-0.501*) showed negatively significant correlation with aphid population. RH max (r = -0.029), RH min (r = -0.277) and rainfall (r = -0.365) showed non-significant negative correlation. In third year of study during 2013-14, T max (r = -0.397), T day (r = -0.471), RH max (r = -0.371) and rainfall showed non-significant negative correlation with pest population. While T min (r = -0.530*) and T night (-0.498*) revealed negatively significant correlation and RH min (r = 0.122) showed non-significant positive correlation with the aphid population. In the fourth year of investigation i.e. in 2014-15, only minimum temperature (r =-0.479*) showed significant negatively correlated with the pest while other parameters like temperature maximum, day, night, relative humidity (min) and rainfall showed non-significant negative correlation with the aphid population whereas relative humidity (max) revealed positive non-significant relation. During the year 2015-16, RH max (r = 0.053) showed non-significant positive effect, while other parameters like T max, T min, T day, T night, RH min and rainfall showed negatively non-significant correlated with the pest. But in the year 2016-17, it was found that all the abiotic parameters viz. temperature (max & min, day & night), RH (max & min) and rainfall were found to be negatively non-significant. However, in the last year of investigation (2017-18), T max (r = -0.549*) was found to have negatively significant correlation with the aphid population and RH min (r = 0.169) showed non-significant positive correlation while T min, T day, T night, RH max and rainfall showed negative non-significant correlation. The overall seven years data i.e. 2011-12 to 2017-18, depicted that the weather variables showed mostly negative and non-significant correlation with the pest population.

Table 15.1: Correlation between aphid and weather parameters during *rabi* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.208	-0.418*	-0.324	-0.364	-0.227	-0.570**	-0.724**
2012-13	-0.463*	-0.502*	-0.495*	-0.501*	-0.029	-0.277	-0.365
2013-14	-0.397	-0.530*	-0.471	-0.498*	-0.371	0.122	-0.009
2014-15	-0.341	-0.479*	-0.427	-0.453	0.094	-0.092	-0.452
2015-16	-0.261	-0.173	-0.225	-0.207	0.053	-0.005	-0.030
2016-17	-0.236	-0.215	-0.229	-0.224	-0.135	-0.138	-0.434
2017-18	-0.549*	-0.354	-0.481	-0.436	-0.040	0.169	-0.038

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.4 Population dynamics of aphid (*Aphis gossypii*) in *summer* season (2012-2018)

Population dynamics of aphid on tomato crop during the period of investigation i.e. 2012 to 2018 is presented in Table 16 and Fig. 4. It could be revealed that in the year 2012, the pest made its first appearance on the crop on fourth week of January with a population load of 0.72 aphid/leaf and it remained on the crop for 19 weeks. During the period the average of T max was 25.01°C and T min was 10.59°C with an average RH max of 91.43 % and RH min of 43.86 % and there was no rainfall found to be recorded. Population of aphid during the period continued to increase and highest population was recorded during 3rd week of March with a population load of 3.76 aphid/leaf. Later the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 0.40 aphid/leaf during 22nd SMW (last week of May). And during the period the average weekly T max & T min was recorded to be 36.17°C& 28.10°C respectively with average RH max of 90.71% & RH min of 61.86 % with receipt of an average rainfall of 0.30 mm during the period.

During 2013, due to late transplanting, aphid appeared from second week of March with population of 4.29 aphid/leaf and it remained on the crop for 15 weeks. During the period the average of T max was 33.59°C and T min was 14.54°C with an average RH max of 89.43 % and RH min of 30.57 % and no rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during last week of March with a population load of 6.72 aphid/leaf, during the period the average weekly T max & T min was recorded to be 38.54°C & 22.41°C respectively with average RH max of 89.14% & RH min of 34.29 % with no rainfall during the period. Later, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 0.96 aphid/leaf during 24th SMW (2nd week of June). And during the period the average weekly T max & T min was recorded to be 34.44°C & 26.60°C respectively with average RH max of 94.00% & RH min of 81.57 % with receipt of an average rainfall of 53.90 mm during the period.

In 2014, the first incidence of the pest occurred during last week of January (1.32 aphid/leaf) and it remained on the crop for 16 weeks. During the period the average of T max was 25.50°C and T min was 9.89°C with an average RH max of 82.60 % and RH min of 58.43 % and there no rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during 2ndweek of March with a population load of 5.12 aphid/leaf, during the period the average weekly T max & T min was recorded to be 32.29°C &15.84°C respectively with average RH max of 83.71% & RH min of 42.57 % with no rainfall during the period.Later, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 2.00 aphid/leaf during 20th SMW (3rd week of May). And during the period the average weekly T max & T min was recorded to be 39.36°C & 27.06°C respectively with average RH max of 85.00% & RH min of 48.57 % with receipt of an average rainfall of 5.80 mm during the period.

During the year 2015, the first appearance was recorded during the fourth week of February. During the period the average of T max was 34.19°C and T min was 19.67°C with an average RH max of 85.86 % and RH min of 50.14 % and an average of 5.30 mm rainfall was recorded. Population of aphid during the period continued to increase and highest population was recorded during 1st week of April with a population load of 6.33 aphid/leaf, during the period the average weekly T max & T min was recorded to be 36.11°C & 24.09°C respectively with average RH max of 90.86% & RH min of 59.86 % with average 20.10 rainfall during the period was recorded. Later, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.67 aphid/leaf during 22nd SMW (last week of May). And during the period the average weekly T max & T min was recorded to be 38.69°C & 29.34°C respectively with average RH max of 83.43% & RH min of 51.00 % with no rainfall during the period.

And in the following years i.e., 2016, 2017 & 2018 the pest's first incidence was observed during second week of February (6th SMW) and it remained on the crop for 12, 16 and 14 weeks respectively. During 2016 the average of T max was 28.39°C and T min was 14.56°C with an average RH max of 92.14 % and RH min of 59.86 % and no rainfall was recorded during the period. While, in 2017 the average of T max was 29.64°C and T min was 13.43°C with an average RH max of 89.57 % and RH min of 41.43 % and no rainfall was recorded during the period. And in 2018, the average of T max was 29.39°C and T min was 15.73°C with an average RH max of 89.00 % and RH min of 43.71 % and no rainfall was recorded during the period. Population of aphid during 2016 and 2018 period continued to increase and highest population was recorded during 2ndweek of March with a population load of 5.25 and 10.04 aphid/leaf respectively, and in 2017, highest population was recorded during last week of March with a population load of 10.72 aphid/leaf. Later, in 2106, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 0.83 leaf aphid/leaf during 17th SMW (last week of May). And during the period the average weekly T max & T min was recorded to be 40.10°C & 27.49°C respectively with average RH max of 88.14% & RH min of 45.29 % with no rainfall during the period. Whereas, in 2017, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 1.36 aphid/leaf during 21st SMW (last week of May). And during the period the average weekly T max & T min was recorded to be 37.40°C & 27.44°C respectively with average RH max of 84.29% & RH min of 53.14 % with record of 1.76 mm rainfall during the period. During 2018, the aphid population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of aphid population load was found to be 2.44 aphid/leaf during 19th SMW (2nd week of May). And during the period the average weekly T max & T min was recorded to be 36.00°C & 25.66°C respectively with average RH max of 90.57% & RH min of 61.57 % with record of 0.73 mm rainfall during the period.

The overall data for seven years i.e. 2012 to 2018, during summer season revealed that the first appearance of aphids on tomato crop from fourth week of January to first week of March (4^{th} to 10^{th} SMW). Peak periods were recorded from second week of March to first week of April (11^{th} to 14^{th} SMW) with highest infestation load of 10.04 aphid/leaf observed on 11^{th} SMW, i.e. second week of March. The present results are more or less similar with the findings of Shakeel *et al*. (2010) who observed high aphid population in the first week of February and thereafter the population gradually decreased and lowest number was recorded in the month of April. The overall aphid population was highest at initial stage of crop and declined as crop grew towards maturity. Sarkar *et al*. (2018) also reported that aphid first appeared on the crop in third week of January. The peak populations of both the pest were observed in the third and fourth week of February. Similar observations were also reported by Gosh (2017).

4.1.2.4.1 Correlation studies between aphid and weather parameters during ***summer*** season

From the data presented in Table 16.1, it is revealed that during first year of study (2012), only RH min (r = -0.664**) showed highly negative significance with the aphid population while maximum, day & night temperature showed non-significant positive correlation and T min (r = -0.050), RH max (r = -0.399) and rainfall (r = -0.246) revealed negatively non-significant relation. During the second year of study (2013), T max (r = 0.588*) showed significant positive correlation while RH max (r = -0.543*) and RH min (r = -0.896**) showed significant negative correlation. T min, T night and rainfall however, showed non-significant negative correlation with the population of aphid. In third year of study during 2014, T max (r = 0.321), T min (r = 0.228), T day and T night showed non-significant positive correlation whereas RH max and rainfall (r = - 0.005) showed non-significant negative correlation and RH min (r = -0.494*) showed significant negative correlation with aphid population. In 2015, however, all the weather parameters like temperatures, relative humidity and rainfall were non-significantly positively correlated with the pest population. In 2016, the results revealed that all temperature parameters and RH min were non-significantly negatively correlated while maximum relative humidity (r = 0.146) and rainfall (r = 0.431) were found to have positive non-significant relation with the pest population. During 2017, temperature (max & min, day & night) and maximum relative humidity showed non-significant positive correlation while RH min and rainfall showed positive non-significant correlation. However, in 2018, RH min revealed negative significant correlation with aphid population but temperature (max, min, day and night) showed positive non-significant correlation and RH max and and rainfall showed negative non-significant correlation with the pest.

The overall seven years data i.e. 2012 to 2018, revealed that the weather factors had mostly positive and non-significant correlation with the pest population but in 2012 and 2013, it showed negative significant correlation with minimum relative humidity. Shakeel *et al*. (2014) reported that aphid population had significant negative correlation with minimum and maximum temperature, significant positive correlation with relative humidity, and non-significant negative correlation with rainfall. Chakraborty (2011b) also reported that abiotic conditions such as maximum temperature, minimum temperature, minimum relative humidity and sunshine hours had significant negative influence on *A. gossypii* population. In case of maximum relative humidity, a positive influenced was observed and that of rainfall expressed insignificant positive effects on population development. But Shukla (2014) reported that aphids showed positive correlation with rainfall (r = 0.261) and relative humidity while negative correlation with both maximum and minimum temperature. Sharma *et al*. (2013) on the other hand, reported aphid population was positively but non-significantly correlated with the maximum, minimum temperatures and sunshine hours and negative non-significantly with relative humidity and rainfall. Ghosh (2017) also concluded that the weather parameter such as temperature (maximum, minimum and average) had a non-significant positive influence on aphid population while non-significant negative influence found with weekly total rainfall. Average relative humidity express significant positive effect on population development. Thus, the above reports are more or less in corroboration with the present findings.

Table 16.1: Correlation between aphid and weather parameters during *summer* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2012	0.169	-0.050	0.067	0.023	-0.399	-0.664**	-0.246
2013	0.588*	-0.500	0.041	-0.215	-0.543*	-0.896**	-0.446
2014	0.321	0.228	0.285	0.267	-0.237	-0.494*	-0.005
2015	0.056	0.055	0.060	0.059	0.282	0.118	0.337
2016	-0.168	-0.127	-0.155	-0.146	0.146	-0.256	0.431
2017	0.281	0.297	0.294	0.296	0.285	-0.170	-0.306
2018	0.481	0.178	0.336	0.275	-0.098	-0.532*	-0.224

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.5 Population dynamics of whitefly in rabi season

The data regarding population dynamics of whitefly on tomato crop during the seven years of investigation i.e. 2011-12 to 2017-18 are presented in Table 17, figure 5. From the table and figure, it could be revealed that during 2011-12, the pest made its first appearance on the crop on second week of September with a population load of 1.76/leaf and it remained on the crop for a duration of 22 weeks. During this period, the average of T max was 32.08 °C and T min was 26.37°C with an average RH max of 94.86 % and RH min of 78.71 % and average weekly rainfall was found to be 57.80 mm. Population of whitefly during the period continued to increase and highest population was recorded during 3rd week of November (46th SMW) with a population load of 2.80 whitefly/leaf. During this period, the average of T max was 30.16 °C and T min was 19.91°C with an average RH max of 94.14 % and RH min of 62.43 % and average weekly rainfall was recorded to be 8.00 mm. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.60 leaf whitefly /leaf during 6th SMW (2nd week of February). And during the period the average weekly T max & T min was recorded to be 27.86°C& 13.26°C respectively with average RH max of 89% & RH min of 42.29 % without rainfall.

During 2012-13, the incidence occurred in the first week of October, the whitefly population recorded was 0.96/leaf and it remained on the crop for of 14 weeks. At that period the average of T max was 34.37 °C and T min was 26.17°C with an average RH max of 94.43 % and RH min of 69.14 % and average weekly rainfall was found to be 2.30 mm. Population of whitefly during the period continued to increase and highest population was recorded during 2nd week of November (45th SMW) with a population load of 6.08 whitefly /leaf. During this period, the average of T max was 28.76 °C and T min was 20.73°C with an average RH max of 97.00 % and RH min of 71.86 % and average weekly rainfall was recorded to be 47.10 mm. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.28 leaf whitefly /leaf during 1st SMW (first week of January). And during the period the average weekly T max & T min was recorded to be 24.03°C& 11.99°C respectively with average RH max of 94.86% & RH min of 57.14 % with receipt of an average rainfall of 1.90 mm during the period.

In 2013-14 & 2017-18, the population of whitefly was in second week of November (0.76 & 0.28 whitefly/leaf) and it remained on the crop for a duration of 16 and 15 weeks respectively. During 2013-14 the average of T max was 29.86°C and T min was 18.50°C with an average RH max of 87.57 % and RH min of 58.57 % without any rainfall, however, during 2017-18 T max was 31.83°C and T min was 19.89°C with an average RH max of 94.00 % and RH min of 53.86 % with nil precipitation was recorded. In 2013-14, population of whitefly during the period continued to increase and highest population was recorded during last week of November (48th SMW) with a population load of 3.56 whitefly/leaf, while during 2017-18 it was recorded during 50th SMW (2nd week of December) with a population load of 2.76 whitefly/leaf. During 2013-14, the average of T max was 29.36°C and T min was 15.37°C with an average RH max of 80.00 % and RH min of 60.86 % and no rainfall was recorded. And during 2017-18, the average of T max was 27.50°C and T min was 17.41°C with an average RH max of 95.57 % and RH min of 68.71 % with 1.83 mm rainfall was recorded. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.48 & 1.16 leaf whitefly /leaf during 8th& 7th SMW i.e. 3rd and 2nd week of February respectively during the year 2013-14 and 2017-18.

During 2014-15 it was seen that the pest incidence was recorded during 3rd week of October (2.24 whitefly/leaf) and it remained on the crop for a duration of 13 weeks. In which the average of T max was 31.80 °C and T min was 21.43°C with an average RH max of 83.71 % and RH min of 69.00 % with 1.00 mm of rainfall recorded during the period. Whereas, in 2015-16 & 2016-17 the pest's first incidence was during second week of October (0.6 & 0.8 whitefly/leaf) and it remained on the crop for 16 weeks in both the years. And in 2015-16, the average of T max was 33.36 °C and T min was 23.79°C with an average RH max of 94.14 % and RH min of 65.14 % with 2.20 mm of rainfall was recorded during the period. In 2016-17 the average of T max was 33.77°C and T min was 22.57°C with an average RH max of 94.29 % and RH min of 56.14 % with no precipitation recorded during the period. However, during 2014-15 and 2016-17 the highest population of whitefly during the period continued to increase and highest population was recorded during last week of November (48th SMW) with a population load of 6.00 and 6.80 whitefly/leaf respectively. But during 2015-16 the highest population recorded during 2nd week of November (46th SMW) with a population load of 7.60 whitefly/leaf.

The overall results of seven years of investigation from 2011-12 to 2017-18, indicated that population of whitefly in rabi season first appeared on tomato crop in between second week of September to second week of November (37th to 45th SMW). The population varied in different experimental years but attained peak from second week of November to third week of November (45th to 50th SMW) with highest infestation recorded on 46th SMW i.e. third week of November with population load of 7.60 whitefly/leaf. Konar and Paul (2006) reported that whitefly becomes active from October to March-April in Gangetic plains of India. Arnal *et al*. (1998) observed that the adult whiteflies (*B. tabaci*) were present throughout the growing period of tomato and also found that their population was higher at the end of the rainy season. Srinivasan *et al*. (2012) revealed that the peak incidence of whiteflies varied seasonally from year to year and in general, whitefly populations were not uniformly distributed. Thus, the above reports are more or less in line with the findings of the present investigation.

4.1.2.5.1 Correlation studies between whitefly and weather parameters during *rabi* season

Correlation among different weather factors and population of whitefly is presented in table 17.1. From the results of first year of present investigation (2011-12), it was found that the population of whitefly was non-significant and negatively correlated with all the weather parameters like T max (r = -0.085), T min (r = - 0.219), T day (r = -0.157), T night (r = -0.182), RH max (r = -0.058) and RH min (r = -0.202) & rainfall. While in 2012-13 whitefly pest population was non-significant positive correlated with T max (r = 0.136), T min (r = 0.109), T day, T night and rainfall (r = 0.013) while RH min (r = - 0.194) and RH min (r = -0.055) showed non-significant negative correlation with pest population. However, in the third year of study (2013-14), whitefly population was found to be highly significant and negatively correlated with RH max (r = -0.714**) and rest of the parameters showed negatively non-significant correlation with the pest. And during the fourth year of investigation (2014-15), rainfall showed negatively significant correlation with whitefly population. T max, T day, T night showed negative non-significant correlation while T min, RH max & min showed positive non-significant correlation with the pest. In 2015-16, T max (r = 0.301), T min (r = 0.334), T day, T night and RH max (r = 0.122) showed non-significant positive correlation with the whitefly population while RH min (r = -0.055) and rainfall (r = -0.208) revealed non-significant negatively correlation. In the year of 2016-17, all the parameters were found to reveal non-significant negatively correlation. And in 2017-18, RH min and rainfall showed non-significant positively correlation with the pest but the other parameters viz. T max, T min, T day & T night and RH max showed non-significant negatively correlation with the whitefly population.

The overall seven years data i.e. 2011-12 to 2017-18, revealed that the weather inputs showed negative and non-significant correlation with whitefly population, while in 2013-14, maximum relative humidity was found to have negative and significant correlation with the pest population.

Table 17.1: Correlation between whitefly and weather parameters during *rabi* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.085	-0.219	-0.157	-0.182	-0.058	-0.202	-0.131
2012-13	0.136	0.109	0.126	0.120	-0.194	-0.055	0.013
2013-14	-0.164	-0.267	-0.216	-0.237	-0.714**	-0.005	-0.071
2014-15	-0.021	0.005	-0.010	-0.004	0.150	0.212	-0.472*
2015-16	0.331	0.304	0.325	0.319	0.122	-0.055	-0.208
2016-17	-0.299	-0.295	-0.302	-0.300	-0.194	-0.213	-0.457
2017-18	-0.131	-0.106	-0.126	-0.120	-0.110	0.075	0.128

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.6 Population dynamics of whitefly in *summer* season

Population dynamics of whitefly on tomato crop in summer during all seven years of investigation i.e. from 2012 to 2018 presented in Table 18, Fig. 6. From figure 4, it could be revealed that in the year 2012, the pest made its first appearance on the crop on fourth week of January with population load of 2.40 whitefly/leaf and it remained present on the crop for 19 weeks. During the period the average of T max was 25.01°C and T min was 10.59°C with an average RH max of 91.43 % and RH min of 43.86 % and there was no rainfall found to be recorded during the period. Population of whitefly during the period continued to increase and highest population was recorded during 2nd week of April to last week of April with a population load of 6.00 whitefly /leaf. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 2.40 leaf whitefly /leaf during 22nd SMW (last week of May). And during the period the average weekly T max & T min was recorded to be 36.17°C& 28.10°C respectively with average RH max of 90.71% & RH min of 61.86 % with receipt of an average rainfall of 0.30 mm during the period.

In 2013, the incidence of white fly was recorded during first week of March with population of 1.80 whitefly/leaf and it remained present on the crop for 15 weeks. During the period the average of T max was 33.59°C and T min was 14.54°C with an average RH max of 89.43 % and RH min of 30.57 % and no rainfall was recorded during the period. Population of whitefly during the period continued to increase and highest population was recorded during 1stweek of with a population load of 6.30 whitefly /leaf. During this period, the average of T max was 37.97°C and T min was 24.54°C with an average RH max of 81.86.00 % and RH min of 36.14 % and no rainfall was recorded. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.52 leaf whitefly /leaf during 24thSMW (2nd week of June). And during the period the average weekly T max & T min was recorded to be 34.44°C&26.60°C respectively with average RH max of 94.00% & RH min of 81.57 % with receipt of an average rainfall of 53.90 mm during the period.

In 2014, whitefly population was found to be recorded for 16 weeks and it was observed in first week of February (1.40 whitefly/leaf). During the period the average of T max was 25.50°C and T min was 9.89°C with an average RH max of 82.60 % and RH min of 58.43 % and there was no rainfall was recorded during the period. Highest pest population was recorded during 2nd week of March with a population load of 4.20whitefly/leaf and the average of T max was 32.29°C and T min was 15.84°C with an average RH max of 83.71 % and RH min of 42.57 % and no rainfall was recorded during the period. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.12 leaf whitefly /leaf during 20th SMW (2nd week of May).

And during 2015 first appearance of pest on the crop was during third week of February (0.20 whitefly/leaf) which remained present on the crop for 15 weeks and the average of T max was 34.19°C and T min was 19.67°C with an average RH max of 85.86 % and RH min of 50.14 % and an average of 5.30 mm rainfall was recorded during the period. Highest pest population was recorded during 2nd week of April with a population load of 4.14 whitefly/leaf and the average of T max was 36.70°C and T min was 24.26°C with an average RH max of 88.57 % and RH min of 50.57 % and an average of 23.80 mm rainfall was recorded during the period. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.20 leaf whitefly /leaf during 22nd SMW (last week of May).

During 2016, 2017 & 2018 the appearance first seen to be during the second week of February (0.77, 1.72 and 1.72 whitefly/leaf respectively) and it remained present on the crop for 12, 16 and 14 weeks respectively. During the period the average of T max was 28.39/29.64/29.39°C and T min was 14.56/13.43/15.73°C respectively with an average RH max of 92.14/89.57/89.00 % and RH min of 59.86/41.43/43.71 % respectively during the year and no rainfall was recorded in the year 2016, 2017 & 2018. In the year 2016 highest pest population was recorded during 3rdweek of March with a population load of 4.59whitefly/leaf and the average of T max was 37.29°C and T min was 18.91°C with an average RH max of 80.43 % and RH min of 33.86 % with no rainfall during the period. While in 2017, highest pest population was recorded during last week of March with a population load of 5.28 whitefly/leaf and the average of T max was 35.70°C and T min was 25.91°C with an average RH max of 92.14 % and RH min of 55.00 % with no rainfall during the period. And in the year 2018, highest pest population was recorded between last week of Feb & first week of March with a population load of 9.00whitefly/leaf and the average of T max was 34.77°C and T min was 19.90°C with an average RH max of 91.43 % and RH min of 34.57 % with no precipitation during the period. Later the whitefly population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of whitefly population load was found to be 1.00, 1.12 and 1.68 leaf whitefly /leaf during 17th, 21st and 19th SMW during 2016, 2017 & 2018 respectively.

The overall seven years data during the period of investigation from 2012 to 2018 in summer season revealed that initiation of whitefly population started from last week of January to first week of March (4th to 10th SMW). While, peak was observed in second week of March to second week of April (11th to 15th SMW). Highest population load of 9.00 whitefly/leaf was recorded on 9th SMW i.e. last week of February in 2018.

The present results are in close affirmation with the reports of Shivanna *et al*. (2011) who observed that whitefly population started increasing from February onwards and reached highest population on the second fortnight of April. Konar and Paul (2006) also reported that whitefly becomes active from October to March-April in Gangetic plains of India. Also, Chaudhuri *et al*. (2001b) revealed that the highest population density of white fly was observed during mid-February on tomato crop. High infestation levels were maintained from mid-Febuary to mid-March. The findings of Kishore *et al.* (2005) regarding the population dynamics of whitefly on tomato were also in the line of present investigation. According to them, population of whitefly remained low till fourth week of January and attained a peak in the first week of March. Similarly, Kharpuse and Bajpai (2007) recorded peak population of whitefly during first week of March. Subba *et al*. (2017) also observed that maximum population level was maintained during 11th standard week to 18th standard week that is during 2nd week of March to 3rd week. Kumar (2008) however reported that on tomato, whitefly appeared during the 2nd week of January and the peak activity was recorded during last week of February. Chakraborty (2012) also reported that the population initiated at about 48th standard weeks, increased slowly and then steadily attaining the maximum at about 6th standard weeks which was maintained up to about 9th standard weeks. According to Srinivasan *et al*. (2012) revealed that the peak incidence of whiteflies varied seasonally from year to year and in general, whitefly populations were not uniformly distributed. Barde (2006) also studied the seasonal incidence of whitefly on tomato and reported that it first appeared during the second week of January and remained active until the crop was harvested.

4.1.2.6.1 Correlation studies between whitefly and weather parameters during *summer* season

Correlation among different weather factors and population of whitefly is presented in table 18.1. From the results of first year of investigation (2012), it was found that the population of whitefly was positively significant with maximum temperature (r = 0.571**) day temperature (r = 0.510*) and night temperature (r = 0.481*) and negatively significant with RH max (r = -0.617**). While, T min (r = 0.427), and rainfall (r = 0.305) showed non-significantly positive correlation with whitefly population and RH min (r = -0.222) revealed non-significantly negative correlation with the pest. During the second year of study (2013), the parameters maximum temperature (r = 0.776**) and day temperature (r = 0.570*) revealed significant and positive relation with whitefly population. Also, RH max (r = -0.664**) and RH min (r = -0.565*) showed significant negative correlation while T min (r = 0.127), T night and rainfall (r = -0.231) showed non-significantly positive correlation. In 2014, maximum temperature and rainfall showed non-significant positive correlation whereas, rest of the parameters showed negative non–significant correlation with whitefly population. Again in 2015, all the abiotic parameters under investigation i.e., maximum & minimum, day & night temperature, maximum & minimum relative humidity, and rainfall showed positive correlation with whitefly population. In the year 2016, RH max (r = 0.224) and rainfall (r = 0.505) was revealed to have positive correlation but other factors like T max (r = -0.114), T min (r = -0.028), T day, T night & RH min (r = -0.134) showed non–significant negative correlation with the pest. Also, maximum, minimum, day and night temperature for in both the years 2017 and 2018 and RH max in 2018 were found to have non–significant positive with whitefly, while RH min and rainfall in 2017 showed non-significant and negative correlation. However, in 2018, RH min (r = -0.694**) showed highly significant correlation and RH max and rainfall showed non–significant negative correlation with whitefly population.

The overall seven years data i.e. 2012 to 2018, revealed that weather factors showed positive and non-significant correlation with whitefly population, but in 2012 and 2013, it showed positive significant correlation with maximum temperature and negative significant correlation with minimum relative humidity, also in 2018, a negative significant correlation with minimum relative humidity was observed.

The present findings are partially in line with the findings of Abdel *et al*. (1998) who reported that temperature had a significant effect on nymphal population of white fly on tomato while relative humidity had no significant effect. Chakraborty (2012) also revealed that abiotic conditions had significant negative influence on *B. tabaci* population. Sharma *et al*. (2013) however, reported that correlation studies between whitefly and abiotic factors showed positive correlation for temperature and sunshine hours, while the correlation was negative relative humidity and rainfall. Kharia *et al*. (2018) also concluded that whitefly population had a significant positive correlation with temperature, while significant negative correlation with relative humidity. But Subba *et al*. (2017) stated that weekly population counts on white fly showed non-significant negative correlation (p=0.05) with temperature and weekly total rainfall where as significant negative correlation with relative humidity. Mondal *et al*. (2019) also revealed non-significant effect of maximum temperature (r=-0.010) and rainfall (r=0.007) with white fly population. Thus, the results of the present investigation are more or less in validation with the above reports.

Table 18.1: Correlation between whitefly and weather parameters during *summer* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2012	0.571**	0.427	0.510*	0.481*	-0.617**	-0.222	0.305
2013	0.776**	0.127	0.570*	0.390	-0.664**	-0.565*	-0.231
2014	0.023	-0.065	-0.013	-0.031	-0.304	-0.289	0.079
2015	0.116	0.215	0.190	0.204	0.403	0.221	0.348
2016	-0.114	-0.028	-0.081	-0.063	0.224	-0.134	0.505
2017	0.248	0.236	0.246	0.242	0.128	-0.200	-0.325
2018	0.371	0.007	0.188	0.117	-0.148	-0.694**	-0.332

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.7 Population dynamics of thrips in *rabi* season

The data regarding population dynamics of thrips on tomato crop during the period of investigation i.e. 2011-12, 2012-13, 2013-14, 2014-15, 2015-16, 2016-17 & 2017-18 are presented in Table 19 and Fig. 7. It could be revealed that in the year 2011-12, the pest made its first appearance on the crop on second week of September with a population load of 1.08 thrips/leaf and it remained on the crop for 22 weeks. During this period, the average of T max was 32.08°C and T min was 26.37°C with an average RH max of 94.86 % and RH min of 78.71 % and average weekly rainfall found to be 57.80 mm. Population of thrips during the period continued to increase and highest population was recorded during 2nd week of November (46th SMW) with a population load of 1.56 thrips/leaf. During this period, the average of T max was 30.16 °C and T min was 19.91°C with an average RH max of 94.14 % and RH min of 62.43 % and average weekly rainfall found to be 8.00 mm. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 0.96 thrips/leaf during 6th SMW (2nd week of February).

During 2012-13, the pest made its arrival during fourth week of October with a population of 1.15 thrips/leaf and it remained on the crop for 15 weeks. During this period, the average of T max was 33.01°C and T min was 20.11°C with an average RH max of 91.14 % and RH min of 48.86 % and no rainfall was recorded. Population of thrips during the period continued to increase and highest population was recorded during 2nd week of December (50th SMW) with a population load of 5.82 thrips/leaf. During this period, the average of T max was 27.79°C and T min was 15.20°C with an average RH max of 95.43 % and RH min of 64.29 % and average weekly rainfall found to be 7.30 mm. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 0.88 thrips/leaf during 5th SMW (last week of January).

In 2013-14, the pest made its first appearance in third week of November (1.56 thrips/leaf) and it remained on the crop for 14 weeks. During this period, the average of T max was 28.93°C and T min was 14.63°C with an average RH max of 79.71 % and RH min of 53.43 % and no rainfall was recorded. Population of thrips during the period continued to increase and highest population was recorded during 1stweek of December (49th SMW) with a population load of 3.56 thrips/leaf. During this period, the average of T max was 27.64°C and T min was 14.04°C with an average RH max of 83.57 % and RH min of 58.57 % with no rainfall. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.60 thrips/leaf during 8th SMW (3rdweek of February).

During 2014-15, the first appearance of Thrips population was recorded during third week of November and it remained on the crop for 15 weeks. During this period, the average of T max was 32.54 °C and T min was 15.77°C with an average RH max of 77.29 % and RH min of 47.14 % and no rainfall was recorded. Population of thrips thereafter continued to increase and highest population was recorded during 2ndweek of January (50th SMW) with a population load of 2.00 thrips/leaf. During this period, the average of T max was 26.31°C and T min was 13.86°C with an average RH max of 88.29 % and RH min of 59.86 % with no rainfall. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 0.24 thrips/leaf during 8th SMW (3rd week of February).

And 2015-16, the first appearance of thrips was observed during second week of November and it remained on the crop for 13 weeks. During this period, the average of T max was 32.36°C and T min was 20.03°C with an average RH max of 92.57 % and RH min of 50.57 % and no rainfall was recorded. Population of thrips then continued to increase and highest population was recorded during 2^{nd} week of December (49^{th} SMW) with a population load of 2.12 thrips/leaf. During this period, the average of T max was 28.74°C and T min was 17.91°C with an average RH max of 93.71% and RH min of 59.57% with no rainfall. Later, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.16 thrips/leaf during 5^{th} SMW (last week of January).

However, during the year 2016-17, the pest incidence could be recorded for 14 weeks with its arrival in third week of October with population load of 0.72 thrips/leaf. During this period, the average of T max was 33.77°C and T min was 22.57°C with an average RH max of 94.29 % and RH min of 56.14% and no rainfall was recorded. Population of thrips during the period continued to increase and highest population was recorded during 2^{nd} week of December (49^{th} SMW) with a population load of 7.28 thrips/leaf. During this period, the average of T max was 27.76°C and T min was 14.99°C with an average RH max of 93.71% and RH min of 57.00% with no rainfall. Later, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.20 thrips/leaf during 3^{rd}SMW (3^{rd}week of January).

And in the year 2017-18, the pest incidence was recorded during last week of November with population load of 0.64 thrips/leaf. During this period, the average of T max was 27.69°C and T min was 12.83°C with an average RH max of 89.71% and RH min of 46.57% and no rainfall was recorded. Population of thrips during the period continued to increase and highest population was recorded during last week of December (52^{nd}SMW) with a population load of 0.72 thrips/leaf. During this period, the average of T max was 26.00°C and T min was 11.63°C with an average RH max of 95.13% and RH min of 53.13% with no rainfall. Later, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 0.72 thrips/leaf during 7^{th}SMW (2^{nd} to 3^{rd}week of February).

The overall seven years data of investigation from 2011-12 to 2017-18 revealed that thrips population first appeared on tomato crop in rabi season from second week of September to last week of November i.e. 37^{th} to 48^{th} SMW. Peak population was observed from third week of November to last week of December (46^{th} to 52^{nd} SMW) with highest population load of 7.28 thrips/leaf recorded at 49^{th} SMW i.e. first week of December in 2016-17.

The present findings are in close conformity with Jamuna *et al.* (2019) who revealed that population of thrips increased gradually from first week after transplanting to flowering and fruit development stage and later it decreased as crop matures. Maximum thrips population was observed during the last week of November and first week of December. Subba and Ghosh (2016) recorded minimum number of thrips (0.42-53/leaf) population during 38^{th} to 44^{th} standard week and observed maximum level of population during 45^{th} to 2^{nd} (1.05-1.89/leaf) and again during 6^{th} to 20^{th} (1.00-2.22/leaf) standard week. Chavan *et al*. (2014) also reported that thrips started appearing on tomato plants during the first week of October and the peak population was seen from the third week of October to the second week of November.

4.1.2.7.1 Correlation studies between thrips and weather parameters during *rabi* season

Data presented in Table 19.1, indicates that the population of thrips was affected by various weather parameters. In first year of study (2011-12), population of thrips showed non-significant negative correlation with T max (r = -0.223), T min (r = -0.347), T day (r = -0.294), T night (r = -0.317), RH max (r = -0.089), RH min (r = -0.368) and rainfall (r = -0.279). However, in the second year (2012-13), T min (r = -0.456*) and T night (r = -0.456*) showed significant negative correlation with thrips population, whereas T max (r = -0.424), T day (r = -0.452), RH max (r = -0.001), RH min(r = -0.219) and rainfall (r = -0.287) showed non-significant negative correlation with thrips population. In third year of study (2013-14), thrips population was significantly and negatively correlated with T max (r = -0.486*) and T min (r = -0.614**), T day (r = -0.562*) and T night (r = -0.587**), while RH max (r = -0.324), and rainfall (r = -0.005) showed non-significant negative correlation and RH min (r = 0.205) showed non-significant positive correlation. In 2014-15, again it was found maximum, minimum, day and night temperatures had high significant and negative correlation with thrips population, whereas relative humidity (max & min) showed non-significant positive correlation and rainfall (r = -0.274) showed non-significant negative correlation. In the year 2015-16, also all temperatures were found to exhibit high significant and negative correlation while relative humidity (max & min) showed non-significant negative correlation and rainfall showed non-significant positive correlation with the pest. During the year 2016-17 of investigation, minimum temperature, night temperature and rainfall were significant and negatively correlated however, maximum temperature, day temperature, maximum and minimum relative humidity showed non-significant negative correlation with the thrips population. Lastly, during 2017-18 it was observed that T max (r = -0.808**) and T min (r = -0.690**), T day (r = -0.799**) and T night (r = -0.767**) showed high significant negative correlation and RH max (r = 0.081) revealed non-significant positive correlation and RH min and rainfall were found to be non-significant and negatively correlated with the thrips population.

The overall seven years data i.e. 2011-12 to 2017-18, revealed that the temperature (maximum, minimum, day and night) showed negative and significant correlation with thrips population. The present findings are partially in accordance with the findings of Subba and Ghosh (2016) who reported that temperature difference had significant positive influence on thrips, while significant negative correlation with temperature (minimum and average), relative humidity (minimum, average) and weekly total rainfall. In case of maximum relative humidity and maximum temperature non-significant negative influence was observed. While Jamuna *et al.* (2019) also revealed that minimum temperature, rainfall, rainy days and evening relative humidity were found significant negative correlation with the thrips population, while morning relative humidity found significant positive correlation with the thrips population.

Table 19.1: Correlation between thrips and weather parameters during *rabi* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.223	-0.347	-0.294	-0.317	-0.089	-0.368	-0.279
2012-13	-0.424	-0.456*	-0.452	-0.456*	-0.001	-0.219	-0.287
2013-14	-0.486*	-0.614**	-0.562*	-0.587*	-0.324	0.205	-0.005
2014-15	-0.696**	-0.618**	-0.697**	-0.677**	0.372	0.116	-0.274
2015-16	-0.670**	-0.670**	-0.683**	-0.682**	-0.103	-0.306	0.079
2016-17	-0.455	-0.485*	-0.480	-0.483*	-0.365	-0.292	-0.523*
2017-18	-0.808**	-0.690**	-0.799**	-0.767**	0.081	-0.024	-0.253

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.8 Population dynamics of thrips in *summer* season

The data regarding population dynamics of thrips on tomato crop in summer season during the period of investigation i.e. 2012 to 2018 presented in Table 20 and Fig. 8. From the table and figure mentioned, it could be revealed that in the year 2012, the pest made its first appearance on the crop on first week of February with population load of 0.56 thrips/leaf and it remained on the crop for 18 weeks. During this period, the average of T max was 24.97°C and T min was 10.47°C with an average RH max of 91.29 % and RH min of 41.71 % and no rainfall was recorded. Population of thrips then continued to increase and highest population was recorded during 2nd week of March (12th SMW) with a population load of 3.36 thrips/leaf. During this period, the average of T max was 34.53°C and T min was 21.91°C with an average RH max of 91.43 % and RH min of 39.57 % with no rainfall. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.00 thrips/leaf during last week of May (6th SMW) with weekly average of T max was 36.17 °C and T min was 28.10°C with an average RH max of 90.71 % and RH min of 61.86 % and average weekly rainfall 0.30 mm was recorded during the period.

However, in 2013, the pest could be recorded on the crop for 15 weeks and its arrival was observed in second week of March with a population load of 1.15 thrips/leaf. During this period, the average of T max was 33.59°C and T min was 14.54°C with an average RH max of 89.43% and RH min of 30.57% and no rainfall was recorded. Population of thrips continued to increase and highest population was recorded during 1stweek of April (14th SMW) with a population load of 5.57 thrips/leaf. During this period, the average of T max was 37.97°C and T min was 24.54°C with an average RH max of 81.86 % and RH min of 36.14 % with no rainfall. Later, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.52thrips/leaf during 2ndweek of June (24thSMW) with weekly average of T max was 34.44^{0}C and T min was 26.60 ^{0}C with an average RH max of 94.00 % and RH min of 81.57 % and average weekly rainfall 53.90 mm was recorded during the period.

In 2014, the incidence of pest was recorded in the third week of February (1.2 thrips/leaf) and it remained on the crop for 14 weeks. During the period the average of T max was 30.24 °C and T min was 14.41°C with an average RH max of 81.86% and

RH min of 44.71% and no rainfall was recorded. The population of thrips continued to increase and highest population was recorded during 2ndweek of April (15th SMW) with a population load of 5.60 thrips/leaf. During this period, the average of T max was 37.53°C and T min was 25.03°C with an average RH max of 89.57% and RH min of 43.43% with no rainfall. Later, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 3.80 thrips/leaf during 3rdweek of May (20th SMW) with weekly average of T max was 39.36^{0}C and T min was 27.06^{0}C with an average RH max of 85.00 % and RH min of 48.00 % and average weekly rainfall 5.80 mm was recorded.

And in 2015, pest incidence was observed during the first week of March with a population load of 0.32 thrips/leaf and it remained on the crop for 14 weeks. During this period, the average of T max was 35.17°C and T min was 20.47°C with an average RH max of 86.14% and RH min of 46.29% and average weekly rainfall 5.80 mm was recorded during the period. Population of thrips during the period continued to increase and highest population was recorded during 2nd week of April (16th SMW) with a population load of 2.80 thrips/leaf. During this period, the average of T max was 37.13°C and T min was 25.63°C with an average RH max of 85.71% and RH min of 52.43% with average weekly rainfall of 0.70 mm was recorded. Later the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.36 thrips/leaf during last week of May (22ndSMW) with weekly average of T max was 36.69°C and T min was 29.34°C with an average RH max of 83.43% and RH min of 51.00% and no rainfall was recorded during the period.

In 2016, the incidence of pest was third week of February (1.30 thrips/leaf) and it remained on the crop for 11 weeks. The average of T max was 31.46°C and T min was 19.79°C with an average RH max of 94.86% and RH min of 56.14% and no rainfall was recorded. The population of thrips during the period continued to increase and highest population was recorded during last week of February (9th SMW) with a population load of 5.00 thrips/leaf. During this period, the average of T max was 31.50°C and T min was 20.07°C with an average RH max of 96.57% and RH min of 61.14% with average weekly rainfall of 33.30 mm was recorded..While in 2016, last observation of thrips population load was found to be 1.12 thrips/leaf during 3rd week of April (17th SMW) with weekly average of T max was 40.10^{0}C and T min was 27.49^{0}C with an average RH max of 88.14 % and RH min of 45.29 % and no rainfall was recorded.

During the year 2017 & 2018 the pest incidence was found during second week of February with population loads of 1.52 thrips/leaf and 2.08 thrips/leaf respectively. During this period in 2017, the average of T max was 29.64 °C and T min was 13.43°C with an average RH max of 89.57 % and RH min of 41.43 % and no rainfall was recorded. While in 2018, the average of T max was 29.39 °C and T min was 15.73°C with an average RH max of 89.00 % and RH min of 41.71 % and no rainfall was recorded. Population of thrips in 2017 period continued to increase and highest population was recorded during 2nd week of March (10th SMW) with a population load of 7.00 thrips/leaf and it remained on the crop for 16 weeks. During this period, the average of T max was 33.67°C and T min was 21.59°C with an average RH max of 92.29 % and RH min of 49.71% with no rainfall. Also in 2018, the thrips continued to increase and highest population was recorded during 3rd week of March (11th SMW) with a population load of 8.40 thrips/leaf and during this period, the average of T max was 35.26 °C and T min was 20.94°C with an average RH max of 88.71 % and RH min of 39.57% with no rainfall. Later, in 2017 the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 1.12 thrips/leaf during third week of May (21th SMW) with weekly average of T max was 37.40°C and T min was 27.44°C with an average RH max of 84.29 % and RH min of 53.14 % and average weekly rainfall 1.76 mm was recorded during the period. In 2018, the thrips population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of thrips population load was found to be 8.40 thrips/leaf during second-third week of March (11th SMW) with weekly average of T max was 35.26 °C and T min was 20.90°C with an average RH max of 88.71% and RH min of 39.57% and average weekly rainfall 0.04 mm was recorded during the period.

The overall seven years of investigation from 2012 to 2018, summer season reveal that initiation of thrips population started from first week of February to first week of March i.e. 5th to 10th SMW, then increased its incidence on crop and peak population was recorded from first week of March to third week of April i.e. 10th to 16th SMW with highest population load of 8.40 thrips/leaf in second week of March i.e. 11th SMW in 2018.

The present study is more or less in line with Navas *et al*. (1991) who reported that thrips species on tomato were common between late April and early June, with greatest densities during May. Subba and Ghosh (2016) also observed maximum level of population during 45th to 2nd (1.05-1.89/leaf) and again during 6th to 20th (1.00-2.22/leaf) standard week.

4.1.2.8 Correlation between thrips and weather parameters during *summer* season

The correlation results of thrips population with weather parameters during 2012 to 2018 are presented in Table 20.1. From the investigations it was revealed that temperatures (max, min, day and night) with regard to thrips population was non-significant and positively correlated during 2016, 2017 and 2018. But during 2012 and 2013, maximum, day and night temperatures showed significant positive interaction, and similar observations during 2015 was observed with temperatures (min, day and night) and RH (max & min) whereas, maximum temperature and rainfall showed non-significant positive correlation. Again, in 2014, temperatures (max, min, day and night) showed highly significant positive correlation while rainfall revealed highly significant negative relation. During 2012, 2014 and 2018, RH (min) was found to be negatively significant with relation to the pest and during 2013, 2016 and 2017 a negative non-significant relation was observed. On the other hand, RH max showed negatively non-significant relation in 2012, 2013 and 2018 and positively non-significant correlation in 2014, 2016 & 2017. During 2012, 2014 & 2015, rainfall was revealed to show positively non-significant correlation and negative non-significant correlation during 2013, 2017 & 2018. But in 2016 rainfall was found to be positively correlated the thrips population.

The overall seven years data i.e. 2012 to 2018, revealed that weather factors showed positive and non-significant correlation with thrips population, but in 2014, temperature was found to have highly positive significant correlation and highly negative significant correlation with minimum relative humidity.

Table 20.1: Correlation between thrips and weather parameters during *summer* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2012	0.589**	0.400	0.507*	0.469*	-0.412	-0.449*	0.011
2013	0.559*	0.511	0.685**	0.640*	-0.500	-0.074	-0.205
2014	0.882**	0.882**	0.891**	0.891**	0.083	-0.725**	0.020
2015	0.296	0.605*	0.524*	0.567*	0.595*	0.635*	0.416
2016	0.103	0.178	0.134	0.150	0.178	-0.258	0.584*
2017	0.036	0.014	0.024	0.020	0.235	-0.164	-0.359
2018	0.411	0.074	0.245	0.178	-0.132	-0.595*	-0.299

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.9 Population dynamics of *S. litura* in *rabi* season

Population dynamics of *S. litura* on tomato crop during the period of investigation i.e. 2011-12 to 2017-18 are presented in Table 13 and Fig. 9. In the year 2011-12, the pest made its first appearance on the crop on third week of September i.e. in 38th SMW with a population load of 0.68 individual larvae/plant and it remained present on the crop for 21 weeks. During this period, the average of T max was 30.77 °C and T min was 25.61°C with an average RH max of 97.57 % and RH min of 84.43 % and average weekly rainfall 199.60 mm was recorded during the period. Population of *S. litura* continued to increase and the highest population was recorded during the 3rd week of November (46th SMW) with a population load of 3.48 larvae/leaf. During this period, the average of T max was 30.16 °C and T min was 19.91°C with an average RH max of 94.14 % and RH min of 62.43 % with 8.00 mm rainfall. Later, the population started to decline and maintain a decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 1.62 larvae/leaf during last week of May (6th SMW) with weekly average of T max was 27.86°C and T min was 13.26°C with an average RH max of 89.00 % and RH min of 42.29 % and no rainfall was recorded during the period.

While in 2012-13, it was recorded to be present on the crop for 14 weeks with its arrival in second week of October with a population of 0.60 larvae/plant. During this period, the average of T max was 33.74 °C and T min was 22.01°C with an average RH max of 93.14 % and RH min of 55.43 % and no rainfall was recorded. Population of *S.*

litura during the period continued to increase and highest population was recorded during last week of October (44^{th} SMW) to 2^{nd} week of November (46^{th} SMW) with a population load of 2.88 larvae/leaf. Later the population started to decline and maintain a decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 1.72 larvae/leaf during last week of November (48^{th} SMW) with weekly average of T max was 28.74 °C and T min was 11.76°C with an average RH max of 91.57 % and RH min of 42.43 % with no rainfall.

In 2013-14, the incidence of pest was observed during third week of November (0.48 larvae/ plant) and it remained present on the crop for 14 weeks. During this period, the average of T max was 29.74°C and T min was 18.41°C with an average RH max of 80.43 % and RH min of 49.86 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during 3^{rd}week of November (47^{th} SMW) with a population load of 1.04 larvae/leaf. Later the population started to decline and a decreasing trend was observed up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.12 larvae/leaf during 3^{rd}week of February (7^{th} SMW) with weekly average of T max was 26.23°C and T min was 13.91°C with an average RH max of 84.43 % and RH min of 57.14 % with 28.50 mm of rainfall recorded during the period.

During the year 2014-15, the pest was first observed in second week of November (0.48 larvae/ plant) and remained on the crop for 12 weeks. During this period, the average of T max was 33.47°C and T min was 19.71°C with an average RH max of 81.29 % and RH min of 56.57 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during last week of October (48^{th} SMW) with a population load of 0.64 larvae/leaf. Later the *S. litura* population started to decline and maintain a decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.28 larvae/leaf during 3^{rd} week of February (7^{th}SMW) with weekly average of T max was 31.09°C and T min was 15.51°C with an average RH max of 85.14 % and RH min of 51.43 % with 8.30 mm of rainfall recorded during the period.

Whereas, in 2015-16 the incidence of pest was observed in third week of October which remained present on the crop for 13 weeks and during this period the population load was of 0.20 larvae/leaf, the average of T max was 33.33°C and T min was 21.36°C with an average RH max of 92.43 % and RH min of 53.43% and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during last week of November (47th SMW) with a population load of 1.28 larvae/leaf. Later the *S. litura* population started to decline and maintain a decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.24 larvae/leaf during 3rd week of January (3rdSMW) with weekly average of T max was 25.44°C and T min was 13.91°C with an average RH max of 91.71 % and RH min of 59.86 % with 3.00 mm of rainfall recorded during the period.

And in 2016-17 the first incidence of pest recorded during the end of October month with a population load of 0.80 larvae/leaf and it remained present on the crop for 15 weeks. During this period, the average of T max was 31.57°C and T min was 23.87°C with an average RH max of 95.71 % and RH min of 72.29 % and 1.10 mm rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during first week of December (49th SMW) with a population load of 0.88 larvae/leaf. Later the *S. litura* population started to decline and maintain a decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.08 larvae/leaf during end of January & first week of February (5th SMW) with weekly average of T max was 26.90°C and T min was 11.79°C with an average RH max of 91.71 % and RH min of 53.86 % with no rainfall recorded during the period.

During 2017-18, the first incidence of pest was recorded during the 2nd week of November with a population load of 0.04 larvae/leaf. It remained present on the crop for 15 weeks. During this period, the average of T max was 30.20°C and T min was 20.24°C with an average RH max of 95.43 % and RH min of 62.14 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during 5th and 7th SMW with a population load of 0.44 larvae/leaf i.e., during end of January & second week of February.

The overall seven years of investigation from 2011-12 to 2017-18 revealed that *S. litura* population first appeared on tomato crop in rabi season from third week of September to third week of November (38th to 46th SMW). Peak was observed in rabi season from third week of November to first week of December (46th to 49th) but in 2017-18, peak population was noticed in first week of February (5th SMW). These findings are more or less in congruence with the findings of Sharma *et al.* (2000) who reported that the peak population of *S. litura* was observed from the third week of November to the second week of December and from the last week of February to the second week of March.

4.1.2.9.1 Correlation studies between *S. Litura* and weather parameters during *rabi* season

Correlation among different weather factors and population of *S. litura* is presented in table 21.1. From the results of first year of present investigation (2011-12), it was found that the population of *S. litura* was significantly negative correlated with T min (r = -0.458*), T night (r = -0.414*), RH min (r = -0.502*) and rainfall (r = -0.573**). Whereas, T max (r = -0.278) and RH max (r = -0.157) showed non-significant negative correlation with *S. litura* population. But during the second year of study i.e. 2012-13, it was observed that all the weather parameters showed non-significant relationship with the pest. T max (r = 0.345), T min (r = 0.322), T day (r = 0.343), T night (r = 0.337) and rainfall (r = 0.089) showed non-significant positive correlation, while RH max (r = -0.316) and RH min (r = -0.052) showed non-significant and negative correlation. During the third year (2013-14), only RH max (r = -0.640**) showed a significant negative correlation. T max (r = - 0.043), T min (r = -0.147), T day (r = - 0.090), T night (r = -0.111), RH min (r = -0.048) and rainfall (r = - 0.217) showed non-significant and negative correlation. In the following years, i.e. 2014-15 and 2015-16, it was observed that all the weather parameters (T max, T min, T day, T night, RH max, RH min and rainfall) showed non-significant relationship with the pest population. However, during the year 2016-17, T max (r = -0.687**), T min (r = -0.604*), T day (r = -0.654**), T night (-0.636**), significant negative correlation whereas, RH max (r = -0.235), RH min (r = -0.294) and rainfall (r = - 0.448) were found to be negatively non-significant correlation with *S. litura* population. Lastly in the year 2017-18, it was found that T min (r = -0.612*) T day (r = -0.503*), T night (-0.556*) and RH max (-0.503*) were found to be significantly and negatively correlated whereas, T max, RH min and rainfall were found to be non-significantly and negatively correlated with *S. litura* population.

The overall seven years data i.e. 2011-12 to 2017-18, revealed that the different weather variables were found to have mostly non-significant correlation but in 2011-12, 2016-17 and 2017-18, temperature showed a negative significant correlation with *H. armigera* population and minimum relative humidity and rainfall revealed a negative significant correlation in 2011-12, while maximum relative humidity was found to have negative significant correlation in 2013-14.

Table 21.1: Correlation between *S. litura* and weather parameters during *rabi* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.278	-0.458*	-0.380	-0.414*	-0.157	-0.502*	-0.573**
2012-13	0.345	0.322	0.343	0.337	-0.316	-0.052	0.089
2013-14	-0.043	-0.147	-0.090	-0.111	-0.640**	-0.048	-0.217
2014-15	-0.327	-0.389	-0.375	-0.386	0.146	0.045	-0.411
2015-16	0.142	0.111	0.130	0.124	0.060	-0.118	-0.189
2016-17	-0.687**	-0.604*	-0.654**	-0.636**	-0.235	-0.294	-0.448
2017-18	-0.328	-0.612*	-0.503*	-0.556*	-0.502*	-0.487	-0.270

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.10 Population dynamics of *S. litura* in *summer* season

Population dynamics of *S. litura* on tomato crop during the period of investigation i.e. 2012 to 2018 is presented in Table 25 and figure 10. In the year 2012, the pest made its first appearance on the crop on first week of February with 0.16 larvae/plant and it remained on the crop for 17 weeks. During this period, the average of T max was 27.86°C and T min was 13.26°C with an average RH max of 89.00 % and RH min of 42.29 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during last week of March (13th SMW) with a population load of 1.76 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.64 larvae/leaf during end of May & first week of June (22nd SMW) with weekly average of T max was 36.17°C and T min was 28.10°C with an average RH max of 90.71 % and RH min of 61.86 % with 0.30 mm rainfall recorded during the period.

In 2013, the first incidence of pest was during first week of March with a population load of 0.12 larvae/plant and it remained on the crop for 15 weeks. During this period, the average of T max was 33.59°C and T min was 14.54°C with an average RH max of 89.43 % and RH min of 30.57 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during 1st week of May (18th SMW) with a population load of 2.40 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.60 larvae/leaf during second week of June (24th SMW) with weekly average of T max was 34.44°C and T min was 26.60°C with an average RH max of 94.00 % and RH min of 81.57 % with 53.90 mm rainfall recorded during the period.

In 2014, the pest remained on the crop for 16 weeks and the first incidence was observed during fourth week of January (0.20 larvae/ plant). During this period, the average of T max was 25.50°C and T min was 9.89°C with an average RH max of 82.60 % and RH min of 58.43 % and no rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during 2nd week of March (10th SMW) with a population load of 1.60 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.32 larvae/leaf during third week of May (20th SMW) with weekly average of T max was 39.36°C and T min was 27.06°C with an average RH max of 85.00 % and RH min of 48.00 % with 5.80 mm rainfall recorded during the period.

In 2015, the pest could be recorded on the crop for 14 weeks with its first appearance in the end of February (0.28 larvae/ plant) and in this period, the average of T max was 35.17°C and T min was 20.30°C with an average RH max of 86.14 % and RH min of 46.29 % and 5.80 mm rainfall was recorded. Population of *S. litura* during the period continued to increase and highest population was recorded during end of March (13th SMW) with a population load of 1.20 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.28 larvae/leaf during third week of May (22nd SMW) with weekly average of T max was 38.69°C and T min was 29.34°C with an average RH max of 83.43 % and RH min of 51.00 % with no rainfall recorded during the period.

In 2016, the pest initiation was observed during the third week of February (0.24 larvae/ plant) and it remained on the crop for 12 weeks. The average of T max was 33.50°C and T min was 19.81°C with an average RH max of 90.57 % and RH min of 45.00 % and 11.10 mm rainfall was recorded during the period. Population of *S. litura* continued to increase and highest population was recorded during third week of

March (12th SMW) with a load of 1.00 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.32 larvae/leaf during last week of April (17th SMW) with weekly average of T max was 38.69°C and T min was 29.34°C with an average RH max of 83.43 % and RH min of 51.00 % with no rainfall recorded during the period.

Whereas in 2017 and 2018 the pest started observing during 2nd week of February (0.08 and 0.24 larvae/ plant) respectively and remained on the crop for 16 and 14 days respectively. In 2017 the average of T max was 29.64 °C and T min was 13.43°C with an average RH max of 89.57 % and RH min of 41.43.00 % and no mm rainfall was recorded during the period. While in 2018 the average of T max was 29.39 °C and T min was 15.73°C with an average RH max of 89 % and RH min of 43.71.00 % and no mm rainfall was recorded during the period. Population of *S. litura* during the 2017 continued to increase and highest population was recorded 1.04 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.24 larvae/leaf during third week of May (21st SMW) with weekly average of T max was 37.40°C and T min was 27.44°C with an average RH max of 84.29 % and RH min of 53.14 % with 1.76 mm rainfall was recorded during the period. However, in 2018, Population of *S. litura* continued to increase and highest population was recorded 0.88 larvae/leaf. Later the *S. litura* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *S. litura* population load was found to be 0.48 larvae/leaf during second week of May (19th SMW) with weekly average of T max was 36.00°C and T min was 25.66°C with an average RH max of 90.57 % and RH min of 61.57 % with no rainfall was recorded during the period.

The overall seven years of investigation from 2012 to 2018 revealed that *S. litura* population was first noticed on tomato crop in summer season first week of February to first week of March (5th to 10th SMW) and peak population was observed from first week of March to first week of May (10th to 18th SMW). The present findings are in close proximity with the reports of Hanamant *et. al.* (2013) where incidence started from 6th SMW and reached its peak during the 11th SMW with 19.50 % leaf damage and declined thereafter. Shakya *et al*. (2015) also reported that infestation of *S.*

litura on tomato started from 15th January with the peak infestation of 0.9 insects per plant noticed on 26th February and declining trend in pest population was noticed with minimum infestation of 0.15 insects per plant on 23rd April. While, Monobrullah *et al*. (2004) stated that the larvae started appearing from the 17th standard week. A gradual increase in the larval population was recorded until the 25th standard week. Larval population declined gradually after the 27th standard week at the time of crop harvest. The peak population was observed during the 25th standard week i.e. 3rd week of June.

4.1.2.10.1 Correlation between *S. litura* and weather parameters during *summer* season

From the data presented in Table 22.1, it is revealed that during the first year of study i.e. 2012, T max (r = 0.817**), T min (r = 0.731**), T day (r = 0.786**) and T night (r = 0.768**) showed highly significantly positive correlation with *S. litura* population, while RH max (r =-0.422) and RH min (r = 0.055) showed non-significant negative correlation and rainfall (r = 0.221) showed non-significant positive correlation with the pest. In 2013, T min (r = 0.609*), T day (r = 0.604*) and T night (r = 0.640*) showed positive and significant correlation with *S. litura* population while T max, RH min & rainfall showed non-significant positive influence with *S. litura* population and RH max (r = -0.269) had non-significant negative influence. However, during the year 2014, temperature and rainfall both the factors showed non-significant positive correlation with *S. litura* population while, relative humidity prevailed to be non-significant and negatively correlated with the pest. In 2015, T max (r = -0.015), T min (r = -0.001), T day (r = -0.007) & T night (r = -0.004) were found to be non-significant negative influence whereas, RH max (r = 0.273) and RH min (r = 0.016) and rainfall (r = 0.321) showed non-significant positive correlation. In 2016, only RH min (r = -0.616*) showed significant negative correlation, temperature (max & min, day & night) showed non-significant positive correlation while RH max and rainfall showed negative non-significant correlation. Similarly, in 2017, temperature (max & min, day & night) and RH max were observed to have non- significant positive correlation while RH min and rainfall showed non-significant negative relation In the year 2018, T max (r = 0.683**), T day (r = 0.616*) and T night (r = 0.578*) were found to be positive and significantly correlated with *S. litura* population while, T min & RH max were observed to be positive and non-significant correlated. RH min and rainfall, on the other hand showed non-significant negative influence on *S. litura* population during the year.

The overall seven years data i.e. 2012 to 2018, revealed that the different weather inputs were found to have non-significant correlation with the pest population however in 2012, 2013 and 2018, it was observed temperature showed positive significant correlation and minimum relative humidity showed negative significant correlation with *S. litura* population.

The present findings are partly in agreement with Prashant *et al*., (2007) who reported that the population of *S. litura* was positively correlated with the mean temperature but negatively correlated with relative humidity. While Shakya *et al*. (2015) reported that *S. litura* exhibited significant negative correlation with maximum temperature (r=-0.5698) and minimum temperature (r=-0.5684) and significant positive correlation with maximum relative humidity (r=0.6813) and minimum relative humidity (r=0.4397) and rainfall (r= 0.1800). Selvaraj *et al*. (2010) also reported that *S. litura* showed a positive correlation with relative humidity. However, Satyanarayana *et al*. (2010) reported that larval population of *S. litura* showed non-significant relationship with maximum temperature and relative humidity, but significant relationship with minimum temperature.

Table 22.1: Correlation between *S. litura* and weather parameters during *summer* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2012	0.817**	0.731**	0.786**	0.768**	-0.422	-0.055	0.221
2013	0.326	0.609*	0.604*	0.640*	-0.269	0.169	0.103
2014	0.119	0.047	0.090	0.076	-0.236	-0.331	0.013
2015	-0.015	-0.001	-0.007	-0.004	0.273	0.016	0.321
2016	0.536	0.528	0.540	0.539	-0.325	-0.616*	-0.037
2017	0.257	0.292	0.280	0.285	0.308	-0.108	-0.363
2018	0.683**	0.509	0.616*	0.578*	0.102	-0.045	-0.108

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.11 Population dynamics of *H. armigera* in *rabi* season

Population dynamics of *H. armigera* on tomato crop during the period of investigation i.e. 2011-12 to 2017-18 are presented in table 15 and figure 11. From figure 11, it could be revealed that in the year 2011-12, the pest made its first appearance on the crop on during third week of October with population load of 0.44

larvae/plant (42nd SMW) and it remained on the crop for a duration of 17 weeks. During this period, the average of T max was 32.90 °C and T min was 25.29°C with an average RH max of 92.71 % and RH min of 70.57 % and 10.20 mm rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during last week of November (48th SMW) with a load of 1.28 larvae/plant. Later the *H. armigera* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation with a population load of 0.76 larvae/plant was found to be during 2nd week of February (6th SMW) with weekly average of T max was 27.86 °C and T min was 13.26°C with an average RH max of 89.00 % and RH min of 42.29 % with no rainfall.

While in 2012-13, the pest incidence was during first week of December with population of 0.2 larvae/plant (49th SMW) and was observed to stay on the crop for a duration of 9 weeks. During this period, the average of T max was 28.80 °C and T min was 10.91°C with an average RH max of 91.29 % and RH min of 43.00 % and no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 3rd week of January (3rd SMW) with a population load of 0.92 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.56 larvae/plant during last week of January (5th SMW) with weekly average of T max was 27.73 °C and T min was 10.29°C with an average RH max of 91.86 % and RH min of 47.57 % and no rainfall was observed during the period.

In 2013-14, the pest incidence was observed during second week of January (0.16 larvae/ plant) and it remained on the crop for a duration of 7 weeks. During this period, the average of T max was 23.83 °C and T min was 10.04°C with an average RH max of 84.86 % and RH min of 59.71 % and no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during end of January month (5th SMW) with a population load of 0.60 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.08 larvae/plant during 3rd week of February (8th SMW) with weekly average of T max was 29.17 °C and T min was 14.09°C with an average RH max of 85.14 % and RH min of 54.43 % and no rainfall was observed during the period.

In 2014-15, the first pest initiation was observed during end of December (0.12 larvae/plant) with its duration on the crop for 9 weeks. During this period, the average of T max was 24.63 °C and T min was 09.85°C with an average RH max of 87.75 % and RH min of 59.38 % and no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 3rd week of January (3rd SMW) with a population load of 0.48 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.12 larvae/plant during 3rd week of February (8th SMW) with weekly average of T max was 34.19 °C and T min was 19.67°C with an average RH max of 85.86 % and RH min of 50.14 % and 5.30 mm rainfall was observed during the period.

And in 2015-16 and 2016-17, the pest was noticed to remain on the crop for 8 weeks with its arrival during second week of December i.e., 50th SMW and a population load of 0.16 and 0.08 larvae/plant respectively. During 2015-16, the average of T max was 26.63 °C and T min was 17.19°C with an average RH max of 92.57 % and RH min of 57.71 % and no rainfall was recorded during the period. And in 2016-17, the average of T max was 25.30 °C and T min was 10.80°C with an average RH max of 94.00 % and RH min of 54.57 % and no rainfall was recorded during the period. In 2015-16, population of *H. armigera* continued to increase and highest population was recorded during end of December (52nd SMW) with a population load of 0.36 larvae/plant. Later the *H. armigera* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population was found to be 0.08 larvae/plant during end of January (5th SMW) with weekly average of T max was 28.14 °C and T min was 14.90°C with an average RH max of 92.43 % and RH min of 48.57 % and no rainfall was observed during the period. However, in 2016-17, population of *H. armigera* during the period continued to increase and highest population was recorded during 1st week of January (1st SMW) with a population load of 0.44 larvae/plant. Later the *H. armigera* population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population was found to be 0.16 larvae/plant during end of January (5th SMW) with weekly average of T max was 26.90 °C and T min was 11.79°C with an average RH max of 91.71 % and RH min of 53.00 % and no rainfall was observed during the period.

In the last year of investigation i.e. 2017-18, the first pest incidence was observed in second week of November with a population load of 0.08 larvae/plant and it remained on the crop for a duration of 15 weeks. During this period, the average of T max was 31.83 °C and T min was 19.89°C with an average RH max of 94.00 % and RH min of 53.86 % and no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 2nd to 3rd week of February (7th SMW), last stage of crop with a population load of 0.40 larvae/plant with weekly average of T max was 29.41 °C and T min was 13.96°C with an average RH max of 88.14 % and RH min of 43.43 % and no rainfall was observed during the period.

The overall seven years data i.e. from 2011-12 to 2017-18, showed that *H. armigera* first appeared on tomato crop in rabi season with wide range i.e. from third week of October to second week of January (42nd to 2nd SMW) and peak population was observed from last week of November to third week of February (48th to 7th SMW). Sapkal *et al*. (2018) reported that incidence of *H. armigera* population started during 35th SMW (0.5 larvae/plant) and there after the population reaches 2.8 larvae plant in the 47th SMW and the highest population was recorded during fruiting stage of the crop in the range of 4.2 larvae per plant. Chavan *et al*. (2016) revealed that *H. armigera* population was higher during 42nd SMW at Parbhani. Nadaf and Kulkarni (2006) recorded peak incidence of larvae during November first fortnight. Kamble *et al*. (2005) reported that first incidence of *H. armigera* on 35th SMW. The peak larval population coincided with the flowering and fruiting season. Thus, the above reports are more or less corroborated with the present findings.

4.1.2.11.1 Correlation studies between *H. armigera* and weather parameters during *rabi* season

From the data presented in Table 23.1, it is revealed that during first year of study (2011-12), *H. armigera* population was highly significantly and negatively correlated with T max (r = -0.632**), T min (r = -0.801**), T day (r = -0.741**), T night (r = -0.770**), RH min (r = -0.630**) and rainfall (r = -0.610**) and only RH max (r= -0.109) showed non-significant negative correlation. In the second year of study i.e. 2012-13, T max (r = -0.781**), T min (r = -0.752**), T day (r = -0.787**) and T night (r = -0.779**) showed highly significant negative correlation. RH min (r = -0.218) and rainfall (r = -0.361) showed non-significant negative correlation while RH max (r = 0.163) showed non-significant positive relation. However, during the third year (2013-14), all the temperature parameters were found to be non-significant negatively correlated and relative humidity (min & max) and rainfall showed non-significant positive correlation with the *H. armigera* population. In the following year of investigation i.e. 2014-15, maximum, minimum, day and night temperature were observed to be significant and negatively correlated while relative humidity (min & max) showed non-significant negative relation. Rainfall however, was found to have non-significant positive correlation with the pest population. In the following year (2015-16) of investigation maximum and minimum temperature was observed to show a highly significant negative correlation while relative humidity (min & max) showed non-significant negative correlation. While, rainfall was found to be in non-significant positive correlation with the *H. armigera* population. Similarly, in the year 2016-17, results showed that temperature was observed to be significantly and negatively correlated while relative humidity and rainfall (r = - 0.300) showed non-significant negative correlation. Finally, in 2017-2018, RH max (r = -0.688**), RH min (r - 0.674**) were found to have highly significant negative correlation while T min (r = - 0.541*) was significantly and negatively correlated with the *H. armigera* population whereas T max, T day, T night & rainfall showed non-significant negative relation with *H. armigera* population.

The overall seven years data i.e. 2011-12 to 2017-18, indicated that temperature showed mostly negative significant correlation with *H. armigera* population and negative significant correlation with relative humidity in 2017-18, while minimum relative humidity and rainfall was found to have negative significant correlation in 2011-12.

Table 23.1: Correlation between *H. armigera* and weather parameters during *rabi* season

Year	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	-0.632**	-0.801**	-0.741**	-0.770**	-0.109	-0.630**	-0.610**
2012-13	-0.781**	-0.752**	-0.787**	-0.779**	0.163	-0.218	-0.361
2013-14	-0.321	-0.431	-0.382	-0.405	0.289	0.015	0.223
2014-15	-0.490*	-0.488*	-0.516*	-0.513*	-0.020	-0.090	0.038
2015-16	-0.826**	-0.798**	-0.829**	-0.822**	-0.404	-0.147	0.310
2016-17	-0.751**	-0.685**	-0.729**	-0.714**	-0.300	-0.365	-0.300
2017-18	-0.134	-0.541*	-0.363	-0.441	-0.688**	-0.674**	-0.379

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.1.2.12 Population dynamics of *H. armigera* in *summer* season

Perusal of the data (Table 24 and figure 12) regarding population dynamics of *H. armigera* on tomato crop in summer during the period of investigation i.e. 2012 to 2018, revealed that in the year 2012, the pest made its first appearance on the crop on third week of March with a population load of 0.28 larvae/plant and it remained on the crop for 11 weeks. During this period, the average of T max was 34.53 °C and T min was 21.91°C with an average RH max of 91.43 % and RH min of 39.57 % with no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during last week of April (17th SMW) with a population load of 2.24 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.32 larvae/plant during end of May (22nd SMW) with weekly average of T max was 36.17 °C and T min was 28.10°C with an average RH max of 90.71 % and RH min of 61.86 % with 0.30 mm rainfall was recorded during the period.

During 2013, the first pest incidence was recorded during the fourth week of April with a population load of 0.16 larvae/plant and it remained on the crop for 8 weeks. During this period, the average of T max was 34.53 °C and T min was 21.91°C with an average RH max of 91.43 % and RH min of 39.57 % with no rainfall was. Population of *H. armigera* during the period continued to increase and highest population was recorded during last week of April (17th SMW) with a population load of 2.24 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.32 larvae/plant during end of May (22nd SMW) with weekly average of T max was 36.17 °C and T min was 28.10°C with an average RH max of 90.71 % and RH min of 61.86 % with 0.30 mm rainfall was recorded during the period.

In 2014, the first pest incidence was recorded during the last week of March (0.12 larvae/plant) and it remained on the crop for 8 weeks. During this period, the average of T max was 34.40 °C and T min was 19.87°C with an average RH max of 86.00 % and RH min of 52.00 % with 26.20 mm rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during last week of April (17th SMW) with a population load of 0.64

larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.20 larvae/plant during 3rd week of May (20th SMW) with weekly average of T max was 39.26 °C and T min was 27.06°C with an average RH max of 85.00 % and RH min of 48.00 % with 5.80 mm rainfall was recorded during the period.

However, in 2015, the pest was noticed to be present for 6 weeks and its initiation was found during the last week of April (0.08 larvae/plant). During this period, the average of T max was 35.66 °C and T min was 24.14°C with an average RH max of 92.29 % and RH min of 49.86 % with 13.30 mm rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 3rd week of May (20th SMW) with a population load of 0.72 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.24 larvae/plant during last week of May (22nd SMW) with weekly average of T max was 38.69 °C and T min was 29.34°C with an average RH max of 83.43 % and RH min of 51.00 % with no rainfall was recorded during the period.

In the year 2016, the pest could be observed on the crop for 5 weeks and its initiation was recorded at the end of March with a population load of 0.08 larvae/plant. During this period, the average of T max was 35.13 °C and T min was 23.77°C with an average RH max of 92.43 % and RH min of 49.86 % with no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 3rd week of Aril (16th SMW) with a population load of 0.2 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.80 larvae/plant during 3rd week of April (17th SMW) with weekly average of T max was 40.10°C and T min was 27.49°C with an average RH max of 88.14 % and RH min of 45.29 % with no rainfall was recorded during the period.

In 2017, the pest remained on the crop for 12 weeks and its first initiation could be observed in the 2nd week of March with a population load of 0.04 larvae/plant. During this period, the average of T max was 31.43 °C and T min was 19.29°C with an average RH max of 94.25 % and RH min of 60.86% with 0.46 mm rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest population was recorded during 3rd week of May (20th SMW) with a population load of 0.64 larvae/plant. Later the population started to decline and maintained the decreasing trend up to the last stage of crop and the last observation of *H. armigera* population load was found to be 0.48 larvae/plant during last week of May (21st SMW) with weekly average of T max was 37.40°C and T min was 27.44°C with an average RH max of 84.29 % and RH min of 53.14 % with 1.76 mm rainfall was recorded during the period.

And in the last year of study, 2018 the pest initiation was first recorded during 3rd week of February (0.08 larvae/plant) and it remained on the crop for 13 weeks. During this period, the average of T max was 29.41 °C and T min was 13.96°C with an average RH max of 88.14 % and RH min of 43.43% with no rainfall was recorded. Population of *H. armigera* during the period continued to increase and highest and last population was recorded during 2nd week of May (19th SMW) with a population load of 0.32 larvae/plant with weekly average of T max was 36.00°C and T min was 25.66°C with an average RH max of 90.57 % and RH min of 61.57 % with 0.73 mm rainfall was recorded during the period.

The overall seven years data i.e. from 2012 to 2018, showed that *H. armigera* appearance on tomato crop in summer season was first noticed from second week of February to fourth week of April (7th to 17th SMW) and peak population was recorded from third week of April to first week of June (16th to 22nd SMW).

The present investigation is more or less in concordance with the findings of Harshita *et. al*. (2018) who reported peak infestation of *H. armigera* was recorded during March. The first incidence of *H. armigera* was observed on 12th December with a mean population of 0.46 larvae per plant and maximum population of 6.06 larvae per plant on 22nd March. The next incidence of fruit borer was noticed on 17th January with a mean population of 0.9 larvae per plant and maximum population of 6.3 larvae per plant on 20th March. Singh *et al.* (2011) reported the first appearance of *H. armigera* in 50th and 52nd standard week with its peak in 15th standard week (2nd week of April). Kurl and Kumar (2010) also reported that the fruit borer, *Helicoverpa armigera* (Hubner**)** larvae appeared on tomato crop in 2nd standard week (January) and continue till 21st standard week with highest build-up of larvae was recorded in the 15th standard week, while Mahapatra *et al*. (2018) noticed a maximum population of *H. armigera* was during 5th Standard week of February. Hath and Das (2004) observed the incidence of fruit borer from the third week of March and second week of April, and the level of infestation was always high. The peak was recorded during the first week of April. Kharia *et al*. (2018) reported that the first appearance of the fruit borer was noticed during 11th standard week (12th -18th March) and it reached maximum in 16th standard week (16th - 22nd April), while the population decreased up to crop maturity. Thus, the results are in line with these studies as well.

4.1.2.12.1 Correlation between *H. armigera* and weather parameters during summer season

From the data presented in Table 24.1, it is revealed that during first year of study (2012), *H. armigera* population was positively significant with T max (r = 0.648**), T min (r = 0.670**), T day (r = -0.667**) and T night (r = -0.670**), while it was negatively non-significant with RH max (r = -0.345). In case of RH min (r = 0.276) and rainfall (r = 0.410), it showed non-significant positive correlation. While, in the second year of study (2013), T max (r = -0.596*) showed negatively significant relation with *H. armigera* population and RH max (r = 0.594*) and RH min (r = -0.878**) showed significant positive correlation. In case of T min (r = 0.492), T night (r = 0.204) and rainfall (r = 0.471) they were positively non-significant while T day showed non-significant negative correlation. During 2014, *H. armigera* population was positively significant with T max (r = 0.824**), T min (r = 0.806**) T day (r = -0.825**) and T night (r = -0.822**) and negatively significant in case of RH min (r = -0.692**) and was negatively non-significant with rainfall (r = -0.131), while RH max showed (r = 0.083) non-significant positive correlation. During the year 2015, the T min (r = 0.645**) T day (r = -0.641*), T night (r = -0.650**) and RH min (r = 0.567*) revealed positively significant correlation with the pest population. And T max and RH max showed non-significant positive correlation. In case of rainfall (r = -0.013) negative non-significant relation was observed. In the year 2016, T max (r = 0.770**), T min (r = 0.802**), T day (r = -0.793**) and T night (r = -0.800**) showed highly positive significant relation with *H. armigera* population, while RH max (r = -0.618*) showed significant negative correlation and RH min and rainfall (r = -0.370) were both negatively non-significant. However, in 2017, T max, T min, T day, T night, RH min and rainfall showed positive significant correlation with *H. armigera* population and only RH max showed non-significant negative correlation. And in the last year of study i.e. 2018, all the abiotic factors except RH max (r = 0.029) were found to be positively and significantly correlated with *H. armigera* population.

The overall seven years data i.e. 2012 to 2018, revealed that the different weather factors with temperature in particular, showed positive significant correlation with the pest population. The present findings are more or less in agreement with the results of Chula *et al.* (2017) who reported that maximum and minimum temperatures showed significantly positive correlation whereas, the relative humidity and rainfall revealed negative significant correlation with fruit borer population. Kumar *et al*. (2017) also showed positive and significant correlation between fruit borer population and mean atmospheric temperature. Vikram *et al*. (2018) reported that maximum (r = 0.625) and minimum (r = 0.668) showed significant positive correlation with larval population. But relative humidity i.e. morning (r=-0.160) and evening (r=-0.388) had non-significant negative correlation and rainfall had non-significant positive correlation (r=0.091) with larval population. While, Kakati *et al*. (2005) reported that the population build-up of the tomato fruit borer pest had significant negative correlation with minimum temperature and non-significant correlation with maximum temperature. Kharia *et al*. (2018) also reported that the fruit borer population had a significant positive correlation with maximum temperature, minimum temperature and bright sunshine while significant negative correlation with morning and evening relative humidity. The present results are in congruence with these studies as well.

Table 24.1: Correlation between *H. armigera* and weather parameters during summer season

Year	**Temperature (°C)**				**Relative Humidity (%)**		**Rainfall (mm)**
	Maximum	**Minimum**	**Day**	**Night**	**Maximum**	**Minimum**	
2012	0.648**	0.670**	0.667**	0.670**	-0.345	0.276	0.410
2013	-0.596*	0.492	-0.052	0.204	0.594*	0.878**	0.471
2014	0.824**	0.806**	0.825**	0.822**	0.083	-0.692**	-0.131
2015	0.513	0.645**	0.641*	0.650**	0.396	0.567*	-0.013
2016	0.770**	0.802**	0.793**	0.800**	-0.618*	-0.248	-0.370
2017	0.722**	0.728**	0.736**	0.735**	-0.190	0.539*	0.740**
2018	0.627*	0.810**	0.751**	0.781**	0.029	0.709**	0.653**

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level

4.2 Biology of leaf miner, *L. trifolii* (Burgess) on tomato

Adults were very small flies. Mating occurred within 24 hours of emergence from puparia and thereafter the female laid eggs singly in the leaves. Eggs were oval in shape and slightly translucent. There were three larval stages and they predominantly fed on the leaves in which the eggs were laid. Initially, the larva was colourless then became yellowish as it matures. The third and final instar cut an opening at the end of the mine to exit for pupation. The pupa was yellow in color which turned orange brown as it got older. The fly emerged after making a slit on the anterior end of the puparium. Male fly was smaller in size than female.

4.2.1 Morphometric parameters of *L. trifolii* on tomato

The results regarding the length and breadth of various developmental stages of *L. trifolii* on tomato i.e. egg, larva (first, second third instars), pupa, adult male and female are shown in Table 25.

4.2.1.1 Egg

The eggs were laid singly on the upper surface of leaf. Freshly laid eggs were oval in shape, white and translucent which turned creamy white at maturity. It measured about 0.21 ± 0.03 mm in length and 0.11 ± 0.02 in breadth. These findings are in close conformity with the observations recorded by Demetry (1971), Beri (1974), Bartlett and Powell (1981), Charlton and Allen (1981), Minkenburg (1988), Mujica *et al*. (2016) and Capinera (2017).

4.2.1.2 Larva

The first instar larva was apodous, transparent and minute. On an average those measured about 0.54 ± 0.07 mm in length and 0.33 ± 0.07 mm in width. Minkenburg (1988) reported that length of first instar larva was 0.39 mm and Hemalatha and Uma Maheshwari (2004) reported that a mean length and width of first instar larva was 0.57 mm and 0.14 mm, respectively on tomato. Gondhalekar (2005) reported that length and width of first instar were 0.44 mm and 0.17 mm, respectively on gerbera. The second instar larva was observed to be pale yellowish in colour and measured about 1.41 ± 0.06 mm in length and 0.5 ± 0.04 mm in width. The last and third instar larva showed distinctively yellowish colouration and measured about 2.09 ± 0.02 mm in length and 1.19 ± 0.04 mm in width. The present findings are in close conformity with that of Hemalatha and Uma Maheshwari (2004) on tomato and Gondhalekar (2005) on gerbera.

4.2.1.3 Pupa

The pupa became yellow brown in colour assuming a deeper yellow brown as they matured. The pupae were measured about 1.78 ± 0.09 mm in length and 0.68 ± 0.06 mm in breadth. The present findings are in close conformity with that of Okram *et al*. (2017) who observed pupal length and breadth to be of 1.60 ± 0.08 mm and 0.74 ± 0.03 mm, respectively.

4.2.1.4 Adult

The observed colouration and morphology of adult was similar to that of described by Spencer (1973), Barlett and Powell (1981), Mujica *et al*. (2016) and Capinera (2017). The head was yellow with reddish eyes and yellow hind margins. The thorax and abdomen were greyish black with a noticeable yellow patch at the hind end of the mesonotum. The mesonotum was matte, greyish black while the underside and legs were mostly yellow. The wings were transparent. The length of body and wing expanse were found to be in a range of 1.46 ± 0.08 mm and 1.22 ± 0.06 mm, respectively in adult males, whereas in case of females the body length and wing expanse were found to be in the range of 1.68 ± 0.09 mm and 1.35 ± 0.07 mm, respectively (Table 10). These findings are in agreement with the findings by Okram *et al*. (2017) who observed that male flies were smaller in size than the female flies. Parrella, (1987) also reported a similar finding that adult females were usually larger than males and emerged from larger puparia.

Table 25: Morphometric parameters of *L. trifolii* on tomato

<table>
<tr><th colspan="2">Life stages</th><th>Length (mm)</th><th>Breadth (mm)</th></tr>
<tr><td colspan="2">Egg</td><td>0.21 ± 0.03</td><td>0.11 ± 0.02</td></tr>
<tr><td colspan="2">1st Instar</td><td>0.54 ± 0.07</td><td>0.33 ± 0.07</td></tr>
<tr><td colspan="2">2nd Instar</td><td>1.41 ± 0.06</td><td>0.52 ± 0.04</td></tr>
<tr><td colspan="2">3rd Instar</td><td>2.09 ± 0.02</td><td>1.19 ± 0.04</td></tr>
<tr><td colspan="2">Pupa</td><td>1.78 ± 0.09</td><td>0.68 ± 0.06</td></tr>
<tr><td rowspan="2">Adult</td><td>Male</td><td>1.46 ± 0.08 (body length)</td><td>1.22 ± 0.06 (wing length)</td></tr>
<tr><td>Female</td><td>1.68 ± 0.09 (body length)</td><td>1.35 ± 0.07 (wing length)</td></tr>
</table>

4.2.2 Effect of different temperature regimes (15°C, 20 °C, 25 °C and 30 °C) on the developmental period (in days) of *L. trifolii* on tomato

The results pertaining the developmental period of various life stages of *L. trifolii* on tomato in different levels of temperature i.e. 15°C, 20°C, 25°C and 30°C is given in Table 26. It reveals that temperature has a significant effect on development time of egg, larva, pupa and adult of *L. trifolii*. The eggs took significantly longer time to hatch at 15°C (8.6 ± 0.97 days) and significantly shorter time at 30°C (1.9 ± 0.74 days). At temperatures 20°C and 25°C the egg period observed were 5.4 ± 0.84 days and 3.8 ± 0.92 days respectively. Similar findings are reported by Leibee (1984) who found that the incubation period of eggs of *L. trifolii* were 1.99 ± 0.03, 2.38 ± 0.05, 2.33 ± 0.04, 4.4 ± 0.04 and 9.97 ± 0.47 days at 35°C, 30°C, 25°C, 20°C and 15°C, respectively. Lanzoni *et al*. (2002) also noted that the development time for egg ranged between, 6.3 ± 0.7 days, 3.6 ± 0.2 days, 2.1 ± 0.1 days and 1.6 ± 0.1 days at 15°C, 20°C, 25°C, and 30°C, respectively. Further, Parella (1987) reported that the period of egg development varies with temperature and ranges from 2-8 days. The larval period observed at 15°C was 13.7 ± 1.57 days, at 20°C it was 6.4 ± 1.3, at 25°C it was 4.9 ± 0.99 days and at 30°C it was 3.5 ± 0.85 days. These are findings are more or less in close conformity with that of Lanzoni *et al*. (2002) who reported that the larval period ranged from 14.3 ± 1.1 days, 6.7 ± 0.5 days, 4.6 ± 0.5 days and 3.6 ± 0.4 days at 15°C, 20°C, 25°C, and 30°C, respectively. A similar trend was reported by Van Elferen and Yarhom, (1989) where the larval period (±SE) at temperatures of 20, 25 and 30°C were 9.9 ± 0.2, 4.4 ± 0.1 and 3.7 ± 0.1 on gypsophila and 5.5 ± 0. l, 3.7 ± 0.1 and 2.4 ± 0.1 days, on bean, respectively. The pupal and the adult developmental periods were also found to vary with temperature. Lowest pupal development time (6.9 ± 1.37) was recorded at 30°C and highest development time (22.4 ± 1.71) was recorded at 15°C. The pupal period at 20°C and 25°C were found to be 14.7± 1.49 days and 10.2 ± 1.32 days, respectively. Lanzoni *et al*. (2002) reported the pupal period to be 33.2 ± 2.3 days, 13.3 ± 0.6 days, 9.2 ± 0.4 days and 6.9 ± 0.3 days at 15, 20, 25, and 30°C, respectively. Similarly, Van Elferen and Yarhom, (1989) also observed that the pupal period at 17, 20, 25 and 30°C lasted 19.9 ± 0.2, 14.7 ± 0.1, 10.4 ± 0.1 and 7.8 ± 0.1 days, respectively. The adult male development period was noted to be 15.1 ± 1.37 days at 15°C, 10.90 ± 1.20 days at 20°C, 7.5 ± 1.27 days at 25°C and 3.9 ± 0.88 days at 30°C, while for adult female it was 18.5 ± 1.58 days, 13.3 ± 1.77 days, 9.7 ± 1.16 days and 5.4 ± 0.97 days at 15°C, 20°C, 25°C and 30°C, respectively. The total developmental period was longest at 15°C (♂- 60.5 ± 1.40 days; ♀- 63.2 ± 1.46 days) with the minimum period (♂-16.4 ± 0.96 days; ♀- 17.9 ± 0.98 days) observed at 30°C. At temperatures 20°C and 25°C, the total period observed were; ♂- 37.4 ± 1.22 days; ♀- 39.8 ± 1.36 days and ♂- 26.4 ± 1.12 days; ♀- 28.6 ± 1.10 days, respectively. These findings are in agreement with results of studies carried out by Liebee (1984), Parella (1987) and Minkenberg (1988) who observed similar trends on *Liriomyza* genus (*L. huidobrensis*, *L. sativa* and *L. trifolii*). It is also in agreement with Head *et al.* (2002) who carried out studies on the developmental rates of leaf miners in lettuce at different temperatures (11-28°C). His study revealed a linear increase in developmental rates with temperature. As with all insects, the rate of immature development of *Liriomyza* spp. is dependent on temperature. Similar observations were made by Parella (1987) who found that longevity decreased with an increase in temperature. Thus, it can be concluded from the findings above that temperature played a significant role in the development period of leaf miner and showed an inverse relationship with temperature.

Table 26: Developmental period (in days) of *L. trifolii* at 15°C, 20°C, 25°C and 30°C on tomato

Life stages		15°C (mean±SD) (Days)	20°C (mean±SD) (Days)	25°C (mean±SD) (Days)	30°C (mean±SD) (Days)
Egg		8.6 ± 0.97	5.4 ± 0.84	3.8 ± 0.92	1.9 ± 0.74
Larva		13.7 ± 1.57	6.4 ± 1.3	4.9 ± 0.99	3.5 ± 0.85
Pupal		22.4 ± 1.71	14.7± 1.49	10.2 ± 1.32	6.9 ± 1.37
Adult	**Male**	15.1 ± 1.37	10.90 ± 1.20	7.5 ± 1.27	3.9 ± 0.88
	Female	18.5 ± 1.58	13.3 ± 1.77	9.7 ± 1.16	5.4 ± 0.97
Total	**Male**	60.5 ± 1.40	37.4 ± 1.22	26.4 ± 1.12	16.4 ± 0.96
	Female	63.2 ± 1.46	39.8 ± 1.36	28.6 ± 1.10	17.9 ± 0.98

4.3 Relationship of population build-up of leaf miner and other insect pests infesting tomato with weather parameters and development of prediction models.

Using the weather parameters collected weekly for seven consecutive years (2011-12 to 2017-18), prediction models were developed for forecasting the incidence of insect pests of tomato in experimental plot C-Block farm of Kalyani, BCKV. The weather variables considered were maximum temperature (T max), minimum temperature (T min), day temperature (T day), night temperature (T night), maximum relative humidity (RH max), minimum relative humidity (RH min) and rainfall (RF).

4.3.1 Development of prediction models based on weather variables for different insect pest of tomato using Principal Component Multinomial Regression method

According to Hosmer and Lemeshow (1989) and Ryan (1997), a logistic model becomes unstable when there exists strong dependence among variables/predictors (i.e. multicollinearity between the variables) so that it seems no single variable is important when all the others are in the model. In such case the estimation of the model parameters given by most statistical packages becomes too inaccurate because of the need to invert near-singular and ill-conditioned information matrices. As a consequence, the interpretation of the relationship between the response and each explicative variable in terms of odds ratios may be erroneous. The term multicollinearity refers to a situation in which there is an exact (or nearly exact) linear relation among two or more of the explanatory variables (Hawking and Pendleton,1983, Bowerman and O‟Connell, 2006). Adeboye *et al*. (2014) and Neter, (1989) noted that multicollinearity may cause serious difficulties in regression analysis. A remedial measure to solve this problem is the use of principal component regression (PCR) introduced by Massy (1965). However, in the present investigation a new method of approach as suggested by Camminatiello and Lucadamo (2010) was adopted in which Principal Component Multinomial Regression (PCMR) method was used. This method was based on the technique of principal component analysis and multinomial logit regression method together. Principal component analysis (PCA) is a multivariate technique introduced by Hotelling (1933) that explains the variability of a set of variables in terms of a reduced set of uncorrelated linear spans of such variables with maximum variance, known as principal components (PC's). The central idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables (Jolliffe, 2002). Milewska *et al*. (2014) described PCA as one of the data mining methods that allow one to discover connections hidden in the data and better their understanding. On the other hand, it can be used as a preliminary method when the final statistical tests require analyzing independent variables. The procedure then involves eliminating some of the principal components which contribute in explaining relatively less variation. Multinomial logistic regression on the other hand is the extension for the (binary) logistic regression when the categorical dependent outcome has more than two levels (Chan, 2005). Camminatiello and Lucadamo (2010) explained that it is the simplest model in discrete choice analysis when more than two alternatives are in a choice set.

4.3.1.1 Weather variables-based Regression model for leaf miner, *L. trifolii* in rabi season

4.3.1.1.1 Correlation Matrix

A correlation analysis between the variables was first performed to detect the presence of multicollinearity and the result of the analysis is given in the Table 27. It revealed that significant correlation or multicollinearity was found between most of the variables (<0.1). The variable selected for the study therefore, could not be treated as independent variables for the purpose of research. Hence, principal component analysis was further carried out to remove the multicollinearity among the variables.

Table 27: Correlation between the variable factors for leaf miner in rabi season

Variable	Leaf miner	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Leaf miner	1	-.416**	-.538**	-.500**	-.521**	-.176*	-.350**	-.242**
Tmax	-.416**	1	.822**	.955**	.913**	-0.085	0.114	.246**
Tmin	-.538**	.822**	1	.954**	.983**	.295**	.561**	.531**
Tday	-.500**	.955**	.954**	1	.993**	0.109	.353**	.407**
Tday	-.521**	.913**	.983**	.993**	1	.185*	.440**	.461**
RHmax	-.176*	-0.085	.295**	0.109	.185*	1	.391**	.281**
RHmin	-.350**	0.114	.561**	.353**	.440**	.391**	1	.600**
RF	-.242**	.246**	.531**	.407**	.461**	.281**	.600**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

4.3.1.1.2 Principal component analysis (PCA)

For the beginning of the analysis a testing step is necessary in order to determine the suitability of data for such a method. In this respect, Kaiser-Meyer- Olkin Measure of Sampling Adequacy (KMO) and Bartlett's Test of Sphericity was conducted. The KMO index ranges from 0 to 1 and the sample is considered suitable for PCA if this index is equal or higher than 0.50. Also, the Bartlett's Test of Sphericity should be significant ($p<0.05$).

The results presented in Table 28, showed that KMO index was observed to be 0.655 while that of Bartlett's test of sphericity was found to be significant ($p<0.05$). Therefore, the data used for the study was adequate for PCA.

Table 28: KMO Statistics for Sampling Adequate and Bartlett's Test for Homogeneity for leaf miner in rabi season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.655
Bartlett's Test of Sphericity	Approx. Chi-Square	3971.933
	df	21
	Sig.	0.000

After these two tests, the number of factors or principal components that should be retained in the model had to be decided. Every component has an eigenvalue which represents the amount of variance that is accounted for by a given component. Usually the first variables have the greatest eigenvalues. One of the most commonly used criteria for principal component selection is the Kaiser's criterion known also as eigenvalue-one criterion. According to this one only the variables with the eigenvalue greater than 1 will be retained in model.

In Table 29, we can see that only the first two components have the eigenvalue greater than 1 (i.e. the first component with 4.33 and second component with 1.54 eigenvalues). It is clearly shown that most of the variance (61.859 % of the variance) can be explained by the first principal component alone. The second principal component still bears some information (21.967 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 83.83%, so we can include in the two components in the model.

Table 29: Total Variance Explained for leaf miner in rabi season

Component	Initial Eigen values		
	Total	% of Variance	Cumulative %
1	4.330	61.859	61.859
2	1.538	21.967	83.826
3	0.702	10.026	93.852
4	0.394	5.622	99.474
5	0.037	0.526	100.000
6	6.243E-07	8.918E-06	100.000
7	1.642E-07	2.346E-06	100.000

In order to make the interpretation of the meaning of every factor the variables that have the greatest loadings on a factor are analysed in terms of their similarity regarding the measured construct. From the component matrix results presented in Table 30, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum and minimum relative humidity.

Table 30: Component Matrix for leaf miner in rabi season

Variables	Component	
	1	2
T max	0.845	-0.512
T min	0.989	-0.004
T day	0.960	-0.271
T night	0.982	-0.167
RH max	0.269	0.704
RH min	0.566	0.650
RF	0.598	0.507

Since the first two principal components explained over 83% of the variance in the data, we used PC1 and PC2 to construct our model and exclude the remaining PC's.

4.3.1.1.3 Multinomial logistic regression modelling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 31). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 336.760. The final log likelihood value obtained for the model by considering all independent variables is 276.767. The chi-square value obtained is 59.993. As the p-value obtained is below 0.05, we can conclude that the final model explained a significant relationship between the dependent variable and the set of independent variables.

Table 31: Model Fitting Information for leaf miner in rabi season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	336.760			
Final	276.767	59.993	6	0.000

For the modelling purpose, the dependent variables for this study i.e. leaf miner population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 live mine, 1 = 0.1 - 0.9 live mine, 2 = 1.0 - 1.9 live mines and lastly 3 = > 2 live mines and the reference or base category was chosen as 0.

Table 32. Parameter Estimates for leaf miner in rabi season

Leafminer[a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	0.832			
	Z1	-1.184	0.306	0.151	0.619
	Z2	0.311	1.365	0.742	2.511
2.00	Intercept	1.249			
	Z1	-2.107	0.122	0.055	0.270
	Z2	0.514	1.672	0.882	3.170
3.00	Intercept	0.181			
	Z1	-2.635	0.072	0.025	0.208
	Z2	0.128	1.137	0.529	2.444

a. The reference category is: .00.

The multinomial logistic regression model used is generally effective where the dependent variable is composed of a polytomous category having multiple choices. The basic concept was generalized from binary logistic regression (Aldrich and Nelson, 1984, Hosmer and Lemeshow, 2000). In a multinomial logistic regression model, the estimates for the parameter can be identified compared to a baseline category (Long, 1997). The multinomial logistic regression model with a baseline category used to identify the relationships between dependent variable (pest incidence) and independent variables (weather variables) would be expressed as follows (Hyun and Ditton, 2007);

$\ln(p/1\text{-}p) = \beta o + \beta i\ Zi$,

where, p = the probability of leaf miner incidence;

(p/1-p) = odds of leaf miner incidence;

βo = constant;

βi = parameter estimate for the ith independent variable;

Zi = vector of ith independent predictor variables.

Thus, from the parameters obtained in the Table 32, three parts labelled with outcome variable designation corresponded to three equations shown below as fitted model for the logistic regression;

$$\text{Log}\,[P(1)/P(0)] = \beta_{10} + \beta_{11} Z_1 + \beta_{12} Z_2$$

$$\text{Log}\,[P(1)/P(0)] = 0.832 + (-1.184)\, Z_1 + (0.311)\, Z_2 \qquad \text{……….} \ (1)$$

$$\text{Log}\,[P(2)/P(0)] = \beta_{20} + \beta_{21} Z_{21} + \beta_{22} Z_{22}$$

$$\text{Log}\,[P(2)/P(0)] = 1.249 + (-2.107)\, Z_1 + (0.514)\, Z_2 \qquad \text{……….} \ (2)$$

$$\text{Log}\,[P(3)/P(0)] = \beta_{30} + \beta_{31} Z_{31} + \beta_{33} Z_{32}$$

$$\text{Log}\,[P(3)/P(0)] = 0.181 + (-2.635)\, Z_1 + (0.128)\, Z_2 \qquad \text{……….} \ (3)$$

Using the equations 1, 2 and 3 from the above, the probability of leaf miner incidence was predicted for leaf miner population and 10% of the entire data set i.e. 2017-18 was validated and the outcome revealed 50% success (Table 33).

Table 33: Predicted and observed population of leaf miner in *rabi* season 2017-18

SMW	Predicted category	Observed category	Predicted population range	Observed population
44	0	0	0	0
45	0	1	0	0.12
46	1	1	0.1 - 0.9	0.48
47	2	1	1.0 - 1.9	0.44
48	2	1	1.0 - 1.9	0.36
49	2	1	1.0 - 1.9	0.44
50	2	1	1.0 - 1.9	0.36
51	2	1	1.0 - 1.9	0.36
52	2	1	1.0 - 1.9	0.76
1	2	1	1.0 - 1.9	0.88
2	2	2	1.0 - 1.9	1.2
3	2	2	1.0 - 1.9	1.32
4	2	2	1.0 - 1.9	1.36
5	2	2	1.0 - 1.9	1.4
6	2	2	1.0 - 1.9	1.48
7	2	2	1.0 - 1.9	1.52

4.3.1.2 Weather variables-based regression model for leaf miner, *L. trifolii* in summer season

4.3.1.2.1 Correlation Matrix

The results of the correlation analysis is presented in the Table 34. It reveals that significant correlation or multicollinearity was found between most of the variables (<0.1). The variable selected for the study therefore, could not be treated as independent variables for the purpose of research. Hence, principal component analysis was further carried.

Table 34: Correlation between the factors for leaf miner in summer season

Variable	Leaf miner	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Leaf miner	1	.580**	.597**	.608**	.609**	0.084	0.012	0.144
Tmax	.580**	1	.871**	.971**	.942**	-0.183	-0.177	0.057
Tmin	.597**	.871**	1	.963**	.986**	0.068	.238*	.224*
Tday	.608**	.971**	.963**	1	.995**	-0.068	0.018	0.140
Tday	.609**	.942**	.986**	.995**	1	-0.016	0.102	0.174
RHmax	0.084	-0.183	0.068	-0.068	-0.016	1	.438**	.242*
RHmin	0.012	-0.177	.238*	0.018	0.102	.438**	1	.503**
RF	0.144	0.057	.224*	0.140	0.174	.242*	.503**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.3.1.2.2 Principal component analysis (PCA)

Kaiser-Meyer- Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity was conducted (Table 35). The KMO index was 0.651 and the Bartlett's Test of Sphericity showed p-value of 0.00 which was significant at <0.05% level. Hence, the data used for the study was adequate for PCA.

Table 35: KMO Statistics for Sampling Adequate and Bartlett's Test for leaf miner in summer season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.651
Bartlett's Test of Sphericity	Approx. Chi-Square	3446.490
	Df	21
	Sig.	0.000

In Table 36, it could be observed that only the first two components have eigenvalue greater than 1 (i.e. PC 1 with 3.903 and PC 2 with 1.858 eigenvalues). It was clearly shown that most of the variance (61.859 % of the variance) could be explained by the PC 1 alone, while PC 2 also showed some information (26.536 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 82.299 %, so we can include the two components in the model.

Table 36: Total Variance Explained for leaf miner in summer season

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3.903	55.762	55.762
2	1.858	26.536	82.299
3	0.739	10.559	92.858
4	0.463	6.616	99.475
5	0.037	0.525	100.000
6	5.141E-07	7.344E-06	100.000
7	2.079E-07	2.971E-06	100.000

From the component matrix results presented in Table 37, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum and minimum relative humidity and rainfall.

Table 37: Component Matrix for leaf miner in summer season

Variables	Component	
	1	2
Tmax	0.950	-0.259
Tmin	0.978	0.123
Tday	0.996	-0.083
Tnight	0.998	-0.005
RHmax	-0.033	0.715
RHmin	0.096	0.867
RF	0.216	0.711

4.3.1.2.3 Multinomial logistic regression modelling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 38). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 227.171. The final log likelihood value obtained for the model by considering all independent variables is 167.892. The chi-square value obtained is 59.279. As the p-value obtained is below 0.05, we can infer that the final model depicted a significant relationship between the dependent variable and the set of independent variables.

Table 38: Model Fitting Information for leaf miner in summer season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	227.171			
Final	167.892	59.279	6	0.000

The dependent variables for this study i.e. leaf miner population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 live mine, 1 = 0.1 - 0.9 live mine, 2 = 1.0 - 1.9 live mines and lastly 3 = > 2 live mines. For the modelling purpose, the reference or base category was chosen as 0.

Table 39: Parameter Estimates for leaf miner in summer season

Leafminer[a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	2.354			
	Z1	1.391	4.018	0.908	17.789
	Z2	-1.238	0.290	0.064	1.307
2.00	Intercept	3.712			
	Z1	2.166	8.725	2.030	37.494
	Z2	-1.003	0.367	0.091	1.470
3.00	Intercept	4.712			
	Z1	3.255	25.914	5.636	119.152
	Z2	-0.770	0.463	0.117	1.826

a. The reference category is: 0.00.

Thus, the variable shown in the Table 39, has three parts labelled with outcome variable designation. This corresponded to three equations shown below as fitted model for logistic regression;

$$\text{Log}\,[P(1)/P(0)] = 2.354 + (1.391)\,Z_1 + (-1.238)\,Z_2 \qquad \text{……….} (1)$$

$$\text{Log}\,[P(2)/P(0)] = 3.712 + (2.166)\,Z_1 + (-1.003)\,Z_2 \qquad \text{……….} (2)$$

$$\text{Log}\,[P(3)/P(0)] = 4.712 + (3.255)\,Z_1 + (-0.770)\,Z_2 \qquad \text{……….} (3)$$

Where, the multinomial probability of P(1) over P(0) is given by equation 1, probability of P(2) over P(0) by equation 2 and probability of P(3) over P(0) by equation 3. Using these equations, the probability of predicting leaf miner incidence was validated for leaf miner population set in 2017-18 and the outcome revealed 73.33% success (Table 40).

Table 40: Predicted and observed population of leaf miner in summer season 2018

SMW	Predicted category	Observed category	Predicted population (range)	Observed population
5	0	0	0	0
6	2	2	1.0 - 1.9	1.28
7	2	3	1.0 - 1.9	2.12
8	3	3	> 2	3
9	3	3	> 2	3.84
10	3	3	> 2	4.48
11	3	3	> 2	5.12
12	3	3	> 2	4.08
13	3	3	> 2	3.52
14	3	3	> 2	3
15	3	3	> 2	2.56
16	3	3	> 2	2.32
17	3	2	> 2	1.8
18	3	2	> 2	1.68
19	3	2	> 2	1.32

4.3.1.3 Weather variables-based regression model for *S. litura* in rabi season

4.3.1.3.1 Correlation Matrix

A correlation analysis between the variables was performed and the result of the analysis is given in the Table 41. It was revealed that significant correlation or multicollinearity was found between most of the variables (<0.1). The variables selected for the study were therefore subjected to principal component analysis to remove the multicollinearity among the variables.

Table 41: correlation between the factors for *S. litura* in rabi season

Variable	Y	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Y	1	0.019	0.163	0.095	0.123	.236**	0.038	0.149
Tmax	0.019	1	.822**	.955**	.913**	-0.085	0.114	.246**
Tmin	0.163	.822**	1	.954**	.983**	.295**	.561**	.531**
Tday	0.095	.955**	.954**	1	.993**	0.109	.353**	.407**
Tday	0.123	.913**	.983**	.993**	1	.185*	.440**	.461**
RHmax	.236**	-0.085	.295**	0.109	.185*	1	.391**	.281**
RHmin	0.038	0.114	.561**	.353**	.440**	.391**	1	.600**
RF	0.149	.246**	.531**	.407**	.461**	.281**	.600**	1

4.3.1.3.2 Principal component analysis (PCA)

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity was conducted (Table 42). The KMO index was 0.655 and the Bartlett's Test of Sphericity showed p-value of 0.00 which was significant at <0.05% level.

Table 42: KMO and Bartlett's Test for *S. litura* in rabi season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**0.655**
Bartlett's Test of Sphericity	Approx. Chi-Square	3971.933
	df	21
	Sig.	0.000

In Table 43, it could be observed that only the first two components have eigenvalue greater than 1 (i.e. PC 1 with 3.903 and PC 2 with 1.858 eigenvalues). It was clearly shown that most of the variance (61.859 % of the variance) could be explained by the PC 1 alone, while PC 2 also showed some information (26.536 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 82.299 %, so we can include the two components in the model.

Table 43: Total Variance Explained for *S. litura* in rabi season

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	4.330	61.859	61.859
2	1.538	21.967	83.826
3	0.702	10.026	93.852
4	0.394	5.622	99.474
5	0.037	0.526	100.000
6	6.243E-07	8.918E-06	100.000
7	1.642E-07	2.346E-06	100.000

From the component matrix results presented in Table 44, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum & minimum relative humidity and rainfall.

Table 44: Component Matrix for *S. litura* in rabi season

Variables	Component	
	1	2
Tmax	0.845	-0.512
Tmin	0.989	-0.004
Tday	0.960	-0.271
Tday	0.982	-0.167
RHmax	0.269	0.704
RHmin	0.566	0.650
RF	0.598	0.507

4.3.1.3.3 Multinomial logistic regression modelling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 45). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 342.76. The final log likelihood value obtained for the model by considering all independent variables is 294.77. The chi-square value obtained is 59.99. As the p-value obtained is below 0.05, we can deduce that the final model showed a significant relationship between the dependent variable and the set of independent variables.

Table 45: Model Fitting Information for *S. litura* in rabi season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	294.850			
Final	275.641	19.208	6	0.004

The dependent variables for this study i.e. *S. litura* population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 larva, 1 = 0.01 - 0.9 larvae, 2 = 1.0 - 1.9 larvae and lastly 3 = > 2 larvae.

Table 46: Parameter Estimates for *S. litura* in rabi season

S. litura [a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	0.805			
	Z1	-0.693	0.500	0.309	0.810
	Z2	-0.051	0.951	0.593	1.524
2.00	Intercept	-1.423			
	Z1	0.274	1.315	0.595	2.909
	Z2	-0.536	0.585	0.251	1.363
3.00	Intercept	-0.323			
	Z1	-0.068	0.934	0.555	1.572
	Z2	0.396	1.485	0.861	2.564
a. The reference category is: .00.					

Thus, the variable shown in the Table 46, has three parts labelled with outcome variable designation. This corresponded to three equations shown below as fitted model for logistic regression;

$$\text{Log}\,[P(1)/P(0)] = 0.805 + (-0.693)\, Z_1 + (-0.051)\, Z_2 \qquad \ldots\ldots\ldots\ (1)$$

$$\text{Log}\,[P(2)/P(0)] = -1.423 + (0.274)\, Z_1 + (-0.536)\, Z_2 \qquad \ldots\ldots\ldots\ (2)$$

$$\text{Log}\,[P(3)/P(0)] = -0.323 + (-0.068)\, Z_1 + (0.396)\, Z_2 \qquad \ldots\ldots\ldots\ (3)$$

Where, the multinomial probability of P(1) over P(0) is given by equation 1, probability of P(2) over P(0) by equation 2 and probability of P(3) over P(0) by equation 3. Using these equations, the probability of predicting leaf miner incidence was validated for data set collected in 2017-18 *for S. litura* population set and the outcome revealed 93.75% success (Table 47).

Table 47: Predicted and observed population of *S. litura* in rabi season 2017-18

SMW	Predicted category	Observed category	Predicted population range	Observed population
44	1	0	0.01 - 0.9	0
45	1	1	0.01 - 0.9	0.04
46	1	1	0.01 - 0.9	0.12
47	1	1	0.01 - 0.9	0.12
48	1	1	0.01 - 0.9	0.16
49	1	1	0.01 - 0.9	0.2
50	1	1	0.01 - 0.9	0.24
51	1	1	0.01 - 0.9	0.4
52	1	1	0.01 - 0.9	0.32
1	1	1	0.01 - 0.9	0.32
2	1	1	0.01 - 0.9	0.2
3	1	1	0.01 - 0.9	0.36
4	1	1	0.01 - 0.9	0.4
5	1	1	0.01 - 0.9	0.44
6	1	1	0.01 - 0.9	0.4
7	1	1	0.01 - 0.9	0.44

4.3.1.4 Weather variables-based regression model for *S. litura* in summer season

4.3.1.4.1 Correlation matrix

The result of the correlation analysis is presented in the Table 48. It reveals that significant correlation or multicollinearity was found between most of the variables (<0.1). The variable selected for the study therefore, could not be treated as independent variables for the purpose of research. Hence, principal component analysis was further carried out to remove the multicollinearity among the variables.

Table 48: Correlation between the factors for *S. litura* in summer season

Variable	Y	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Y	1	.355**	.354**	.367**	.365**	-0.133	0.000	.276**
Tmax	.355**	1	.871**	.971**	.942**	-0.183	-0.177	0.057
Tmin	.354**	.871**	1	.963**	.986**	0.068	.238*	.224*
Tday	.367**	.971**	.963**	1	.995**	-0.068	0.018	0.140
Tday	.365**	.942**	.986**	.995**	1	-0.016	0.102	0.174
RHmax	-0.133	-0.183	0.068	-0.068	-0.016	1	.438**	.242*
RHmin	0.000	-0.177	.238*	0.018	0.102	.438**	1	.503**
RF	.276**	0.057	.224*	0.140	0.174	.242*	.503**	1

4.3.1.4.2 Principal component analysis (PCA)

Kaiser-Meyer- Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity was conducted (Table 49). The KMO index was 0.651 and the Bartlett's Test of Sphericity showed p-value of 0.00 which was significant at <0.05% level.

Table 49: KMO and Bartlett's Test for *S. litura* in summer season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**0.651**
Bartlett's Test of Sphericity	Approx. Chi-Square	3446.490
	df	21
	Sig.	0.000

In Table 50, we can see that only the first two components have the eigenvalue greater than 1 (i.e. the first component with 3.903 and second component with 1.858 eigenvalues). It is clearly shown that most of the variance (55.762 % of the variance) can be explained by the first principal component alone. The second principal component still bears some information (26.536 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 82.299 %, so we can include in the two components in the model.

Table 50: Total Variance Explained for *S. litura* in summer season

Component	**Initial Eigenvalues**		
	Total	**% of Variance**	**Cumulative %**
1	3.903	55.762	55.762
2	1.858	26.536	82.299
3	0.739	10.559	92.858
4	0.463	6.616	99.475
5	0.037	0.525	100.000
6	5.141E-07	7.344E-06	100.000
7	2.079E-07	2.971E-06	100.000

From the component matrix results presented in Table 51, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum & minimum relative humidity and rainfall.

Table 51: Component Matrix for *S. litura* in summer season

Variables	Component	
	1	2
Tmax	0.950	-0.259
Tmin	0.978	0.123
Tday	0.996	-0.083
Tday	0.998	-0.005
RHmax	-0.033	0.715
RHmin	0.096	0.867
RF	0.216	0.711

4.3.1.4.3 Multinomial logistic regression modelling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 52). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 215.150. The final log likelihood value obtained for the model by considering all independent variables is 179.874. The chi-square value obtained is 35.276. As the p-value obtained is below 0.05, we can gather that the final model elucidated a significant relationship between the dependent variable and the set of independent variables.

Table 52: Model Fitting Information for *S. litura* in summer season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	215.150			
Final	179.874	35.276	6	0.000

The dependent variables for this study i.e. *S. litura* population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 larva, 1 = 0.01 - 0.9 larvae, 2 = 1.0 - 1.9 larvae and lastly 3 = > 2 larvae.

Table 53: Parameter Estimates for *S. litura* in summer season

S. litura[a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	4.111			
	Z1	2.075	7.965	2.627	24.154
	Z2	-1.083	0.339	0.110	1.042
2.00	Intercept	3.094			
	Z1	2.193	8.966	2.763	29.093
	Z2	-0.967	0.380	0.119	1.214
3.00	Intercept	0.660			
	Z1	3.518	33.710	3.450	329.420
	Z2	-0.553	0.575	0.149	2.221

a. The reference category is: .00.

Thus, the variable shown in the Table 53, has three parts labelled with outcome variable designation. This corresponded to three equations shown below as fitted model for logistic regression;

$$\text{Log}\,[P(1)/P(0)] = 4.111 + (2.075)\,Z_1 + (-1.083)\,Z_2 \qquad \ldots\ldots\ldots\ (1)$$

$$\text{Log}\,[P(2)/P(0)] = 3.094 + (2.193)\,Z_1 + (-0.967)\,Z_2 \qquad \ldots\ldots\ldots\ (2)$$

$$\text{Log}\,[P(3)/P(0)] = 0.660 + (3.518)\,Z_1 + (-0.553)\,Z_2 \qquad \ldots\ldots\ldots\ (3)$$

Where, the multinomial probability of P(1) over P(0) is given by equation 1, probability of P(2) over P(0) by equation 2 and probability of P(3) over P(0) by equation 3. Using these equations, the probability of predicting *S. litura* incidence for 2017-18 was validated and the outcome revealed 93.33 % success (Table 54).

Table 54: Predicted and observed population of *S. litura* in summer season 2018

SMW	Predicted category	Observed category	Predicted population (range)	Observed population
5	1	0	0.01 - 0.9	0
6	1	1	0.01 - 0.9	0.04
7	1	1	0.01 - 0.9	0.08
8	1	1	0.01 - 0.9	0.48
9	1	1	0.01 - 0.9	0.32
10	1	1	0.01 - 0.9	0.48
11	1	1	0.01 - 0.9	0.72
12	1	1	0.01 - 0.9	0.88
13	1	1	0.01 - 0.9	0.6
14	1	1	0.01 - 0.9	0.44
15	1	1	0.01 - 0.9	0.32
16	1	1	0.01 - 0.9	0.24
17	1	1	0.01 - 0.9	0.36
18	1	1	0.01 - 0.9	0.32
19	1	1	0.01 - 0.9	0.48

4.3.1.5 Weather variables-based regression model for *H. armigera* in rabi season

4.3.1.5.1 Correlation matrix

The results of the correlation analysis is presented in the Table 55. It reveals that significant correlation or multicollinearity was found between most of the variables (<0.1). The variables selected for the study therefore, could not be treated as independent variables for the purpose of research. Hence, principal component analysis was further carried out to remove the multicollinearity among the variables.

Table 55: Correlation between the factors for *H. armigera* in rabi season

Variable	Y	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Tmax	1	-.427**	-.317**	-.389**	-.365**	.196*	-0.139	-0.070
Tmin	-.427**	1	.822**	.955**	.913**	-0.085	0.114	.246**
Tday	-.317**	.822**	1	.954**	.983**	.295**	.561**	.531**
Tday	-.389**	.955**	.954**	1	.993**	0.109	.353**	.407**
RHmax	-.365**	.913**	.983**	.993**	1	.185*	.440**	.461**
RHmin	.196*	-0.085	.295**	0.109	.185*	1	.391**	.281**
RF	-0.139	0.114	.561**	.353**	.440**	.391**	1	.600**
Tmax	-0.070	.246**	.531**	.407**	.461**	.281**	.600**	1

4.3.1.5.2 Principal component analysis (PCA)

Kaiser-Meyer- Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity was conducted (Table 56). The KMO index was 0.655 and the Bartlett's Test of Sphericity showed p-value of 0.00 which was significant at <0.05% level.

Table 56: KMO and Bartlett's Test for *H. armigera* in rabi season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**0.655**
Bartlett's Test of Sphericity	Approx. Chi-Square	3971.933
	df	21
	Sig.	0.000

In Table 57, we can see that only the first two components have the eigenvalue greater than 1 (i.e. the first component with 4.330 and second component with 1.538 eigenvalues). It is clearly shown that most of the variance (61.859 % of the variance) can be explained by the first principal component alone. The second principal component still bears some information (21.967 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 83.826%, so we can include in the two components in the model.

Table 57: Total Variance Explained for *H. armigera* in rabi season

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	4.330	61.859	61.859
2	1.538	21.967	83.826
3	0.702	10.026	93.852
4	0.394	5.622	99.474
5	0.037	0.526	100.000
6	6.243E-07	8.918E-06	100.000
7	1.642E-07	2.346E-06	100.000

From the component matrix results presented in Table 58, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum & minimum relative humidity and rainfall.

Table 58: Component Matrix for *H. armigera* in rabi season

Variables	Component	
	1	2
Tmax	0.845	-0.512
Tmin	0.989	-0.004
Tday	0.960	-0.271
Tday	0.982	-0.167
RHmax	0.269	0.704
RHmin	0.566	0.650
RF	0.598	0.507

4.3.1.5.3 Multinomial logistic regression modeling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 59). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 221.951. The final log likelihood value obtained for the model by considering all independent variables is 160.889. The chi-square value obtained is 61.062. As the p-value obtained is below 0.05, we can conclude that the final model explained a significant relationship between the dependent variable and the set of independent variables.

Table 59: Model Fitting Information for *H. armigera* in rabi season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	221.951			
Final	160.889	61.062	4	0.000

The dependent variables for this study i.e. *H. armigera* population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 larva, 1 = 0.01 - 0.9 larvae and lastly 2 = > 1 larvae.

Table 60: Parameter Estimates for *H. armigera* in rabi season

H. armigera[a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	0.343			
	Z1	-1.786	0.168	0.089	0.317
	Z2	0.742	2.101	1.237	3.569
2.00	Intercept	-1.675			
	Z1	-1.156	0.315	0.134	0.740
	Z2	1.158	3.184	1.445	7.016
a. The reference category is: .00.					

Thus, the variable shown in the Table 60, has three parts labelled with outcome variable designation. This corresponded to three equations shown below as fitted model for logistic regression;

Log [P(1)/P(0)] = 0.343 + (-1.786) Z_1 + (0.742) Z_2 ………. (1)

Log [P(2)/P(0)] = -1.675 + (-1.156) Z_1 + (1.158) Z_2 ………. (2)

Where, the multinomial probability of P(1) over P(0) is given by equation 1, probability of P(2) over P(0) by equation 2 and probability of P(3) over P(0) by equation 3. Using these equations, the probability of predicting *H. armigera* incidence was validated for 2017-18 and the outcome revealed a significant 81.25% success (Table 61).

Table 61: Predicted and observed population of *H. armigera* in rabi season 2017-18

SMW	Predicted category	Observed category	Predicted population range	Observed population
44	0	0	0	0
45	0	1	0	0.08
46	0	1	0	0.04
47	1	1	0.01 - 0.9	0.08
48	1	1	0.01 - 0.9	0.16
49	1	1	0.01 - 0.9	0.16
50	1	1	0.01 - 0.9	0.16
51	1	1	0.01 - 0.9	0.2
52	1	1	0.01 - 0.9	0.24
1	1	1	0.01 - 0.9	0.2
2	1	1	0.01 - 0.9	0.16
3	1	1	0.01 - 0.9	0.24
4	1	1	0.01 - 0.9	0.32
5	1	1	0.01 - 0.9	0.24
6	0	1	0	0.36
7	1	1	0.01 - 0.9	0.4

4.3.1.6 Weather variables-based regression model for *H. armigera* in summer season

4.3.1.6.1 Correlation Matrix

The result of the correlation analysis is presented in the Table 62. It reveals that significant correlation or multicollinearity was found between most of the variables (<0.1). The variable selected for the study therefore, could not be treated as independent variables for the purpose of research. Hence, principal component analysis was further carried out to remove the multicollinearity among the variables.

Table 62: Correlation between the factors for *H. armigera* in summer season

Variable	Y	Tmax	Tmin	Tday	Tnight	RHmax	RHmin	RF
Y	1	.321**	.487**	.413**	.445**	0.095	.354**	.389**
Tmax	.321**	1	.869**	.971**	.941**	-0.173	-0.177	0.054
Tmin	.487**	.869**	1	.962**	.985**	0.079	.241*	.223*
Tday	.413**	.971**	.962**	1	.995**	-0.057	0.020	0.138
Tday	.445**	.941**	.985**	.995**	1	-0.005	0.104	0.172
RHmax	0.095	-0.173	0.079	-0.057	-0.005	1	.439**	.246**
RHmin	.354**	-0.177	.241*	0.020	0.104	.439**	1	.504**
RF	.389**	0.054	.223*	0.138	0.172	.246**	.504**	1

4.3.1.6.2 Principal component analysis (PCA)

Kaiser-Meyer- Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity was conducted (Table 63). The KMO index was 0.651 and the Bartlett's Test of Sphericity showed p-value of 0.00 which was significant at <0.05% level. Therefore, the study was adequate for PCA.

Table 63: KMO and Bartlett's Test for *H. armigera* in summer season

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.651
Bartlett's Test of Sphericity	Approx. Chi-Square	3409.773
	df	21
	Sig.	0.000

In Table 64, it is revealed that only the first two components have the eigenvalue greater than 1 (i.e. the first component with 3.9 and second component with 1.86 eigenvalues). It is clearly shown that most of the variance (55.721 % of the variance) can be explained by the first principal component alone. The second principal component still bears some information (26.568 %) while the third and fourth principal components can safely be dropped without losing to much information. Together, the cumulative percent of variance explained by the first two components accounts for 82.289 %, so we can include in the two components in the model.

Table 64: Total Variance Explained for *H. armigera* in summer season

Component	Initial Eigenvalues		
	Total	**% of Variance**	**Cumulative %**
1	3.900	55.721	55.721
2	1.860	26.568	82.289
3	0.738	10.550	92.839
4	0.464	6.629	99.468
5	0.037	0.532	100.000
6	5.214E-07	7.448E-06	100.000
7	2.108E-07	3.012E-06	100.000

From the component matrix results presented in Table 65, the coefficients specify the linear function of the observed variables that define each component was revealed. The first component has a high positive correlation with maximum temperature, minimum temperature, day temperature and night temperature. While, the second component has positive correlation with maximum & minimum relative humidity and rainfall.

Table 65: Component Matrix for *H. armigera* in summer season

Variables	Component	
	1	2
Tmax	0.949	-0.264
Tmin	0.978	0.120
Tday	0.996	-0.087
Tday	0.998	-0.009
RHmax	-0.018	0.715
RHmin	0.101	0.866
RF	0.215	0.711

4.3.1.6.3 Multinomial logistic regression modelling

The overall effectiveness of the model was assessed using the Chi-square statistic (Table 66). The model fitting information revealed that the initial log likelihood value obtained for the model with no independent variables (intercept only model) is 202.069. The final log likelihood value obtained for the model by considering all independent variables is 135.680. The chi-square value obtained is 66.390. As the p-value obtained is below 0.05, we can deduce that the final model showed a significant relationship between the dependent variable and the set of independent variables.

Table 66: Model Fitting Information for *H. armigera* in summer season

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	202.069			
Final	135.680	66.390	4	0.000

The dependent variables for this study i.e. *H. armigera* population infesting tomato categorised into four groups based on their infestation levels viz, 0 = 0 larva, 1 = 0.01 - 0.9 larvae and lastly 2 = > 1 larvae.

Table 67: Parameter Estimates for *H. armigera* in summer season

H. armigera[a]		B	Exp(B)	95% Confidence Interval for Exp(B)	
				Lower Bound	Upper Bound
1.00	Intercept	0.118			
	Z1	1.922	6.833	3.223	14.487
	Z2	0.470	1.600	0.901	2.840
2.00	Intercept	-2.693			
	Z1	2.774	16.016	2.289	112.067
	Z2	1.471	4.356	1.786	10.621

a. The reference category is: .00.

Thus, the variable shown in the Table 67, has three parts labelled with outcome variable designation. This corresponded to three equations shown below as fitted model for logistic regression;

$$\text{Log } [P(1)/P(0)] = 0.118 + (1.922) Z_{1} + (0.470) Z_{2} \quad \text{………. (1)}$$

$$\text{Log } [P(2)/P(0)] = -2.693 + (2.774) Z_{1} + (1.471) Z_{2} \quad \text{………. (2)}$$

Where, the multinomial probability of P(1) over P(0) is given by equation 1, probability of P(2) over P(0) by equation 2 and probability of P(3) over P(0) by equation 3. Using these equations, the probability of predicting *H. armigera* incidence in 2017-18 and the outcome revealed 76.04% success (Table 68).

Table 68: Predicted and observed population of *H. armigera* in summer season 2018

SMW	Predicted category	Observed category	Predicted population (range)	Observed population
5	0	0	0	0
6	0	0	0	0
7	0	1	0	0.04
8	0	1	0	0.08
9	0	1	0	0.08
10	0	1	0	0.12
11	0	1	0	0.08
12	1	1	0.01 - 0.9	0.08
13	1	1	0.01 - 0.9	0.12
14	1	1	0.01 - 0.9	0.2
15	1	1	0.01 - 0.9	0.28
16	1	1	0.01 - 0.9	0.2
17	1	1	0.01 - 0.9	0.24
18	1	1	0.01 - 0.9	0.28
19	1	1	0.01 - 0.9	0.32

4.4.1 To develop a management module of leaf miner and other important insect pests of tomato with botanicals and bio-rational pesticides.

Field experiment was conducted at C-Block Farm of BCKV, Kalyani, West Bengal for two consecutive tomato cropping seasons during 2016-17 and 2017-18 to study the effectiveness of some botanicals and bio-rational insecticides against the insect pests of tomato and their impact on natural enemies. All treatments except control received seed treatment with Thiamethoxam 70% WS @ 3g/kg. Pre-count observations on insect population were taken one day before spray. Post spray observations were recorded at 45 and 60 days after transplanting with an interval of 7 and 14 days after spraying. The results of the insecticide spraying are discussed below.

4.4.1.1 Relative efficacy of different treatment schedules for management of leaf miner, *L. trifolii* population

The data pertaining to the effect of different treatment schedules against leaf miner revealed that all insecticides significantly reduced the leaf miner population on tomato throughout the experimental period and were significantly superior over control (Table 69). In the year 2016-17, the initial infestation of *L. trifolii* per five leaves as recorded one day before spraying of insecticides ranged from 3.83 to 4.54 live mines in different plots and there was no significant difference between them. Among the treatments, Emamectin benzoate was found to be the most effective over rest of the treatments with a mean of 2.22 live mines per five leaves. This was followed by Novaluron + Indoxacarb with 2.45 live mines, NSKE (2.70 live mines), *Beauveria bassiana* (2.95 live mines), *Bacillus thuringiensis* (3.01 live mines) and Azadirachtin (3.09 live mines) as compared to untreated control (4.14 live mines).

Similarly, in 2017-18 during the second year of study, it was observed that all the treatment schedules significantly reduced the leaf miner population on tomato (Table 70). The mean infestation of leaf miner per five leaves as observed one day before spray ranged from 5.10 to 6.25 live mines and showed no significant variation among the treatments. The most effective treatment also turned out to be Emamectin benzoate which exhibited lowest leaf miner infestation i.e. 2.67 lives mines of per five leaves. This was followed by Novaluron + Indoxacarb with 2.80 live mines. Other treatments like NSKE, *Beauveria bassiana*, *Bacillus thuringiensis* and Azadirachtin recorded 3.11, 3.55, 3.63 and 3.75 live mines respectively while in untreated control infestation observed was 4.25 live mines.

These findings are in accordance with Tarate *et al*. (2016) who reported that efficacy of emamectin benzoate 5 SG @ 9.5 g a.i/ha was most effective against leaf miner, *L. trifolii* Burgess. Ishida *et al*. (2002) also opined that emamectin benzoate showed a rapid action against the leaf miner with 100% mortality even a-day after application in laboratory condition at yokohama in Japan. The findings by Patel *et al*.

(2012), Devi *et al.* (2014) and Tarate *et al*. (2016) were also in agreement with the present results as they pointed out that emamectin benzoate was highly effective in controlling tomato leaf miner.

4.4.1.2 Relative efficacy of different treatment schedules for management of whitefly population

Perusal of the data regarding the effect of different treatment schedules against whitefly showed that all insecticides significantly reduced the population throughout the experimental period (Table 71). In the year 2016-17, the initial whitefly population per five leaves as recorded one day before spraying of insecticides ranged from 4.35 to 5.67 in different plots and there was no significant difference between them. Among the treatments, Novaluron + Indoxacarb was found to be the most effective over rest of the treatments with an overall lowest whitefly population of 1.91. The next best treatment was observed in Emamectin benzoate treated plot with 2.02 whitefly population which was closely followed by NSKE with 2.08whitefly population. In treatments with *Beauveria bassiana, Bacillus thuringiensis* and Azadirachtin whitefly population recorded were 2.16, 2.25 and 2.31respectively, as compared to untreated control with highest population of 3.64 whitefly per five leaves.

Similar trend was observed during the second year of study (2017-18), where mean population of whitefly per five leaves as observed one day before spray ranged from 5.11 to 6.02 (Table 72) and showed no significant variation. All treatments were found to be significantly superior over control at 5% level. Among them Novaluron + Indoxacarb recorded the lowest whitefly population (2.10) and turn out to be the most effective treatment. This was followed by Emamectin benzoate (2.25), NSKE (2.31), *Beauveria bassiana* (2.42), *Bacillus thuringiensis* (2.55) and Azadirachtin (2.63) respectively. On the other hand, highest whitefly population was apparently recorded in untreated control with 3.58 whitefly per five leaves.

4.4.1.3 Relative efficacy of different treatment schedules for management of aphid population

The results pertaining to the effect of different treatment schedules against aphids is given in Table 73. It revealed that all the insecticides significantly reduced aphid population throughout the experimental period. During the first year of study (2016-17), the initial aphid population per five leaves was observed from 4.97 to 5.84in different treatment plots and there was no significant difference between them. Among all the treatments, Novaluron + Indoxacarb recorded the most effective with overall lowest aphid population of 2.06 per five leaves. This was followed by Emamectin benzoate treated plot with 2.19 aphids per five leaves, while NSKE, *Bacillus thuringiensis*, *Beauveria bassiana* and Azadirachtin recorded population of 2.24, 2.34, 2.45 and 2.59 aphids respectively. In untreated control plot highest mean population of 3.57 aphids was found.

During the second year of study (2017-18), again all the treatments were found to be significantly superior over control at 5% level. From the results presented in Table 74, it was revealed that the mean aphid population per five leaves as observed one day before spray ranged from 5.82 to 6.57 and showed no significant variation. Among the different treatments, Novaluron + Indoxacarb recorded the lowest aphid population (2.64) and turn out to be the most effective treatment. This was followed by Emamectin benzoate (2.73), NSKE (2.83), *Bacillus thuringiensis* (2.92), *Beauveria bassiana* (3.00) and Azadirachtin (3.08) respectively, as compared to untreated control plot with highest aphid population of 4.21.

4.4.1.4 Relative efficacy of different treatment schedules for management of thrips population

Perusal of the data pertaining to the effect of different treatment schedules against thrips population were revealed in Table 75 & 76. It was observed that all the insecticides significantly reduced the thrips population on tomato throughout the experimental period. In the year 2016-17, the initial thrips population per five leaves as recorded one day before spray ranged from 3.82 to 4.37 in different plots and there was no significant difference between them (Table 75). Among the treatments, Novaluron + Indoxacarb recorded an overall lowest thrips population of 1.75 and was found to be the most effective over rest. Emamectin benzoate treated plot recorded second lowest thrips population of 1.83. While NSKE recorded 1.91 thrips population, followed by *Bacillus thuringiensis* (2.06) which was at par with *Beauveria bassiana* (2.08). Treatment with Azadirachtin recorded 2.15 as compared to untreated control (3.01) with highest thrips population.

In the year 2017-18, it was observed that mean population of thrips per 5 leaves observed one day before spray ranged from 4.23 to 5.20 (Table 76) and showed no significant variation. All the treatments were found to be significantly superior over control. Among them Novaluron + Indoxacarb recorded the lowest thrips population (1.97) and was observed to be the most effective treatment. This was followed by Emamectin benzoate (2.07), NSKE (2.17), *Beauveria bassiana* (2.33), *Bacillus thuringiensis* (2.34) and Azadirachtin (2.40) respectively, as compared to untreated control with highest infestations (3.28).

4.4.1.5 Relative efficacy of different treatment schedules for management of *S. litura* population

The efficacy of different treatment schedules was evaluated against *S. litura* on tomato for two consecutive years. Results revealed that all the insecticides significantly reduced the pest population throughout the experimental period and were significantly superior over control at 5% level. In the year 2016-17, the initial *S. litura* population per plant as recorded one day before spraying of insecticides ranged from 5.03 to 6.01 in different plots and there was no significant difference amongst them (Table 77). Among different treatments Novaluron + Indoxacarb was found to be the most effective with 2.50 mean larvae per plant followed by Emamectin benzoate (2.72), *Beauveria bassiana* (2.86), *Bacillus thuringiensis* (2.89), NSKE (2.95) and Azadirachtin (3.09) as compared to untreated control (3.92).

Similarly, in 2017-18 during the second year of study during, it was shown that all the treatment schedules significantly reduced *S. litura* population (Table 78). The mean infestation of *S. litura* larva per plant as observed one day before spray ranged from 6.25 to 7.07 and showed no significant variation among the treatments. The most effective treatment again was observed to be Novaluron + Indoxacarb which exhibited lowest *S. litura* infestation with 3.36 larva per plant, followed by Emamectin benzoate with 3.56 larvae, NSKE (3.67), *Bacillus thuringiensis* (3.70), *Beauveria bassiana* (3.81) and Azadirachtin (3.99) respectively, while in untreated control the infestation observed was highest with 4.25 larvae.

4.4.1.6 Relative efficacy of different treatment schedules for management of *H. armigera* population

The data regarding the efficacy of different treatment schedules against *H. armigera* population for two consecutive tomato cropping seasons during 2016-17 and 2017-18 are presented in Table 79 and 80, respectively. The results showed that all the insecticides were significantly effective in reducing the *H. armigera* population on tomato throughout the experimental period. In the year 2016-17, the initial pest population per plant recorded one day before spray ranged from 3.54 to 4.18 in different plots and there was no significant difference between them (Table 79). Among the treatments, Novaluron + Indoxacarb recorded an overall lowest *H. armigera* population of 1.26larvae and was found to be the most effective over the rest. Emamectin benzoate treated plot recorded second lowest with 1.40larvae per plant and was followed by *Bacillus thuringiensis* (1.51), while NSKE, *Beauveria bassiana* and Azadirachtin recorded 1.59, 1.651.80larvae respectively, as compared to untreated control (3.04) with highest *H. armigera* population.

During the second year (2017-18), it was observed that mean population of *H. armigera* per plant as recorded one day before spray ranged from 3.58 to 5.00 (Table 80) and showed no significant variation. All the treatments were found to be significantly superior over control at 5% level and among them Novaluron + Indoxacarb showed better performance was observed to be the most effective treatment recording minimum *H. armigera* population of 1.73 larvae per plant and was followed by Emamectin benzoate (1.87), *Bacillus thuringiensis* (2.07),NSKE (2.10), *Beauveria bassiana* (2.25), and Azadirachtin (2.46) respectively. While, highest infestations of was exhibited in untreated control with 3.48 larvae.

The present results are concurrently in agreement with the findings of Ghosal *et al*. (2016) who reported that novaluron 5.25%+ indoxacarb 4.5% SC at 875 and 825 ml/ha showed highest percentage of reduction of *H. armigera* population as compare to other treatments including control. This new ready mixed insecticide reduced the population of *H. armigera* up to 100% within three days after third application initially and reduced the population of *S. litura* within ten days after first application. Yogeeswarudu and Venkata Krishna (2014) in their findings concluded that novel insecticides indoxacarb and novaluron can manage *H. armigera* up to 95.83 per cent and 87.12 per cent respectively. The present results can be also justified with the findings of Das *et al*. (2015), who reported that mixed formulation of novaluron 5.25 + indoxacarb 4.5 SC recorded the most effective insecticides than that of their sole formulation against *H. armigera*. Thus, it can be concluded that the treatment novaluron 5.25%+ indoxacarb 4.5% SC @ 850 ml/ha can reduce the population of *H. armigera* and *S. litura* more efficiently than the other treatments on tomato crop.

4.4.1.7 Relative efficacy of different treatment schedules on the population of Spiders

Perusal of the data pertaining to the effect of different treatment schedules on the population of spiders were revealed in Table 81 and 82. During the first year of study (2016-17), the pre-treatment count made one day before application of insecticides showed that the population of spiders ranged from 4.22 to 5.79 per plant in different plots and there was no significant difference among them (Table 81). Among the various treatments, Azadirachtin recorded an overall highest population with 2.41 spiders per plant and was found to be relatively less harmful than the other treatments. It was closely followed by *Beauveria bassiana* (2.37), *Bacillus thuringiensis* (2.22) and NSKE (2.15). On the other hand, Emamectin benzoate and Novaluron + Indoxacarb treated plots recorded lower spider population with 1.93 and 1.81 spiders per plant. In control plot where no chemicals were imposed a highest spider population of 3.28 per plant was noted.

The population of spiders taken one day before spraying during 2017-18 ranged from 4.73 to 5.76 and showed no significant variation among the treatments (Table 82). However, in the second year of study it was observed *Beauveria bassiana* was the least harmful among all treatments and exhibited more number of spider population with 2.75 spiders per plant. *Bacillus thuringiensis* (2.65), Azadirachtin (2.56) and NSKE (2.49) also recorded higher population of spiders as compared to Emamectin benzoate (2.18) and Novaluron + Indoxacarb (2.10) treatments with lower population of spiders. In control plot where no chemicals were imposed a highest spider population of 3.52 was observed.

4.4.1.8 Relative efficacy of different treatment schedules on the population of Coccinellids

The data pertaining to the effect of different treatment schedules on the population of coccinellids are presented in Table 83 and 84. During the first year of study (2016-17), the pre-treatment count made one day before application of insecticides showed that coccinellid population ranged from 3.13 to 3.40per plant in various plots and there was no significant difference among them (Table 83). Among the treatments, Azadirachtin recorded an overall highest coccinellid population of 1.89 which was at par with *Beauveria bassiana* at 1.88 and both were relatively observed to be least harmful among all the treatments. They were closely followed by, *Bacillus thuringiensis* (1.79), NSKE (1.67), Emamectin benzoate (1.47) and Novaluron + Indoxacarb (1.41) treated plots with lower population of coccinellids. In control plot where no chemicals were imposed a highest number of coccinellid of 2.64 per plant was recorded.

The population of coccinellid taken one day before spray during 2017-18 ranged from 3.62 to 4.84 and showed no significant variation among the treatments (Table 84). During the second year of study similar observations were noted with *Beauveria bassiana* being the least harmful treatment among all the others. It recorded higher population of coccinellids with 2.43 per plant which was followed by *Bacillus thuringiensis* with 2.33 coccinellids per plant, Azadirachtin (2.19) and NSKE (2.13) respectively. Among the treatments, lower population of coccinellids were observed in Emamectin benzoate (1.86) and Novaluron + Indoxacarb (1.78) treated plots. However, as expected a highest coccinellid population of 3.04 was observed in the control plot where no chemical treatments were applied.

The present study reveals botanicals and biorational pesticides are relatively safe on natural enemies like spiders and coccinellids and among them Azadirachtin, *Beauveria bassiana* and *Bacillus thuringiensis* proved to be the safer options. The findings are more or less in corroborates with the reports of Kaethner (1999) who observed that the neem extract and and neem oil were harmless to the egg and larvae of *Chrysoperla carnea* and *Coccinella sepempunctata* and Chakraborti (2001) who also found that that the neem-based treatments like NSKE and neem oil were found safe to natural enemies during his field trial. It is also in agreement with the findings of Tiwari *et al*. (2011) that biological origin and neem-based pesticides were relatively less harmful to various natural enemies in brinjal ecosystem and by Hikal *et al*. (2017) who pointed out botanical insecticides affect only target insects, not destroy beneficial natural enemies and provide residue-free food and safe environment.

SUMMARY AND CONCLUSION

The present investigation entitled “Spatio-temporal variation of insect pests of tomato with special reference to leaf miner, *Liriomyza trifolii* (Burgess)” was carried out at experimental plot of C-Block farm, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, West Bengal. The laboratory studies were conducted in the Plant Protection Laboratory of the Department of Entomology, BCKV, West Bengal. The salient findings of the present investigations are summarized below:

Population buildup of the insect pests of tomato indicated that their initial activity varied with the prevailing weather conditions, sowing and transplanting time and stages of crop.

Leaf miner first appeared on tomato crop in rabi season from first week of October to third week of December (40^{th} to 51^{st} SMW) and in summer season from first week of February to first week of March (5^{th} to 10^{th} SMW), respectively. The peak period was observed with wide range due to variation in transplantation time in rabi season it was from third week of November to third week of February (46^{th} to 8^{th} SMW) while in summer season, it was from first week of March to second week of June (10^{th} to 23^{rd} SMW).

The infestation of aphids on tomato crop in rabi started from first week of October to third week of November (40^{th} to 47^{th} SMW) and in summer season from fourth week of January to first week of March (4^{th} to 10^{th} SMW), respectively. Thereafter, the population increased and attained its peak during the third week of November to second week of December (46^{th} to 50^{th} SMW) and in second week of March to first week of April (11^{th} to 14^{th} SMW) in rabi and summer season respectively. Then its trend was decreasing due to the ageing of crop.

Population of whitefly in rabi season first appeared on tomato crop in between second week of September to second week of November (37^{th} to 45^{th} SMW) and in summer season from last week of January to first week of March (4^{th} to 10^{th} SMW). The population of whitefly also varied in different experimental years but attained peak from second week of November to third week of November (45^{th} to 50^{th} SMW), while in summer season, peak was observed in second week of March to second week of April (11^{th} to 15^{th} SMW).

Thrips population first appeared on tomato crop both in rabi season from second week of September to last week of November (37^{th} to 48^{th} SMW) and in summer season and from first week of February to first week of March (5^{th} to 10^{th} SMW) then increased its incidence on crop. Peak was observed from third week of November to last week of December (46^{th} to 52^{nd} SMW) in rabi season and from first week of March to third week of April (10^{th} to 16^{th} SMW) and summer season, respectively.

S. litura population first appeared on tomato crop in rabi season from third week of September to third week of November (38^{th} to 46^{th} SMW) and in summer season from first week of February to first week of March (5^{th} to 10^{th} SMW). Peak was observed in rabi season from third week of November to first week of December (46^{th} to 49^{th} SMW). While, in summer season, it was from first week of March to first week of May (10^{th} to 18^{th} SMW).

H. armigera first appeared on tomato crop in rabi with wide range i.e. from third week of October to second week of January (42^{nd} to 2^{nd} SMW) and in summer season from second week of February to fourth week of April (7^{th} to 17^{th} SMW), respectively. Peak was observed from last week of November to third week of February (48^{th} to 7^{th} SMW) and from third week of April to first week of June (16^{th} to 22^{nd} SMW) in rabi and summer season, respectively.

Correlation studies with different weather parameters revealed that the weather inputs had both significant and insignificant effects on the population build-up of the various insect pests of tomato. Weather indices-based prediction models were developed using a new method of approach as suggested by Camminatiello and Lucadamo (2010) in which Principal Component Multinomial Regression (PCMR) method was used. The models were all found to be fitted for describing the insect population build-up of tomato against *Liriomyza trifolii*, *Spodoptera litura* and *Helicoverpa armigera* and among the various weather factor inputs, temperature (maximum, minimum, day and night) was observed to have the most pronounced influence on them.

The biology of leaf miner was studied on tomato under ambient laboratory condition. It had four stages of life cycle as egg, three laval instars, pupa and adult. The eggs were laid singly on the upper surface of leaf. Freshly laid eggs were oval in shape, white and translucent which turned creamy white at maturity. It measured about 0.21 ±

0.03 mm in length and 0.11 ± 0.02 in breadth. The first instar larva was apodous, transparent and minute. On an average those measured about 0.54 ± 0.07 mm in length and 0.33 ± 0.07 mm in width. The second instar larva was observed to be pale yellowish in colour and measured about 1.41 ± 0.06 mm in length and 0.5 ± 0.04 mm in width. The last and third instar larva showed distinctively yellowish colouration and measured about 2.09 ± 0.02 mm in length and 1.19 ± 0.04 mm in width. The pupa became yellow brown in colour assuming a deeper yellow brown as they matured. The pupae were measured about 1.78 ± 0.09 mm in length and 0.68 ± 0.06 mm in breadth. The length of body and wing expanse in adult males were found to be in a range of 1.46 ± 0.08 mm and 1.22 ± 0.06 mm, respectively, whereas in case of females the body length and wing expanse were found to be in the range of 1.68 ± 0.09 mm and 1.35 ± 0.07 mm, respectively.

The developmental period of different life stages was also studied in different temperature regimes of 15°C, 20°C, 25°C and 30°C. The duration of egg, larva, pupa and adult stages were longest at 15°C and shortest at 30°C. The total developmental period observed at 15°C was: ♂- 60.5 ± 1.40 days; ♀- 63.2 ± 1.46 days, while at 30°C it was: ♂-16.4 ± 0.96 days; ♀- 17.9 ± 0.98 days. At temperatures 20°C, the total life period observed was: ♂- 37.4 ± 1.22 days; ♀- 39.8 ± 1.36 days and at 25°C, it was: ♂-26.4 ± 1.12 days; ♀- 28.6 ± 1.10 days. Thus, it can be concluded that as the temperature increased, number of days required for development also gradually decreased.

Different insecticidal treatment schedules consisting of botanicals and biorationals were evaluated to develop an effective management module against the insect pests of tomato. Seven different insecticidal treatment schedules consisting of both chemical and non-chemical insecticides along with chemical seed treatment (thiamethoxam 70% WS @ 3g/kg), were evaluated against important insect pests of tomato. It had been observed all treatments significantly reduced the pest population on tomato. Emamectin benzoate 5% SG was the most effective over rest of the treatments for leaf miner while ready mix of Novaluron 5.25% + Indoxacarb 4.5% SC was the most effective over rest of the treatments for aphid, whitefly, thrips, *S. litura* and *H. armigera*. For natural enemies' population consisting of spiders and coccinellids, treatments with Azadirachtin, *Bacillus thuringiensis* and *Beauveria bassiana* recorded higher spiders' and coccinellids' population over the other treatments.

FUTURE SCOPE OF RESEARCH

- The geographical distribution maps of *Liriomyza trifolii* are an important and simple tool that can be used in educating farmers on potential invasion of *L. trifolii* and methods that they can use to ensure their crops are not attacked by the insect.
- Study can be carried out to observe if there is any transmission of plants virus by *L. trifolii* and how climate change would influence this
- Interaction between *L. trifolii* and parasitoids should be determined under different levels of temperature for understanding *Liriomyza*-predator/parasitoid relationship under change in global temperature situation. It would also be imperative to study the important natural enemies associated with other major insect pests of tomato in detail.
- Molecular diversity studies for understanding the phylogenetic relationship of *L. trifolii* of West Bengal with other parts of the country and other countries.
- Effective and sustainable management practices for the farmers to control the various insect pests of tomato should be developed so as to avoid the indiscriminate use of chemical fertilizers which would greatly harm the environment and natural balance of the ecosystem in the long run.
- Validation of the leaf miner prediction model developed in the present dissertation in the different region of the country.

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Table 7. Initiation and peak periods of leaf miner with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	41-44	49-1	46-49	6-9	50-51	5-8	42	2-4	42-45	46-49	45-46	51-1	42-46	1-8
24 PGS (N)	43-44	5-6	47-48	6-8	51	8-9	42-45	4-8	44-46	47-50	46-50	52-3	42-48	7-9
Nadia	42-45	51-3	47-50	2-6	49	6-10	41	2-4	43-44	47-49	47-48	52-1	46	4
Kalyani C block	40	46	47	5	51	8	45	6	44	5	44	51	45	7
24 PGS (N)	**Summer 2012**		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
	4-8	15-18	2-6	12-13	4-6	8-10	4-7	11-17	4 -6	12-17	3-6	10-16	2-8	10-18
Kalyani C block	5	22	10	23	6	16	10	22	7	17	6	11	6	11

Table 8. Initiation and peak periods of aphid with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	39-42	51-1	42-47	48-50	44-46	47-48	40-42	44-45	42-45	46-49	45-46	51-1	39-45	44-47
24 PGS (N)	42-43	45-7	44-46	47-50	46-47	48-4	40-45	45-47	44-46	47-50	46-50	52-3	40-45	46-52
Nadia	41-45	2-6	43-47	48-50	43-47	47-52	40-41	46	43-44	47-49	47-48	52-1	43	45
Kalyani C block	40	46	42	49	47	49	44	48	44	49	42	48	45	50
	Summer 2012		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
24 PGS (N)	4-8	15-18	2-6	12-13	4-6	8-10	4-7	11-17	4-5	8-15	2-5	10-15	2-8	7-14
Kalyani C block	4	12	10	13	5	11	8	14	6	11	6	13	6	11

Table 9. Initiation and peak periods of whitefly with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	39-42	49-52	41-44	45-47	41-43	44-46	37-38	39-44	38-44	46-49	45-46	51-1	39-46	44-49
24 PGS (N)	39-43	44	41-44	47	42-44	46-47	37-44	43-47	44-46	46-48	46-50	52-3	40-45	52
Nadia	41-44	50-3	40-45	46-49	42-46	45-52	38	44	41-42	45-47	47-48	52-1	43	44
Kalyani C block	37	46	40	45	45	47	43	48	42	46	42	48	45	50
	Summer 2012		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
24 PGS (N)	4-7	14-17	3-6	12-15	3-5	8-12	2-7	12-15	4-6	8- 15	2-6	10-15	2-8	6-12
Kalyani C block	4	15	10	14	5	11	8	15	6	12	6	13	6	9

Table 10. Initiation and peak periods of thrips with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	39-42	50-1	43-46	50	43-46	46-47	41-42	45-48	42-45	49-50	45-46	51-52	42-47	48-4
24 PGS (N)	39-44	5-7	46	50	47-48	1-5	42-44	47-48	46-47	50-51	45-50	51-3	41-47	52-1
Nadia	41-44	49-3	42-47	47-50	46-50	52-2	42	47	45-46	50-51	48	52-1	46	52
Kalyani C block	37	46	43	50	47	49	46	50	45	49	42	49	48	52
	Summer 2012		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
24 PGS (N)	4-8	13-16	2-7	12-15	5-8	11-15	4-8	12-18	4-6	9-15	3-5	9-14	2-8	6-12
Kalyani C block	5	12	10	19	7	15	9	16	7	9	6	10	6	11

Table 11. Initiation and peak periods of *S. litura* with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	40-42	51-52	41-45	44-48	42-45	46-47	38-40	42-45	39-44	46-49	45-46	50-52	39-47	42-4
24 PGS (N)	41-43	47-49	40-45	42-47	45	46-48	38-45	44-50	44-46	47	46-51	50-4	42-49	50-2
Nadia	42-46	51-4	40-46	48	43-47	46-49	38	43-44	42-44	47-49	48	52-2	46	50
Kalyani C block	38	46	41	44	46	47	45	48	43	47	44	49	45	5
24 PGS (N)	**Summer 2012**		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
	7-9	15-16	3-6	18-21	6-8	15-19	4-7	16-20	4- 7	9- 12	3-6	12-16	2-8	10-18
Kalyani C block	6	13	10	18	5	10	9	13	8	12	6	13	6	12

Table 12. Initiation and peak periods of *H. armigera* with respect to SMW

Location	Rabi 2011-12		Rabi 2012-13		Rabi 2013-14		Rabi 2014-15		Rabi 2015-16		Rabi 2016-17		Rabi 2017-18	
	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)	Pest Initiation (SMW)	Highest Peak (SMW)
Hooghly	39-42	51-1	42-47	48-50	44-46	47-48	40-42	44-45	42-45	46-49	45-46	51-1	39-46	48-8
24 PGS (N)	42-43	45-7	44-46	47-50	46-47	48-4	40-45	45-47	44-46	47-50	46-50	52-3	42-47	52-7
Nadia	41-45	2-6	43-47	48-50	43-47	47-52	40-41	46	43-44	47-49	47-48	52-1	45	5
Kalyani C block	42	48	49	3	2	5	52	3	50	52	47	1	45	7
	Summer 2012		**Summer 2013**		**Summer 2014**		**Summer 2015**		**Summer 2016**		**Summer 2017**		**Summer 2018**	
24 PGS (N)	4-8	15-18	2-6	12-13	4-6	8-10	4-7	11-17	4-5	8-15	5-8	14-17	5-9	15-18
Kalyani C block	12	17	17	22	13	17	17	20	13	16	10	20	7	19

LAYOUT OF FIELD EXPERIMENT

Table 1: List of fields covered for insect pest surveillance in *rabi* season

Sl. No.	Village	District	Location	Year						
				2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
1.	Tarinipur	Nadia	Elev: 8m, Lat: 23°01´27.1´´, Long: 88°27´56.2´´	Yes	Yes	No	No	No	No	No
2.	Madanpur	Nadia	Elev: 3m, Lat: 23°01´13´´, Long: 88°27´26´´	Yes	Yes	No	No	No	No	No
3.	Chandamari	Nadia	Elev: 4m, Lat: 3°00´12.4´´, Long: 88°27´66´´	Yes	No	No	No	No	No	No
4.	Alaipur	Nadia	Elev: 3m, Lat: 03°01′43.2’’, Long: 88°27′ 23’’	Yes	No	No	No	No	No	No
5.	Bamanpara	Nadia	Elev: 3m, Lat: 22°55´20´´, Long: 88°35´6.0´´	Yes	Yes	No	No	Yes	No	Yes
6.	Bamanberia	Nadia	Elev: 3m, Lat:23°01´43.2´´, Long: 88°27´23´´	No	Yes	Yes	No	No	No	No
7.	Basbona	Nadia	Elev: 5m, Lat:22°55´36.6´´, Lon: 88°35´3.6´´	Yes	Yes	Yes	Yes	No	No	No
8.	Dhupagachi	Nadia	Elev: 8m, Lat: 22°55’16.4’’, Long: 88°35’10.9’’	No	No	Yes	Yes	Yes	Yes	No
9.	Bihadipalli	Hooghly	Elev: 9m, Lat: 22°54´20´´, Long: 88°17´53.9´´	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10.	Duberbadi	Hooghly	Elev:13m,Lat:22°52´57.8´´, Long: 88°17´20.1´´	Yes	Yes	No	Yes	Yes	Yes	Yes
11.	Jarura	Hooghly	Elev: 4m, Lat: 23°0´12.4´´, Long: 88°27´25.6´´	No	Yes	Yes	No	No	No	No
12.	Sugandha	Hooghly	Elev: 8m, Lat:22°56´18.4´´, Long: 88°24´45.6´´	No	No	Yes	Yes	No	No	No
13.	Kedar Nagar	Hooghly	Elev: 5m, Lat: 22°55′19’’, Long: 88°16′46.5’’	No	No	No	Yes	Yes	Yes	Yes
14.	Maheshwarbati	Hooghly	Elev: 14m, Lat: 22°53′46’’, Long: 88°17′ 30.7’’	No	No	No	Yes	Yes	Yes	Yes
15.	Saiya	Hooghly	Elev: 11m, Lat: 22˚55´17.6˝, Long: 88˚16´49.5˝	No	No	No	No	No	No	Yes
16.	Sonadarmath	Hooghly	Elev: 4m, Lat: 22˚54´41˝, Long: 88˚19´3˝	No	No	No	No	No	No	Yes
17.	Kachiyada	24 PGS (N)	Elev: 3m, Lat: 22°52´39´´, Long: 88°32´2.0´´	Yes	Yes	Yes	Yes	Yes	No	No
18.	Koikopur	24 PGS (N)	Elev: 8m, Lat: 22°52´38.3´´, Long: 88°32´3.9´´	Yes	Yes	Yes	No	No	No	No

Sl. No.	Village	District	Location	Year						
				2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
19.	Aamdanga	24 PGS (N)	Elev: 13m, Lat: 22°48’51.8’’, Long: 88°30’59.5’’	No	No	Yes	Yes	Yes	Yes	No
20.	Goldarpada	24 PGS (N)	Elev: 7m, Lat: 22°48’25.5”, Long: 88°31’01.8”	No	No	Yes	No	No	No	No
21.	Dadpur	24 PGS (N)	Elev: 5m, Lat: 22°53′12.2’’, Long: 88° 31′ 08.3’’	No	No	No	Yes	Yes	No	No
22.	Satyapole	24 PGS (N)	Elev: 0m, Lat: 22° 55' 03.33", Long: 88° 35' 01.3"	No	No	No	No	Yes	Yes	No
23.	Anandapur	24 PGS (N)	Elev: 7m, Lat: 22° 55' 16.2", Long: 88° 33' 50"	No	No	No	No	No	Yes	No
24.	Kadpur	24 PGS (N)	Elev: 13m, Lat: 22° 48' 49.6", Long: 88° 31' 07.5"	No	No	No	No	No	Yes	No
25.	Rahana	24 PGS (N)	Elev: 3m, Lat: 22° 49' 34.8", Long: 88° 31' 08.9"	No	No	No	No	No	Yes	No
26.	Bodai	24 PGS (N)	Elevation: 8m, Lat: 22˚47´45″, Long: 88˚29´43″	No	No	No	No	No	No	Yes
27.	Papdara	24 PGS (N)	Elev: 27m, Lat: 22˚53´49.6″, Long: 88˚32´58.2″	No	No	No	No	No	No	Yes
28.	Kamdevpur	24 PGS (N)	Elev: 8m, Lat: 22˚55´04.5″, Long: 88˚17´11.3″	No	No	No	No	No	No	Yes
29.	C- Block, Experimental station, Kalyani	Nadia	Elev: 9m, Lat: 22°59´15.9´´, Long: 88°27´27.3´´	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Elev. = elevation, Lat. = latitude, Long. = longitude

Table 2: List of villages covered for insect pest surveillance in summer season

Sl. No.	Village	District	Location	Year						
				2012	2013	2014	2015	2016	2017	2018
1.	Aamdanga	24 PGS (N)	Elev*: 8m, Lat**:23°01´27.1´´, Long***: 88°27´56.2´´	Yes	Yes	No	No	Yes	No	No
2.	Kasempur	24 PGS (N)	Elev: 3m, Lat: 23°01´13´´, Long: 88°27´26´´	Yes	Yes	No	No	No	No	No
3.	Potincha	24 PGS (N)	Elev: 4m, Lat: 3°00´12.4´´, Long: 88°27´66´´	Yes	No	No	No	No	No	No
4.	Modaeet	24 PGS (N)	Elev: 3m, Lat: 03°01′43.2’’, Long: 88°27′ 23’’	Yes	No	No	No	No	No	No
5.	Mathura	24 PGS (N)	Elev: 3m, Lat: 22°55´20´´, Long: 88°35´6.0´´	Yes	Yes	No	No	No	No	No
6.	Pykepada	24 PGS (N)	Elev: 3m, Lat:23°01´43.2´´, Long: 88°27´23´´	No	Yes	Yes	No	No	No	No
7.	Mirhati	24 PGS (N)	Elev: 5m, Lat:22°55´36.6´´, Lon: 88°35´3.6´´	Yes	Yes	Yes	Yes	No	No	No
8.	Santoshpur	24 PGS (N)	Elev: 8m, Lat: 22°55’16.4’’, Long: 88°35’10.9’’	No	No	Yes	Yes	Yes	No	Yes
9.	Kamdevpur	24 PGS (N)	Elev: 9m, Lat: 22°54´20´´, Long: 88°17´53.9´´	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10.	Bodrait	24 PGS (N)	Elev:13m,Lat:22°52´57.8´´, Long: 88°17´20.1´´	Yes	Yes	No	Yes	No	No	No
11.	Srerampur	24 PGS (N)	Elev: 4m, Lat: 23°0´12.4´´, Long: 88°27´25.6´´	No	Yes	Yes	No	No	No	No
12.	Kadpur	24 PGS (N)	Elev: 8m, Lat:22°56´18.4´´, Long: 88°24´45.6´´	No	No	Yes	Yes	Yes	Yes	No
13.	Goldarpada	24 PGS (N)	Elev: 5m, Lat: 22°55′19’’, Long: 88°16′46.5’’	No	No	No	Yes	No	No	No
14.	Mahadebpur	24 PGS (N)	Elev: 14m, Lat: 22°53′46’’, Long: 88°17′ 30.7’’	No	No	No	Yes	Yes	Yes	No
15.	Zeerat	24 PGS (N)	Elev: 3m, Lat: 22°52´39´´, Long: 88°32´2.0´´	Yes	Yes	Yes	Yes	Yes	No	No
16.	Urala	24 PGS (N)	Elev: 8m, Lat: 22°52´38.3´´, Long: 88°32´3.9´´	Yes	Yes	Yes	No	Yes	Yes	No
17.	Shadanpur	24 PGS (N)	Elev: 13m, Lat: 22°48’51.8’’, Long: 88°30’59.5’’	No	No	Yes	Yes	Yes	Yes	No
18.	Satyapole	24 PGS (N)	Elev: 7m, Lat: 22°48’25.5”, Long: 88°31’01.8”	No	No	Yes	No	No	No	No
19.	Ananadapur	24 PGS (N)	Elev: 5m, Lat: 22°53′12.2’’, Long: 88° 31′ 08.3’’	No	No	No	Yes	No	Yes	No

Sl. No.	Village	District	Location	Year						
				2012	2013	2014	2015	2016	2017	2018
20.	Dahuhli	24 PGS (N)	Elev: 12m, Lat: 22° 53' 16.1", Long: 88° 32' 09.4"	No	No	No	No	Yes	Yes	No
21.	Arkhali	24 PGS (N)	Elev: 16m, Lat: 22° 48' 25.5", Long: 88° 31' 02.1"	No	No	No	No	Yes	Yes	No
22.	Murait	24 PGS (N)	Elev: 15m, Lat: 22° 45' 46.1", Long: 88° 30' 29.4"	No	No	No	No	Yes	No	No
23.	Bodai	24 PGS (N)	Elev: 3m, Lat: 22° 47' 46.8", Long.: 88° 29' 41.9"	No	No	No	No	No	No	Yes
24.	Khelia	24 PGS (N)	Elev: 5m, Lat: 22° 47' 35.3", Long.: 88° 30' 28.1"	No	No	No	No	No	No	Yes
25.	Arkelia	24 PGS (N)	Elev: 27m, Lat: 22° 48' 24.5", Long.: 88° 30' 34.7"	No	No	No	No	No	No	Yes
26.	Uttarpara	24 PGS (N)	Elev: 5m, Lat: 22° 48' 53.5", Long.: 88° 30' 58.5"	No	No	No	No	No	No	Yes
27.	Rahana	24 PGS (N)	Elev: 8m, Lat: 22° 50' 10.4", Long.: 88° 31' 25.3"	No	No	No	No	No	Yes	Yes
28.	Kachiara	24 PGS (N)	Elev: 11m, Lat: 22° 53' 08.0", Long.: 88° 32' 04.1"	No	No	No	No	No	Yes	Yes
29.	Papdara	24 PGS (N)	Elev: 12m, Lat: 22° 53' 47.7", Long.: 88° 32' 56.3"	No	No	No	No	No	No	Yes
30.	Sadamari	24 PGS (N)	Elev: 1m, Lat: 23° 00' 07.5", Long.: 88° 27' 20.7"	No	No	No	No	No	No	Yes
31.	C- Block, Experimental station, Kalyani	Nadia	Elev: 11m, Lat: 22°59´12.9´´, Long: 88°27´17.5´´	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Elev. = elevation, **Lat. = latitude, ***Long. = longitude

Table 69. Effect of different treatments on population of leaf miner, *L. trifolii* during 2016-17

Treatment	Dose/ha	Mean number of live mines per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.54	2.62 (1.77)	3.74 (2.06)	2.45 (1.72)	3.25 (1.94)	3.01
Beauveria bassiana	1500 g/ha	4.12	2.58 (1.75)	3.69 (2.05)	2.35 (1.68)	3.18 (1.92)	2.95
NSKE 5%	1000 ml/ha	4.06	2.30 (1.67)	3.54 (2.01)	2.14 (1.62)	2.81 (1.82)	2.70
Azadirachtin 1%	1000 ml/ha	3.83	2.64 (1.77)	3.82 (2.08)	2.52 (1.74)	3.40 (1.97)	3.09
Emamectin benzoate 5% SG	10g ai/ha	3.73	1.85 (1.53)	2.65 (1.77)	1.95 (1.57)	2.42 (1.71)	2.22
Novaluron 5.25% + Indoxacarb 4.5% SC	850 ml/ha	4.40	2.02 (1.59)	3.12 (1.90)	2.18 (1.64)	2.50 (1.73)	2.45
Control	-	4.38	3.60 (2.02)	4.42 (2.22)	4.20 (2.17)	4.35 (2.20)	4.14
SEm	-	-	0.04	0.05	0.07	0.09	-
CD (5%)	-	-	0.11	0.14	0.21	0.28	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 70. Effect of different treatments on population of leaf miner, *L. trifolii* during 2017-18

Treatment	Dose/ha	Mean number of live mines per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.50	3.52 (2.00)	4.22 (2.17)	3.14 (1.91)	3.64 (2.03)	3.63
Beauveria bassiana	1500 g/ha	5.32	3.46 (1.99)	4.18 (2.16)	3.05 (1.88)	3.51 (2.00)	3.55
NSKE	1000 ml/ha	5.12	3.08 (1.89)	3.55 (2.01)	2.67 (1.78)	3.13 (1.91)	3.11
Azadirachtin	1000 ml/ha	5.64	3.64 (2.04)	4.46 (2.23)	3.12 (1.90)	3.76 (2.06)	3.75
Emamectin benzoate	10g ai/ha	5.84	2.82 (1.82)	3.12 (1.09)	2.14 (1.62)	2.62 (1.77)	2.67
Novaluron + Indoxacarb	850 ml/ha	5.10	2.94 (1.86)	3.14 (1.91)	2.28 (1.67)	2.84 (1.83)	2.80
Control	-	6.25	4.28 (2.19)	4.64 (2.27)	3.82 (2.08)	4.26 (2.18)	4.25
SEm	-	-	0.04	0.07	0.06	0.10	-
CD (5%)	-	-	0.13	0.20	0.18	0.30	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 71. Effect of different treatments on population of whitefly during 2016-17

Treatment	Dose /ha	Mean number of whitefly per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.74	2.43 (1.71)	3.12 (1.90)	1.35 (1.36)	2.10 (1.61)	2.25
Beauveria bassiana	1500 g/ha	4.49	2.31 (1.68)	3.04 (1.88)	1.26 (1.33)	2.03 (1.59)	2.16
NSKE	1000 ml/ha	5.21	2.25 (1.66)	2.96 (1.86)	1.17 (1.29)	1.92 (1.56)	2.08
Azadirachtin	1000 ml/ha	4.35	2.46 (1.72)	3.21 (1.93)	1.42 (1.39)	2.16 (1.63)	2.31
Emamectin benzoate	10g ai/ha	5.67	2.18 (1.64)	2.91 (1.85)	1.15 (1.28)	1.84 (1.53)	2.02
Novaluron + Indoxacarb	850 ml/ha	5.38	2.10 (1.61)	2.75 (1.80)	1.06 (1.25)	1.72 (1.49)	1.91
Control	-	5.26	3.35 (1.96)	4.25 (2.18)	3.12 (1.90)	3.85 (2.09)	3.64
SEm	-	-	0.08	0.06	0.07	0.09	-
CD (5%)	-	-	0.24	0.19	0.21	0.25	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 72. Effect of different treatments on population of whitefly during 2017-18

Treatment	Dose /ha	Mean number of whitefly per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.75	2.75 (1.80)	3.26 (1.94)	1.76 (1.50)	2.42 (1.71)	2.55
Beauveria bassiana	1500 g/ha	5.92	2.60 (1.76)	3.12 (1.90)	1.65 (1.47)	2.31 (1.68)	2.42
NSKE	1000 ml/ha	5.62	2.52 (1.74)	2.90 (1.84)	1.57 (1.44)	2.23 (1.65)	2.31
Azadirachtin	1000 ml/ha	5.28	2.81 (1.82)	3.34 (1.96)	1.81 (1.52)	2.54 (1.74)	2.63
Emamectin benzoate	10g ai/ha	5.11	2.47 (1.72)	2.85 (1.83)	1.52 (1.42)	2.16 (1.63)	2.25
Novaluron + Indoxacarb	850 ml/ha	5.44	2.24 (1.66)	2.77 (1.81)	1.36 (1.36)	2.02 (1.59)	2.10
Control	-	6.02	3.97 (2.11)	4.28 (2.19)	2.61 (1.76)	3.45 (1.99)	3.58
SEm	-	-	0.07	0.08	0.07	0.05	-
CD (5%)	-	-	0.21	0.25	0.20	0.15	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 73. Effect of different treatments on population of aphids during 2016-17

Treatment	Dose /ha	Mean number of aphid per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.12	2.45 (1.72)	3.27 (1.94)	1.43 (1.39)	2.21 (1.65)	2.34
Beauveria bassiana	1500 g/ha	5.05	2.51 (1.73)	3.36 (1.96)	1.58 (1.44)	2.36 (1.69)	2.45
NSKE	1000 ml/ha	5.66	2.32 (1.68)	3.14 (1.91)	1.36 (1.36)	2.14 (1.62)	2.24
Azadirachtin	1000 ml/ha	5.84	2.67 (1.78)	3.47 (1.99)	1.65 (1.47)	2.55 (1.75)	2.59
Emamectin benzoate	10g ai/ha	4.97	2.24 (1.66)	3.12 (1.90)	1.37 (1.37)	2.03 (1.59)	2.19
Novaluron + Indoxacarb	850 ml/ha	5.22	2.01 (1.58)	2.99 (1.87)	1.24 (1.32)	1.98 (1.57)	2.06
Control	-	5.73	3.67 (2.04)	4.38 (2.21)	2.64 (1.77)	3.57 (2.02)	3.57
SEm	-	-	0.08	0.07	0.07	0.08	-
CD (5%)	-	-	0.26	0.22	0.19	0.22	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 74. Effect of different treatments on population of aphids during 2017-18

Treatment	Dose /ha	Mean number of aphid per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	6.24	3.07 (1.89)	3.69 (2.05)	2.10 (1.61)	2.82 (1.82)	2.92
Beauveria bassiana	1500 g/ha	6.45	3.12 (1.90)	3.75 (2.06)	2.17 (1.63)	2.94 (1.85)	3.00
NSKE	1000 ml/ha	6.57	2.95 (1.86)	3.58 (2.02)	2.03 (1.59)	2.75 (1.80)	2.83
Azadirachtin	1000 ml/ha	5.82	3.24 (1.93)	3.84 (2.08)	2.15 (1.63)	3.09 (1.89)	3.08
Emamectin benzoate	10g ai/ha	6.26	2.91 (1.85)	3.42 (1.98)	1.96 (1.57)	2.63 (1.77)	2.73
Novaluron + Indoxacarb	850 ml/ha	6.00	2.86 (1.83)	3.29 (1.95)	1.82 (1.52)	2.58 (1.75)	2.64
Control	-	6.44	4.18 (2.16)	4.79 (2.30)	3.75 (2.06)	4.11 (2.15)	4.21
SEm	-	-	0.10	0.06	0.06	0.09	-
CD (5%)	-	-	0.29	0.19	0.20	0.26	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 75. Effect of different treatments on population of thrips during 2016-17

Treatment	Dose /ha	Mean number of thrips per five leaves					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.37	2.14 (1.62)	2.76 (1.81)	1.35 (1.36)	1.98 (1.57)	2.06
Beauveria bassiana	1500 g/ha	4.26	2.11 (1.62)	2.82 (1.82)	1.48 (1.41)	1.91 (1.55)	2.08
NSKE	1000 ml/ha	3.95	2.02 (1.59)	2.61 (1.76)	1.26 (1.33)	1.76 (1.50)	1.91
Azadirachtin	1000 ml/ha	3.82	2.17 (1.63)	2.89 (1.84)	1.53 (1.42)	2.02 (1.59)	2.15
Emamectin benzoate	10g ai/ha	4.15	1.95 (1.57)	2.52 (1.74)	1.17 (1.29)	1.68 (1.48)	1.83
Novaluron + Indoxacarb	850 ml/ha	3.91	1.81 (1.52)	2.41 (1.71)	1.12 (1.27)	1.64 (1.46)	1.75
Control	-	4.04	2.90 (1.84)	3.45 (1.99)	2.64 (1.77)	3.06 (1.89)	3.01
SEm	-	-	0.08	0.07	0.05	0.08	-
CD (5%)	-	-	0.24	0.21	0.16	0.28	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 76. Effect of different treatments on population of thrips during 2017-18

Treatment	Dose /ha	Mean number of thrips per five leaves					
		before spray	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.12	2.63 (1.77)	3.15 (1.91)	1.53 (1.42)	2.05 (1.60)	2.34
Beauveria bassiana	1500 g/ha	5.06	2.57 (1.75)	3.10 (1.90)	1.57 (1.44)	2.08 (1.61)	2.33
NSKE	1000 ml/ha	4.65	2.44 (1.71)	2.99 (1.87)	1.32 (1.35)	1.94 (1.56)	2.17
Azadirachtin	1000 ml/ha	4.23	2.72 (1.79)	3.24 (1.93)	1.48 (1.41)	2.16 (1.63)	2.40
Emamectin benzoate	10g ai/ha	5.20	2.36 (1.69)	2.91 (1.85)	1.26 (1.33)	1.75 (1.50)	2.07
Novaluron + Indoxacarb	850 ml/ha	4.87	2.28 (1.67)	2.76 (1.81)	1.12 (1.27)	1.70 (1.48)	1.97
Control	-	4.62	3.27 (1.94)	3.97 (2.11)	2.64 (1.77)	3.25 (1.94)	3.28
SEm	-	-	0.13	0.10	0.07	0.08	-
CD (5%)	-	-	0.39	0.30	0.20	0.23	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 77. Effect of different treatments on population of *S. litura* during 2016-17

Treatment	Dose /ha	Mean number of *S. litura* larva per five leaves					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.93	3.04 (1.88)	3.27 (1.94)	2.53 (1.74)	2.71 (1.79)	2.89
Beauveria bassiana	1500 g/ha	5.20	3.12 (1.90)	3.21 (1.93)	2.46 (1.72)	2.65 (1.77)	2.86
NSKE	1000 ml/ha	6.01	3.10 (1.90)	3.35 (1.96)	2.61 (1.76)	2.73 (1.80)	2.95
Azadirachtin	1000 ml/ha	5.87	3.25 (1.94)	3.48 (1.99)	2.70 (1.79)	2.91 (1.85)	3.09
Emamectin benzoate	10g ai/ha	5.16	2.94 (1.85)	3.14 (1.91)	2.33 (1.68)	2.45 (1.72)	2.72
Novaluron + Indoxacarb	850 ml/ha	5.03	2.77 (1.810	3.01 (1.87)	2.00 (1.58)	2.24 (1.65)	2.50
Control	-	5.70	4.23 (2.17)	4.56 (2.25)	3.33 (1.96)	3.57 (2.02)	3.92
SEm	-	-	0.04	0.07	0.05	0.06	-
CD (5%)	-	-	0.12	0.20	0.15	0.17	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 78. Effect of different treatments on population of *S. litura* during 2017-18

Treatment	Dose /ha	Mean number of *S. litura* larva per five leaves					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	6.41	4.03 (2.13)	4.27 (2.18)	3.13 (1.91)	3.35 (1.96)	3.70
Beauveria bassiana	1500 g/ha	6.36	4.12 (2.15)	4.36 (2.20)	3.27 (1.94)	3.47 (1.99)	3.81
NSKE	1000 ml/ha	7.00	4.07 (2.14)	4.23 (2.17)	3.10 (1.90)	3.29 (1.95)	3.67
Azadirachtin	1000 ml/ha	7.07	4.23 (1.17)	4.69 (2.28)	3.44 (1.98)	3.61 (2.03)	3.99
Emamectin benzoate	10g ai/ha	6.80	3.89 (2.10)	4.01 (2.12)	3.07 (1.89)	3.25 (1.94)	3.56
Novaluron + Indoxacarb	850 ml/ha	6.25	3.67 (2.04)	3.83 (2.08)	2.89 (1.84)	3.03 (1.88)	3.36
Control	-	6.53	4.37 (2.21)	4.63 (2.26)	3.89 (2.10)	4.12 (2.15)	4.25
SEm	-	-	0.05	0.06	0.07	0.08	-
CD (5%)	-	-	0.15	0.16	0.20	0.22	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 79. Effect of different treatments on population of *H. armigera* during 2016-17

Treatment	Dose /ha	Mean number of *H. armigera* larva per five leaves					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	3.8	1.58 (1.44)	1.76 (1.50)	1.24 (1.362)	1.46 (1.40)	1.51
Beauveria bassiana	1500 g/ha	3.96	1.72 (1.49)	1.94 (1.56)	1.35 (1.36)	1.57 (1.44)	1.65
NSKE	1000 ml/ha	3.67	1.64 (1.46)	1.78 (1.51)	1.40 (1.38)	1.52 (1.42)	1.59
Azadirachtin	1000 ml/ha	4.11	1.85 (1.53)	2.01 (1.58)	1.56 (1.44)	1.78 (1.51)	1.80
Emamectin benzoate	10g ai/ha	3.54	1.49 (1.41)	1.66 (1.47)	1.15 (1.28)	1.29 (1.34)	1.40
Novaluron + Indoxacarb	850 ml/ha	4.18	1.26 (1.33)	1.54 (1.43)	1.08 (1.26)	1.16 (1.29)	1.26
Control	-	3.72	3.04 (1.88)	3.28 (1.94)	2.71 (1.79)	3.13 (1.91)	3.04
SEm	-	-	0.06	0.04	0.03	0.04	-
CD (5%)	-	-	0.18	0.13	0.10	0.11	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 80. Effect of different treatments on population of *H. armigera* during 2017-18

Treatment	Dose /ha	Mean number of *H. armigera* larva per five leaves					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.24	2.06 (1.60)	2.24 (1.66)	1.84 (1.53)	2.14 (1.62)	2.07
Beauveria bassiana	1500 g/ha	4.36	2.22 (1.65)	2.5 (1.73)	1.95 (1.57)	2.33 (1.68)	2.25
NSKE	1000 ml/ha	4.15	2.14 (1.62)	2.32 (1.68)	1.77 (1.51)	2.15 (1.63)	2.10
Azadirachtin	1000 ml/ha	5.00	2.53 (1.74)	2.67 (1.78)	2.10 (1.61)	2.54 (1.74)	2.46
Emamectin benzoate	10g ai/ha	3.58	1.91 (1.55)	2.03 (1.59)	1.62 (1.46)	1.90 (1.55)	1.87
Novaluron + Indoxacarb	850 ml/ha	4.24	1.87 (1.54)	1.91 (1.55)	1.48 (1.41)	1.66 (1.47)	1.73
Control	-	4.30	3.45 (1.99)	3.76 (2.06)	3.13 (1.91)	3.58 (2.02)	3.48
SEm	-	-	0.05	0.04	0.07	0.06	-
CD (5%)	-	-	0.16	0.11	0.20	0.17	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 81. Effect of different treatments on population of Spiders during 2016-17

Treatment	Dose /ha	Mean number of spiders per plant					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.96	2.3 (1.67)	2.52 (1.74)	1.94 (1.56)	2.1 (1.61)	2.22
Beauveria bassiana	1500 g/ha	4.54	2.46 (1.72)	2.74 (1.80)	2.02 (1.5*9)	2.26 (1.66)	2.37
NSKE	1000 ml/ha	4.22	2.21 (1.65)	2.46 (1.72)	1.82 (1.52)	2.12 (1.62)	2.15
Azadirachtin	1000 ml/ha	5.15	2.52 (1.74)	2.81 (1.82)	1.97 (1.57)	2.35 (1.69)	2.41
Emamectin benzoate	10g ai/ha	4.8	1.80 (1.52)	2.37 (1.69)	1.65 (1.47)	1.91 (1.55)	1.93
Novaluron + Indoxacarb	850 ml/ha	4.73	1.75 (1.50)	2.20 (1.64)	1.48 (1.41)	1.82 (1.52)	1.81
Control	-	5.79	3.14 (1.91)	3.55 (2.01)	3.05 (1.88)	3.37 (1.97)	3.28
SEm	-	-	0.05	0.10	0.08	0.07	-
CD (5%)	-	-	0.16	0.29	0.23	0.22	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 82. Effect of different treatments on population of Spiders during 2017-18

Treatment	Dose /ha	Mean number of spiders per plant					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	5.76	2.86 (1.83)	3.02 (1.88)	2.24 (1.66)	2.48 (1.73)	2.65
Beauveria bassiana	1500 g/ha	5.34	2.95 (1.86)	3.14 (1.91)	2.36 (1.69)	2.54 (1.74)	2.75
NSKE	1000 ml/ha	4.82	2.64 (1.77)	2.82 (1.82)	2.05 (1.60)	2.43 (1.71)	2.49
Azadirachtin	1000 ml/ha	4.87	2.72 (1.79)	2.96 (1.86)	2.18 (1.64)	2.40 (1.70)	2.56
Emamectin benzoate	10g ai/ha	5.12	2.28 (1.67)	2.60 (1.76)	1.92 (1.56)	1.90 (1.55)	2.18
Novaluron + Indoxacarb	850 ml/ha	5.29	2.15 (1.63)	2.57 (1.75)	1.86 (1.54)	1.82 (1.52)	2.10
Control	-	4.73	3.34 (1.96)	3.85 (2.09)	3.12 (1.90)	3.76 (2.06)	3.52
SEm	-	-	0.05	0.05	0.06	0.07	-
CD (5%)	-	-	0.13	0.16	0.18	0.20	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 83. Effect of different treatments on population of Coccinellids during 2016-17

Treatment	Dose /ha	Mean number of coccinellids per plant					
		1 DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	3.24	1.69 (1.48)	2.10 (1.61)	1.58 (1.44)	1.80 (1.52)	1.79
Beauveria bassiana	1500 g/ha	3.16	1.75 (1.50)	2.15 (1.63)	1.66 (1.47)	1.96 (1.57)	1.88
NSKE	1000 ml/ha	3.32	1.53 (1.42)	2.06 (1.60)	1.41 (1.38)	1.67 (1.47)	1.67
Azadirachtin	1000 ml/ha	3.13	1.81 (1.52)	2.18 (1.64)	1.64 (1.46)	1.91 (1.55)	1.89
Emamectin benzoate	10g ai/ha	3.40	1.30 (1.34)	1.73 (1.49)	1.32 (1.35)	1.54 (1.43)	1.47
Novaluron + Indoxacarb	850 ml/ha	3.28	1.23 (1.32)	1.65 (1.47)	1.26 (1.33)	1.48 (1.41)	1.41
Control	-	3.35	2.45 (1.72)	2.91 (1.85)	2.46 (1.72)	2.72 (1.79)	2.64
SEm	-	-	0.04	0.06	0.03	0.05	-
CD (5%)	-	-	0.12	0.18	0.09	0.14	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 84. Effect of different treatments on population of Coccinellids during 2017-18

Treatment	Dose /ha	Mean number of coccinellids per plant					
		1DBS	1st spray		2nd spray		Overall mean
			7 DAS	14 DAS	7 DAS	14 DAS	
Bacillus thuringiensis var. kurstaki	1000 g/ha	4.76	2.35 (1.69)	2.57 (1.75)	1.86 (1.54)	2.54 (1.74)	2.33
Beauveria bassiana	1500 g/ha	4.84	2.51 (1.73)	2.63 (1.77)	1.94 (1.56)	2.62 (1.77)	2.43
NSKE	1000 ml/ha	3.87	2.00 (1.58)	2.56 (1.75)	1.70 (1.48)	2.26 (1.66)	2.13
Azadirachtin	1000 ml/ha	4.66	2.20 (1.64)	2.48 (1.73)	1.65 (1.47)	2.41 (1.71)	2.19
Emamectin benzoate	10g ai/ha	3.93	1.70 (1.48)	2.28 (1.67)	1.54 (1.43)	1.90 (1.55)	1.86
Novaluron + Indoxacarb	850 ml/ha	3.62	1.53 (1.42)	2.32 (1.68)	1.46 (1.40)	1.82 (1.52)	1.78
Control	-	4.15	2.72 (1.79)	3.33 (1.96)	2.86 (1.83)	3.24 (1.93)	3.04
SEm	-	-	0.05	0.06	0.07	0.04	-
CD (5%)	-	-	0.15	0.17	0.21	0.11	-

*Figures in parentheses are angular transformed values; DBS - Day before spray; DAS - Days after spray.

Table 13: Incidence of leaf miner population per plant on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	0.00	-	-	-	-	-	-
38	0.00	-	-	-	-	-	-
39	0.00	0.00	-	-	-	-	-
40	0.36	0.00	-	-	-	-	-
41	0.56	0.00	-	-	-	0.00	-
42	0.72	0.00	-	-	0.00	0.00	-
43	1.24	0.00	-	0.00	0.00	0.00	-
44	1.12	0.00	0.00	0.00	0.40	0.32	0.00
45	1.36	0.00	0.00	0.48	0.68	0.64	0.12
46	1.52	0.00	0.00	0.68	1.08	0.86	0.48
47	1.24	0.20	0.00	1.00	1.32	1.20	0.44
48	1.20	0.44	0.00	1.36	1.48	1.68	0.36
49	1.32	0.76	0.00	1.52	1.56	2.12	0.44
50	1.40	0.88	0.00	1.60	1.56	2.64	0.36
51	1.08	1.04	0.48	1.96	1.68	2.88	0.36
52	1.00	1.00	0.72	2.32	1.68	2.74	0.76
1	1.08	1.00	0.96	2.56	1.92	2.68	0.88
2	1.20	1.04	1.20	2.72	2.36	2.78	1.20
3	0.88	1.04	1.28	2.80	2.88	2.84	1.32
4	1.04	1.12	1.40	2.80	3.24	2.88	1.36
5	1.00	1.20	1.40	2.92	3.68	2.96	1.40
6	0.84	-	1.64	3.00	-	-	1.48
7	-	-	1.64	3.00	-	-	1.52
8	-	-	1.72	3.00	-	-	-

Table 14: Incidence of leaf miner population per plant on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-	-	-	-	-	-
4	0.00	-	0.00	-	-	-	-
5	0.28	-	0.00	-	-	0.00	0.00
6	0.52	-	0.72	-	0.00	0.76	1.28
7	0.80	-	1.00	-	1.68	1.12	2.12
8	1.08	-	1.36	-	2.24	1.28	3.00
9	1.44	-	1.64	0.00	2.60	3.80	3.84
10	1.76	0.20	2.12	0.60	2.88	2.48	4.48
11	1.96	0.32	2.52	1.00	3.44	4.96	5.12
12	2.16	0.80	2.72	1.52	3.76	4.32	4.08
13	2.36	1.40	3.04	2.28	4.08	4.52	3.52
14	2.64	2.00	3.20	2.40	4.32	3.76	3.00
15	2.76	2.40	3.20	2.56	4.40	2.76	2.56
16	2.92	2.04	3.44	2.60	4.64	1.80	2.32
17	2.92	1.92	3.20	2.76	4.72	1.52	1.80
18	3.04	2.12	3.04	2.96	-	1.68	1.68
19	3.08	2.56	3.32	2.96	-	1.32	1.32
20	3.24	3.12	3.12	2.96	-	1.12	-
21	3.36	3.12	-	3.08	-	0.84	-
22	3.40	3.20	-	3.12	-	-	-
23	-	3.40	-	3.12	-	-	-
24	-	3.40	-	-	-	-	-

Table 15: Incidence of aphid population per leaf on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	0.00	-	-	-	-	-	-
38	0.00	-	-	-	-	-	-
39	0.00	0.00	-	-	-	-	-
40	2.76	0.00	-	-	-	-	-
41	3.20	0.00	-	-	-	0.00	-
42	3.40	1.22	-	-	0.00	1.00	-
43	2.92	2.31	-	0.00	0.00	1.60	-
44	3.20	2.45	0.00	2.16	1.60	2.48	0.00
45	3.40	2.72	0.00	3.04	3.00	3.40	0.24
46	3.52	3.81	0.00	4.40	4.00	4.00	0.72
47	3.16	4.76	2.08	5.20	5.00	5.04	1.44
48	2.96	4.22	1.80	7.04	6.20	6.32	2.04
49	3.08	5.10	3.20	6.80	7.00	5.36	2.72
50	3.12	5.92	2.68	6.00	5.80	5.00	3.36
51	2.80	4.42	2.44	4.80	4.40	4.28	2.08
52	2.64	3.81	2.00	4.60	3.60	3.20	1.96
1	2.72	2.72	1.84	4.00	3.20	2.60	1.76
2	2.88	3.20	1.72	3.40	2.80	1.60	2.08
3	2.64	1.68	1.56	3.20	2.80	1.28	1.56
4	2.44	1.32	1.40	3.20	1.80	1.40	1.00
5	2.24	1.20	1.52	2.56	1.84	1.04	1.28
6	1.96	-	1.88	2.00	-	-	1.40
7	-	-	1.56	1.40	-	-	1.20
8	-	-	1.40	1.20	-	-	-

Table 16: Incidence of aphid population per leaf on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-	-	-	-	-	-
4	0.72	-	0.00	-	-	-	-
5	1.00	-	1.32	-	-	0.00	0.00
6	1.60	-	2.56	-	0.60	1.36	2.72
7	1.88	-	2.68	-	1.33	2.20	3.40
8	2.00	-	3.12	0.67	2.59	3.64	6.12
9	2.36	-	4.00	1.67	3.53	5.80	7.28
10	3.00	4.29	4.80	2.80	2.00	6.68	8.92
11	3.60	4.86	5.12	4.27	5.25	7.52	10.04
12	3.76	5.76	4.76	5.73	3.15	9.72	9.40
13	3.40	6.72	4.20	5.33	2.33	10.72	6.48
14	2.80	5.76	4.00	6.33	2.13	7.28	5.12
15	2.12	5.18	3.76	6.13	1.65	6.60	4.60
16	1.60	4.99	3.48	5.47	1.20	5.12	3.76
17	1.32	4.43	2.97	5.20	0.83	4.04	3.28
18	0.80	3.14	2.88	4.80	-	3.36	3.00
19	0.80	2.69	2.40	4.16	-	2.92	2.44
20	0.60	2.24	2.00	3.53	-	2.36	-
21	0.56	1.92	-	2.60	-	1.36	-
22	0.40	2.05	-	1.67	-	-	-
23	-	1.47	-	-	-	-	-
24	-	0.96	-	-	-	-	-

Table 17: Incidence of whitefly population per leaf on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	1.76	-	-	-	-	-	-
38	2.20	-	-	-	-	-	-
39	1.36	0.00	-	-	-	-	-
40	2.32	0.96	-	-	-	-	-
41	1.40	0.90	-	-	-	0.00	-
42	1.68	2.11	-	-	0.60	0.88	-
43	1.72	4.22	-	2.24	3.00	1.52	-
44	2.32	4.16	0.00	3.84	3.80	2.16	0.00
45	2.64	6.08	0.76	3.60	6.40	3.60	0.28
46	2.80	3.84	1.56	4.00	7.60	4.88	0.92
47	2.48	5.34	3.88	5.40	6.80	5.80	1.16
48	2.04	5.63	3.56	6.00	7.40	6.80	2.36
49	2.32	4.67	3.00	5.00	6.00	6.00	1.60
50	2.24	3.90	3.24	4.40	5.00	5.52	2.76
51	1.96	2.69	2.76	3.60	4.00	4.60	1.04
52	1.80	2.18	2.20	3.60	3.40	3.76	1.20
1	1.92	1.28	2.20	3.00	3.00	3.04	1.00
2	2.04	0.00	2.08	2.40	2.40	2.00	0.92
3	1.76	0.00	1.68	1.92	2.00	1.60	1.04
4	1.68	0.00	1.36	0.00	1.00	1.68	0.56
5	1.52	0.00	1.28	0.00	1.08	1.52	1.40
6	1.60	-	1.96	0.00	-	-	1.24
7	-	-	1.77	0.00	-	-	1.16
8	-	-	1.48	0.00	-	-	-

Table 18: Incidence of whitefly population per leaf on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-		-	-	-	-
4	2.40	-	0.00	-	-	-	-
5	3.40	-	1.40	-	-	0.00	0.00
6	4.20	-	2.40	-	0.77	1.72	1.72
7	3.40	-	2.32	-	1.27	1.20	3.12
8	2.80	-	3.40	0.20	2.20	2.28	5.80
9	3.80	-	3.40	0.68	3.20	3.80	9.00
10	4.00	1.80	4.00	1.40	2.40	2.48	8.48
11	4.40	2.22	4.20	2.00	3.33	3.92	7.44
12	4.00	3.00	3.80	3.00	4.59	5.00	5.76
13	4.40	4.50	3.40	3.80	3.60	5.28	4.84
14	5.00	6.30	3.00	4.00	2.87	4.04	3.12
15	6.00	6.00	2.76	4.14	1.44	2.32	2.52
16	5.40	5.10	2.40	3.56	1.33	2.92	2.36
17	6.00	4.20	2.00	3.00	1.00	2.24	2.16
18	5.40	3.79	1.76	2.72	-	1.68	1.92
19	4.20	3.46	1.52	2.52	-	1.52	1.68
20	3.60	2.88	1.12	2.00	-	1.60	-
21	3.00	2.54	-	1.60	-	1.12	-
22	2.40	1.80	-	1.20	-		-
23	-	1.60	-	-	-		-
24	-	1.52	-	-	-		-

Table 19: Incidence of thrips population per leaf on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	1.08	-	-	-	-	-	-
38	1.12	-	-	-	-	-	-
39	0.24	0.00	-	-	-	-	-
40	1.24	0.00	-	-	-	-	-
41	0.52	0.00	-	-	-	0.00	-
42	0.68	0.00	-	-	0.00	0.72	-
43	1.12	1.15	-	0.00	0.00	1.40	-
44	1.24	1.92	0.00	0.00	0.00	2.40	0.00
45	1.44	2.69	0.00	0.00	0.80	3.76	0.00
46	1.56	4.03	0.00	0.40	1.36	4.40	0.00
47	1.08	4.99	1.56	0.89	2.00	5.56	0.00
48	0.92	4.80	2.48	1.34	1.80	6.40	0.64
49	1.24	5.31	3.56	1.76	2.12	7.28	1.48
50	1.36	5.82	3.20	2.00	2.00	6.20	2.25
51	1.04	4.67	2.72	1.84	1.88	5.20	2.60
52	0.92	3.78	2.20	0.96	1.68	4.60	3.12
1	1.00	2.37	2.36	1.38	1.80	3.20	3.01
2	1.08	1.96	2.24	1.20	1.96	2.24	2.66
3	0.80	1.68	2.08	1.04	1.76	1.20	1.80
4	1.12	1.08	2.32	0.80	1.48	-	1.54
5	1.08	0.88	1.76	0.58	1.16	-	1.27
6	0.96	-	2.36	0.48	-	-	1.16
7	-	-	1.88	0.36	-	-	0.72
8	-	-	1.60	0.24	-	-	-

Table 20: Incidence of thrips population per leaf on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-	-	-	-	-	-
4	0.00	-	0.00	-	-	-	-
5	0.56	-	0.00	-		0.00	0.00
6	1.00	-	0.00	-	0.00	1.52	2.08
7	1.44	-	1.20	-	1.30	3.04	3.92
8	1.88	-	2.00	0.00	2.80	3.68	5.96
9	1.72	-	3.00	0.32	5.00	5.36	6.56
10	2.24	1.15	3.40	0.56	3.50	7.00	7.72
11	2.80	1.44	4.00	1.00	4.40	5.00	8.40
12	3.36	1.92	4.20	1.20	4.90	4.32	7.48
13	2.84	4.42	4.00	1.76	3.90	4.08	5.72
14	2.60	5.57	5.32	2.00	3.24	4.68	3.84
15	1.60	4.90	5.60	2.56	2.90	4.00	3.48
16	1.88	4.61	5.40	2.80	2.20	3.44	2.60
17	1.72	3.84	5.00	2.68	1.64	2.36	2.72
18	1.76	5.28	4.68	2.52	-	2.00	2.20
19	1.56	5.86	4.12	2.32	-	2.48	1.96
20	1.40	5.47	3.80	2.00	-	1.28	-
21	1.24	4.80	-	1.76	-	1.12	-
22	1.00	2.12	-	1.36	-	-	-
23	-	1.76	-	-	-	-	-
24	-	1.52	-	-	-	-	-

Table 21: Incidence of *S. litura* population per plant on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	0.00	-	-	-	-	-	-
38	0.68	-	-	-	-	-	-
39	1.20	0.00	-	-	-	-	-
40	2.80	0.00	-	-	-	-	-
41	2.64	0.60	-	-	-	0.00	-
42	2.76	1.08	-	-	0.00	0.00	-
43	2.80	1.88	-	0.00	0.20	0.00	-
44	2.64	2.88	0.00	0.00	0.36	0.08	0.00
45	3.24	2.52	0.00	0.28	0.72	0.20	0.04
46	3.48	2.88	0.48	0.40	1.00	0.36	0.12
47	3.12	2.24	1.04	0.52	1.28	0.44	0.12
48	2.96	1.72	0.76	0.64	1.12	0.56	0.16
49	3.16	0.00	0.64	0.56	0.88	0.88	0.20
50	3.32	0.00	0.72	0.48	0.80	0.68	0.24
51	2.96	0.00	0.48	0.48	0.56	0.80	0.40
52	2.80	0.00	0.36	0.40	0.68	0.64	0.32
1	2.92	0.00	0.32	0.44	0.56	0.60	0.32
2	2.76	0.00	0.40	0.28	0.40	0.48	0.20
3	2.40	0.00	0.28	0.28	0.24	0.32	0.36
4	2.28	0.00	0.20	0.20	0.00	0.20	0.40
5	2.08	0.00	0.20	0.00	0.00	0.08	0.44
6	1.92	-	0.24	0.00	-	-	0.40
7	-	-	0.12	0.00	-	-	0.44
8	-	-	0.00	0.00	-	-	-

Table 22: Incidence of *S. litura* population per plant on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-		-	-	-	-
4	0.00	-	0.00	-	-	-	-
5	0.00	-	0.20	-		0.00	0.00
6	0.16	-	0.52	-	0.00	0.08	0.04
7	0.28	-	0.72	-	0.00	0.16	0.08
8	0.48	-	1.00	0.00	0.24	0.44	0.48
9	0.60	-	1.32	0.28	0.32	0.60	0.32
10	0.88	0.12	1.60	0.56	0.60	0.84	0.48
11	1.08	0.24	1.48	0.60	0.80	0.72	0.72
12	1.40	0.80	1.36	0.88	1.00	0.92	0.88
13	1.76	1.20	1.20	1.20	0.96	1.04	0.60
14	1.72	1.60	1.00	1.08	0.72	0.84	0.44
15	1.60	1.92	0.88	0.88	0.88	0.72	0.32
16	1.60	2.20	0.92	0.76	0.60	0.40	0.24
17	1.40	2.12	0.80	0.76	0.32	0.36	0.36
18	1.32	2.40	0.60	0.60	-	0.24	0.32
19	1.12	2.28	0.48	0.52	-	0.16	0.48
20	1.00	2.00	0.32	0.52	-	0.32	-
21	0.76	1.72	-	0.40	-	0.24	-
22	0.64	1.52	-	0.28	-	-	-
23	-	0.84	-	-	-	-	-
24	-	0.60	-	-	-	-	-

Table 23: Incidence of *H. armigera* population per plant on tomato crop in *rabi* season during 2011-12 to 2017-18

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
36	0.00	-	-	-	-	-	-
37	0.00	-	-	-	-	-	-
38	0.00	-	-	-	-	-	-
39	0.00	0.00	-	-	-	-	-
40	0.00	0.00	-	-	-	-	-
41	0.00	0.00	-	-	-	0.00	-
42	0.44	0.00	-	-	0.00	0.00	-
43	0.72	0.00	-	0.00	0.00	0.00	-
44	1.16	0.00	0.00	0.00	0.00	0.00	0.00
45	0.96	0.00	0.00	0.00	0.00	0.00	0.08
46	1.08	0.00	0.00	0.00	0.00	0.00	0.04
47	1.16	0.00	0.00	0.00	0.00	0.00	0.08
48	1.28	0.00	0.00	0.00	0.00	0.00	0.16
49	1.04	0.20	0.00	0.00	0.00	0.00	0.16
50	0.96	0.28	0.00	0.00	0.16	0.08	0.16
51	1.12	0.44	0.00	0.00	0.24	0.16	0.20
52	1.08	0.56	0.00	0.12	0.36	0.32	0.24
1	0.92	0.72	0.00	0.32	0.32	0.44	0.20
2	1.04	0.68	0.16	0.36	0.12	0.36	0.16
3	0.76	0.92	0.48	0.48	0.24	0.28	0.24
4	0.96	0.68	0.52	0.32	0.16	0.20	0.32
5	0.84	0.56	0.60	0.36	0.08	0.16	0.24
6	0.76	-	0.52	0.40	-	-	0.36
7	-	-	0.36	0.16	-	-	0.40
8	-	-	0.08	0.12	-	-	-

Table 24: Incidence of *H. armigera* population per plant on tomato crop in *summer* season during 2012 to 2018

SMW	2012	2013	2014	2015	2016	2017	2018
3	0.00	-		-	-	-	-
4	0.00	-	0.00	-	-	-	-
5	0.00	-	0.00	-	-	0.00	0.00
6	0.00	-	0.00	-	0.00	0.00	0.00
7	0.00	-	0.00	-	0.00	0.00	0.04
8	0.00	-	0.00	0.00	0.00	0.00	0.08
9	0.00	-	0.00	0.00	0.00	0.00	0.08
10	0.00	0.00	0.00	0.00	0.00	0.04	0.12
11	0.00	0.00	0.00	0.00	0.00	0.08	0.08
12	0.28	0.00	0.00	0.00	0.00	0.04	0.08
13	0.36	0.00	0.12	0.00	0.08	0.12	0.12
14	0.84	0.00	0.24	0.00	0.12	0.16	0.20
15	1.32	0.00	0.40	0.00	0.12	0.20	0.28
16	1.80	0.00	0.60	0.00	0.20	0.24	0.20
17	2.24	0.16	0.64	0.08	0.08	0.28	0.24
18	1.44	0.28	0.40	0.40	-	0.36	0.28
19	1.08	0.68	0.36	0.56	-	0.40	0.32
20	0.76	1.00	0.20	0.72	-	0.64	-
21	0.60	1.28	-	0.64	-	0.48	-
22	0.32	1.64	-	0.24	-		
23	-	1.16	-	-	-	-	-
24	-	0.80	-	-	-	-	-

Table 3: Weekly average meteorological data during rabi season of 2011-12 to 2017-18

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
2011-12	36	31.29	26.33	29.31	28.31	95.43	76.43	28.30
	37	32.08	26.37	29.80	28.65	94.86	78.71	57.80
	38	30.77	25.61	28.71	27.67	97.57	84.43	199.60
	39	32.13	25.26	29.38	28.01	93.86	80.14	184.20
	40	34.18	25.80	30.83	29.15	92.14	65.00	29.20
	41	34.63	25.83	31.11	29.35	93.00	61.57	8.60
	42	32.90	25.29	29.86	28.33	92.71	70.57	10.20
	43	31.24	23.94	28.32	26.86	95.00	60.57	58.80
	44	30.84	18.90	26.06	23.68	92.86	51.71	0.00
	45	30.77	18.79	25.98	23.58	91.14	55.00	0.00
	46	30.16	19.91	26.06	24.01	94.14	62.43	8.00
	47	29.24	17.21	24.43	22.02	93.14	57.29	0.00
	48	28.61	15.06	23.19	20.48	91.57	51.00	0.00
	49	29.01	16.31	23.93	21.39	92.00	54.57	0.00
	50	24.66	14.67	20.66	18.67	96.00	58.57	0.00
	51	21.39	10.11	16.88	14.62	98.43	64.29	0.00
	52	25.59	12.29	20.27	17.61	93.25	55.88	0.00
	1	23.40	16.50	20.64	19.26	96.71	71.86	20.00
	2	21.03	13.03	17.83	16.23	97.28	72.57	37.00
	3	24.93	13.36	20.30	17.99	96.57	58.14	0.00
	4	25.01	10.63	19.26	16.38	91.43	43.86	0.00
	5	24.97	10.47	19.17	16.27	91.29	41.71	0.00
	6	27.86	13.26	22.02	19.10	89.00	42.29	0.00
2012-13	39	35.76	26.03	31.87	29.92	94.29	64.57	49.70
	40	34.37	26.17	31.09	29.45	94.43	69.14	2.30
	41	33.43	24.70	29.94	28.19	95.00	69.86	26.70
	42	33.74	22.01	29.05	26.70	93.14	55.43	0.00
	43	33.01	20.11	27.85	25.27	91.14	48.86	0.00
	44	31.79	19.33	26.81	24.31	90.71	58.71	3.00
	45	28.76	20.73	25.55	23.94	97.00	71.86	47.10
	46	29.64	16.34	24.32	21.66	94.71	51.14	0.00
	47	30.40	18.11	25.48	23.03	88.29	49.29	0.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	48	28.74	11.76	21.95	18.55	91.57	42.00	0.00
	49	28.80	10.91	21.64	18.07	91.29	43.00	0.00
	50	27.79	15.20	22.75	20.24	95.43	64.29	7.30
	51	25.79	12.80	20.59	18.00	98.14	57.29	0.00
	52	20.07	8.90	15.60	13.37	96.77	71.00	0.00
	1	24.03	11.99	19.21	16.81	94.86	57.14	1.90
	2	22.56	6.94	16.31	13.19	94.14	45.86	0.00
	3	27.37	12.96	21.61	18.72	91.00	54.43	0.00
	4	24.14	7.41	17.45	14.10	94.57	42.14	0.00
	5	27.73	10.29	20.75	17.27	91.86	47.57	0.00
2013-14	44	32.84	19.69	27.58	24.95	94.71	57.43	0.00
	45	29.86	18.50	25.32	23.04	87.57	58.57	0.00
	46	29.74	14.81	23.77	20.78	80.43	49.86	0.00
	47	28.93	14.63	23.21	20.35	79.71	53.43	0.00
	48	29.36	15.37	23.76	20.97	81.00	60.86	0.00
	49	27.64	14.04	22.20	19.48	83.57	58.57	0.00
	50	27.29	11.63	21.03	17.89	83.43	55.14	0.00
	51	28.19	12.54	21.93	18.80	83.71	62.14	0.00
	52	24.75	11.44	19.43	16.76	87.38	58.38	0.00
	1	24.19	10.11	18.56	15.74	82.29	60.57	0.00
	2	23.83	10.04	18.31	15.56	84.86	59.71	0.00
	3	23.14	11.56	18.51	16.19	92.00	71.71	0.00
	4	25.46	10.27	19.38	16.35	84.14	59.29	0.00
	5	26.16	9.23	19.39	16.00	89.71	56.57	0.00
	6	30.67	14.14	24.06	20.75	83.43	44.57	0.00
	7	26.23	13.91	21.30	18.84	84.43	57.14	28.50
	8	29.17	14.09	23.14	20.12	85.14	54.43	0.00
2014-15	43	31.80	21.43	27.65	25.58	83.71	69.00	1.00
	44	32.44	19.76	27.37	24.83	83.71	59.71	0.00
	45	33.47	19.71	27.97	25.21	81.29	56.57	0.00
	46	32.54	15.77	25.83	22.48	77.29	47.14	0.00
	47	31.31	13.04	24.00	20.35	78.00	45.86	0.00
	48	30.66	12.43	23.37	19.72	82.71	49.29	0.00
	49	28.94	13.67	22.83	19.78	85.57	60.29	0.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	50	26.31	13.86	21.33	18.84	88.29	59.86	0.00
	51	26.31	10.53	20.00	16.84	82.71	51.43	0.00
	52	24.63	9.85	18.72	15.76	87.75	59.38	0.00
	1	27.00	16.03	22.61	20.42	89.43	65.86	2.50
	2	24.86	9.64	18.77	15.73	85.00	58.43	0.00
	3	25.61	9.84	19.30	16.15	85.43	58.71	0.00
	4	29.19	11.03	21.93	18.29	76.43	49.57	0.00
	5	28.14	10.89	21.24	17.79	80.29	49.00	0.00
	6	28.79	12.66	22.34	19.11	78.14	43.57	0.00
	7	31.09	15.51	24.86	21.74	85.14	51.43	8.30
	8	34.19	19.67	28.38	25.48	85.86	50.14	5.30
	42	33.36	23.79	29.53	27.62	94.14	65.14	2.20
	43	33.33	21.36	28.54	26.15	92.43	53.43	0.00
	44	31.37	21.36	27.37	25.36	94.00	63.57	0.00
	45	32.36	20.03	27.43	24.96	92.57	50.57	0.00
	46	32.07	18.97	26.83	24.21	93.57	52.29	0.00
	47	30.21	17.14	24.98	22.37	93.86	48.86	0.00
	48	30.40	18.50	25.64	23.26	92.71	58.43	0.00
	49	28.74	17.91	24.41	22.24	93.71	59.57	0.00
2015-16	50	26.63	17.19	22.85	20.97	92.57	57.71	0.00
	51	23.73	12.27	19.15	16.85	95.14	58.43	6.60
	52	25.13	11.50	19.68	16.95	91.00	48.38	0.00
	1	26.36	11.34	20.35	17.35	92.57	56.29	0.00
	2	27.06	12.06	21.06	18.06	93.14	47.29	0.00
	3	25.44	13.91	20.83	18.52	91.71	59.86	3.00
	4	23.53	9.27	17.83	14.97	93.43	50.43	0.00
	5	28.14	14.90	22.84	20.20	92.43	48.57	0.00
	41	32.57	24.40	29.30	27.67	98.86	78.86	8.70
	42	33.77	22.57	29.29	27.05	94.29	56.14	0.00
	43	32.24	22.67	28.41	26.50	95.29	64.86	1.60
2016-17	44	31.57	23.87	28.49	26.95	95.71	72.29	1.10
	45	28.94	18.40	24.73	22.62	95.71	66.43	1.70
	46	30.14	16.81	24.81	22.15	92.14	48.57	0.00
	47	29.27	15.11	23.61	20.78	91.43	52.43	0.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	48	29.36	16.57	24.24	21.69	93.00	58.29	0.00
	49	27.76	14.99	22.65	20.09	93.71	57.00	0.00
	50	25.30	10.80	19.50	16.60	94.00	54.57	0.00
	51	25.93	12.43	20.53	17.83	92.00	57.86	0.00
	52	26.11	13.43	21.04	18.50	95.75	66.13	0.00
	1	25.67	12.41	20.37	17.72	94.86	57.14	0.00
	2	24.13	10.59	18.71	16.00	91.00	47.29	0.00
	3	26.29	8.80	19.29	15.79	90.00	43.29	0.00
	4	27.66	11.81	21.32	18.15	90.00	50.43	0.00
	5	26.90	11.79	20.85	17.83	91.71	53.00	0.00
2017-18	44	30.20	20.24	26.22	24.23	95.43	62.14	0.00
	45	31.83	19.89	27.05	24.66	94.00	53.86	0.00
	46	27.97	20.37	24.93	23.41	94.71	75.57	5.29
	47	28.50	16.09	23.53	21.05	92.29	51.86	0.00
	48	27.69	12.83	21.74	18.77	89.71	46.57	0.00
	49	25.97	14.94	21.56	19.35	90.43	62.00	0.37
	50	27.50	17.41	23.47	21.45	95.57	68.71	1.83
	51	23.81	13.80	19.81	17.81	93.71	66.14	0.00
	52	26.00	11.63	20.25	17.38	95.13	53.13	0.00
	1	23.19	9.34	17.65	14.88	93.29	51.86	0.00
	2	21.47	7.34	15.82	12.99	90.57	53.86	0.00
	3	24.97	8.54	18.40	15.11	91.29	46.43	0.00
	4	26.40	9.76	19.74	16.41	89.14	42.14	0.00
	5	28.29	11.29	21.49	18.09	90.71	45.43	0.00
	6	29.39	15.73	23.92	21.19	89.00	43.71	0.00
	7	29.41	13.96	23.23	20.14	88.14	43.43	0.00

Table 4: Weekly average meteorological data during summer season of 2012 to 2018

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	3	24.93	13.36	20.30	17.99	96.71	58.14	0.00
	4	25.01	10.59	19.24	16.36	91.43	43.86	0.00
	5	24.97	10.47	19.17	16.27	91.29	41.71	0.00
	6	27.86	13.26	22.02	19.10	89.00	42.29	0.00
	7	27.87	15.00	22.72	20.15	91.43	55.86	9.80
	8	31.51	15.19	24.98	21.72	91.14	35.86	0.00
	9	31.80	16.30	25.60	22.50	88.71	33.29	2.00
	10	34.20	20.27	28.63	25.84	88.57	38.29	0.00
	11	33.19	17.71	27.00	23.90	83.86	36.14	0.00
2012	12	34.53	21.91	29.48	26.96	91.43	39.57	0.00
	13	36.84	23.97	31.69	29.12	88.14	36.14	0.00
	14	34.01	22.27	29.31	26.97	89.71	50.00	7.30
	15	34.41	22.41	29.61	27.21	87.86	56.00	14.10
	16	37.76	26.29	33.17	30.88	89.86	46.57	0.80
	17	37.71	26.23	33.12	30.82	81.14	44.14	10.80
	18	36.14	23.74	31.18	28.70	93.29	50.14	71.00
	19	35.73	26.00	31.84	29.89	91.71	55.29	0.00
	20	38.13	27.80	34.00	31.93	86.71	51.14	1.20
	21	37.34	27.70	33.48	31.56	91.29	59.86	30.00
	22	36.17	28.10	32.94	31.33	90.71	61.86	0.30
	10	33.59	14.54	25.97	22.16	89.43	30.57	0.00
	11	36.19	20.91	30.08	27.02	88.57	36.43	0.00
	12	36.47	20.67	30.15	26.99	90.29	33.14	0.00
	13	38.54	22.41	32.09	28.86	89.14	34.29	0.00
	14	37.97	24.54	32.60	29.91	81.86	36.14	0.00
2013	15	40.36	24.33	33.95	30.74	88.57	25.29	0.00
	16	36.94	23.33	31.50	28.77	83.71	44.00	85.90
	17	34.20	22.17	29.39	26.98	93.00	59.29	27.10
	18	38.03	27.39	33.77	31.65	89.43	54.43	0.00
	19	36.59	27.57	32.98	31.18	83.00	58.14	0.20
	20	35.56	25.20	31.42	29.34	91.00	62.86	7.40
	21	34.57	24.44	30.52	28.49	94.43	74.57	40.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	22	32.50	25.13	29.55	28.08	94.86	78.00	59.80
	23	35.20	25.51	31.32	29.39	93.14	68.86	47.10
2014	24	34.44	26.60	31.30	29.74	94.00	81.57	53.90
	4	24.16	11.57	19.12	16.61	90.75	68.86	0.00
	5	25.50	9.89	19.26	16.13	82.60	58.43	0.00
	6	27.01	9.61	20.05	16.57	85.00	54.57	0.00
	7	30.24	14.41	23.91	20.74	81.86	44.71	0.00
	8	25.99	13.50	20.99	18.50	84.57	58.86	28.50
	9	29.73	15.01	23.84	20.90	85.67	54.57	0.00
	10	29.37	16.36	24.17	21.56	86.67	55.71	0.00
	11	32.29	15.84	25.71	22.42	83.71	42.57	0.00
	12	35.33	19.61	29.04	25.90	82.67	43.14	0.00
	13	34.40	19.87	28.59	25.68	86.00	52.00	26.20
	14	38.03	23.69	32.29	29.43	85.29	38.29	0.00
	15	37.53	25.03	32.53	30.03	89.57	43.43	0.00
	16	38.94	23.46	32.75	29.65	86.14	34.43	0.00
	17	40.59	25.07	34.38	31.28	81.43	33.71	0.00
	18	41.01	26.50	35.21	32.30	87.29	40.57	0.00
	19	35.03	24.03	30.63	28.43	87.57	59.43	24.90
2015	20	39.36	27.06	34.44	31.98	85.00	48.00	5.80
	8	34.19	19.67	28.38	25.48	85.86	50.14	5.30
	9	35.17	20.30	29.22	26.25	86.14	46.29	5.80
	10	33.69	15.90	26.57	23.01	77.43	35.14	2.30
	11	36.16	18.26	29.00	25.42	78.14	34.29	0.00
	12	37.29	18.91	29.94	26.26	80.43	33.86	0.00
	13	35.66	24.14	31.05	28.75	92.29	49.86	13.30
	14	36.11	24.09	31.30	28.90	90.86	59.86	20.10
	15	36.70	24.26	31.72	29.23	88.57	50.57	23.80
	16	37.13	25.63	32.53	30.23	85.71	52.43	0.70
	17	33.17	21.91	28.67	26.42	91.57	65.00	54.10
	18	37.04	25.21	32.31	29.95	89.71	59.29	2.40
	19	36.67	27.76	33.11	31.32	90.71	61.29	0.10
	20	36.93	25.77	32.47	30.23	91.71	62.57	27.60
	21	39.11	28.46	34.85	32.72	87.57	57.00	3.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
2016	22	38.69	29.34	34.95	33.08	83.43	51.00	0.00
	6	28.39	14.56	22.86	20.09	92.14	59.86	0.00
	7	31.46	19.79	26.79	24.46	94.86	56.14	0.00
	8	33.50	19.81	28.02	25.29	90.57	45.00	11.10
	9	31.50	20.07	26.93	24.64	96.57	61.14	33.30
	10	33.67	21.59	28.84	26.42	92.29	49.71	0.00
	11	34.01	21.39	28.96	26.44	89.29	40.71	0.00
	12	35.04	21.50	29.62	26.92	90.71	44.43	16.00
	13	35.13	23.77	30.59	28.31	92.43	49.86	3.40
	14	36.33	25.26	31.90	29.69	91.29	52.57	1.00
	15	41.47	26.17	35.35	32.29	90.14	36.57	0.00
	16	39.34	27.14	34.46	32.02	85.86	49.14	0.00
2017	17	40.10	27.49	35.06	32.53	88.14	45.29	0.00
	5	26.90	11.79	20.85	17.83	91.71	53.00	0.00
	6	29.64	13.43	23.16	19.91	89.57	41.43	0.00
	7	30.49	15.74	24.59	21.64	89.86	44.43	0.00
	8	31.86	18.59	26.55	23.89	85.60	44.29	0.00
	9	33.41	16.50	26.65	23.27	90.17	47.00	0.00
	10	31.43	19.29	26.57	24.14	94.25	60.86	0.46
	11	32.21	16.73	26.02	22.92	86.71	34.14	0.00
	12	33.80	21.86	29.02	26.63	91.40	40.57	0.81
	13	35.70	25.91	31.79	29.83	92.14	55.00	0.00
	14	35.00	26.29	31.51	29.77	90.43	57.71	0.03
	15	37.10	25.48	32.45	30.13	91.50	38.17	0.00
	16	35.13	25.93	31.45	29.61	85.43	57.29	0.00
	17	37.50	25.76	32.80	30.45	90.43	53.57	1.37
	18	36.14	25.16	31.75	29.55	90.43	56.71	3.43
	19	36.31	25.01	31.79	29.53	89.57	55.00	6.94
	20	35.84	25.20	31.59	29.46	90.86	63.00	4.11
2018	21	37.40	27.44	33.42	31.43	84.29	53.14	1.76
	5	28.29	11.29	21.49	18.09	90.71	45.43	0.00
	6	29.39	15.73	23.92	21.19	89.00	43.71	0.00
	7	29.41	13.96	23.23	20.14	88.14	43.43	0.00
	8	35.54	17.64	28.38	24.80	91.29	44.43	0.00

Year	SMW	Temperature (°C)				Relative Humidity (%)		Rainfall (mm)
		Maximum	Minimum	Day	Night	Maximum	Minimum	
	9	34.77	19.90	28.82	25.85	91.43	34.57	0.00
	10	34.36	18.04	27.83	24.57	84.43	29.86	0.00
	11	35.26	20.94	29.53	26.67	88.71	39.57	0.04
	12	35.54	21.97	30.11	27.40	91.71	44.00	0.03
	13	34.56	23.71	30.22	28.05	92.14	55.71	0.14
	14	33.94	21.93	29.14	26.73	90.57	51.43	0.94
	15	34.84	22.09	29.74	27.19	90.14	55.14	5.16
	16	37.09	25.93	32.62	30.39	92.00	54.14	1.23
	17	36.11	24.24	31.37	28.99	85.14	49.86	0.03
	18	34.11	24.59	30.30	28.40	91.43	64.43	4.34
	19	36.00	25.66	31.86	29.79	90.57	61.57	0.73

CHAPTER-1

Introduction

CHAPTER-2

Review of Literature

CHAPTER-3

Materials & Methods

CHAPTER-4

Results and Discussion

CHAPTER-5

Summary & Conclusion

CHAPTER-6

Future Scope of Research

Bibliography

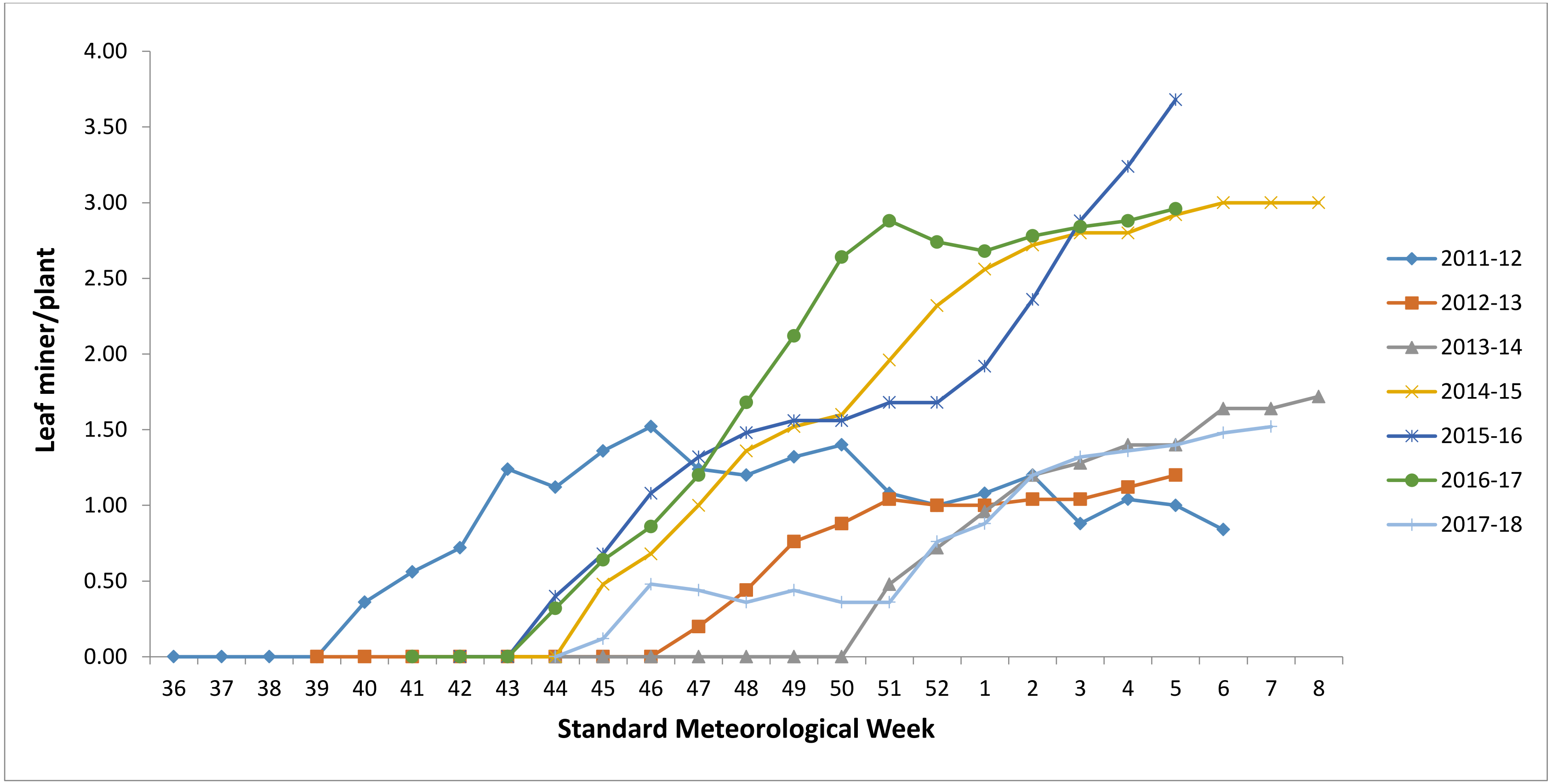

Fig. 1. Population dynamics of leaf miner during 2011-12 to 2017-18 in rabi season

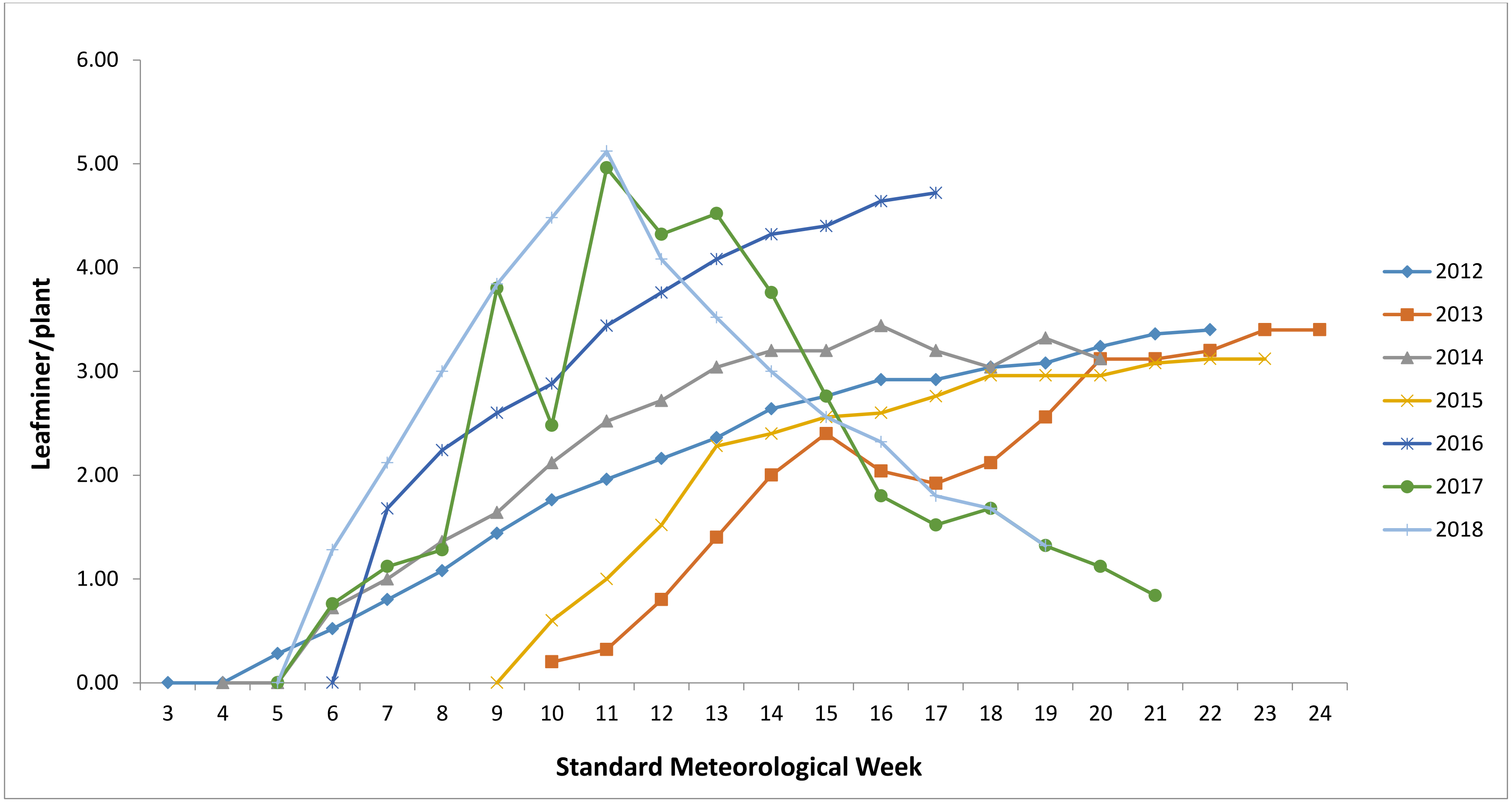

Fig. 2. Population dynamics of leaf miner during 2012 to 2018 in summer season

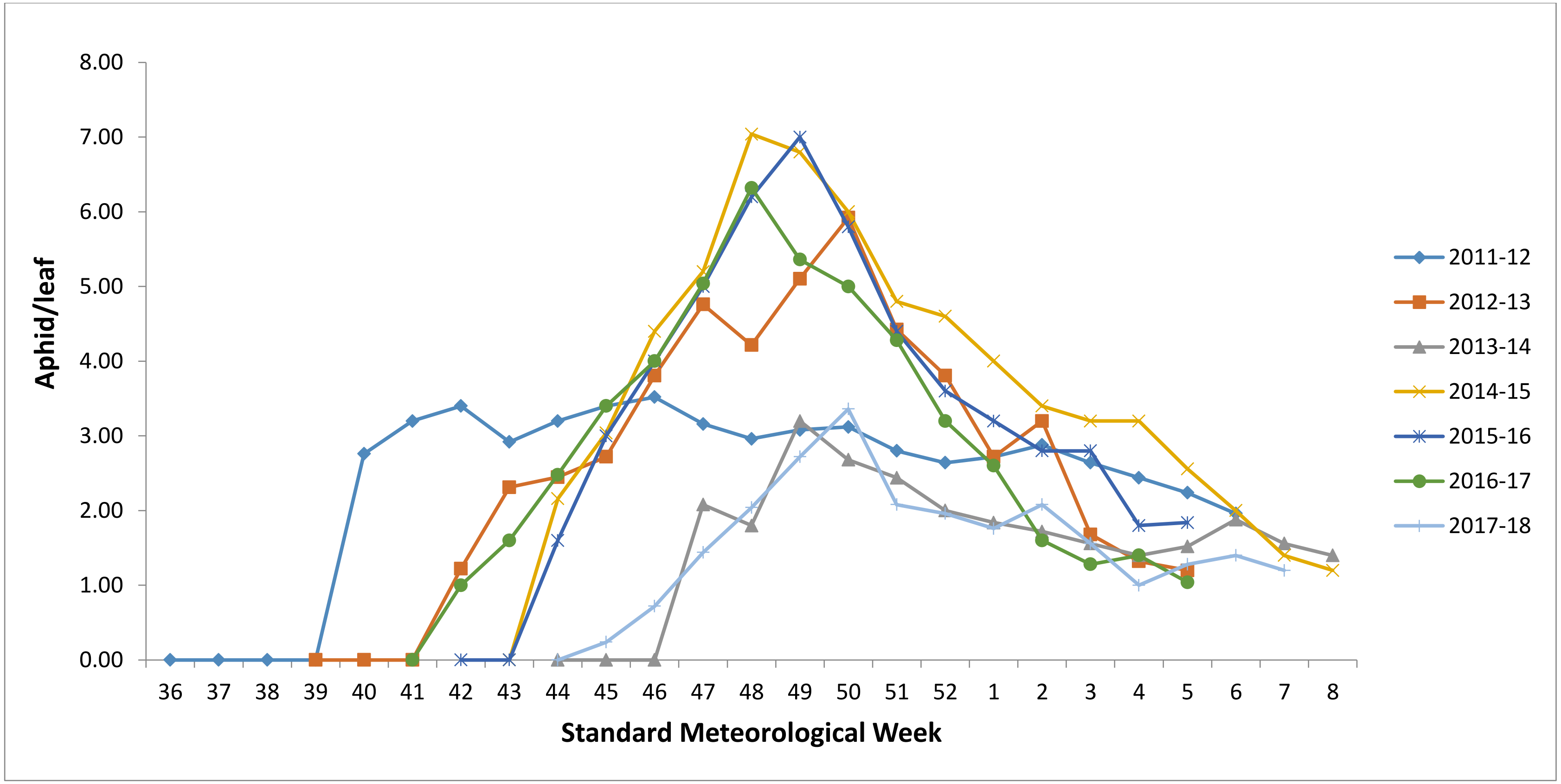

Fig. 3. Population dynamics of aphid during 2011-12 to 2017-18 in rabi season

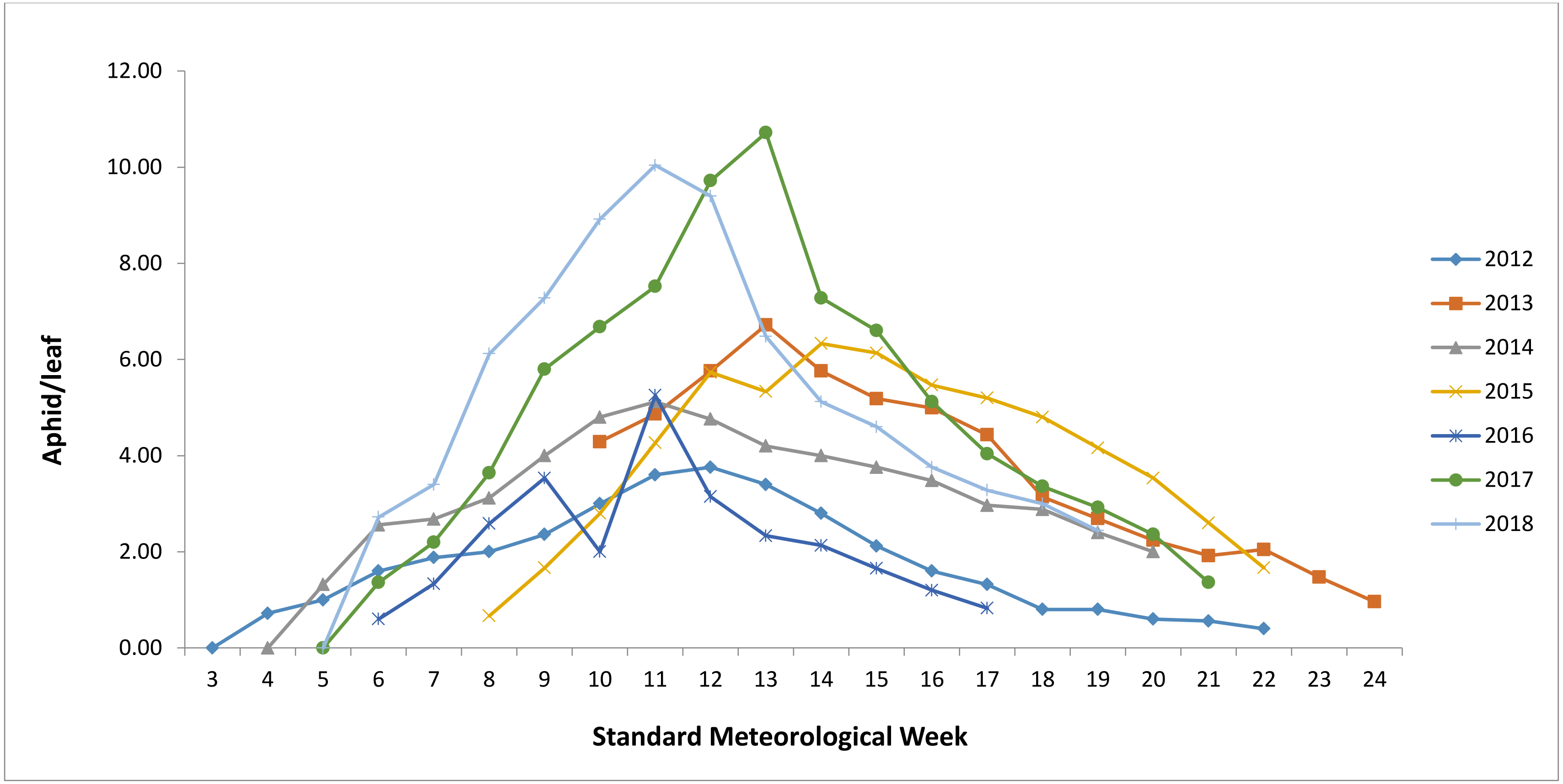

Fig. 4. Population dynamics of aphid during 2012 to 2018 in summer season

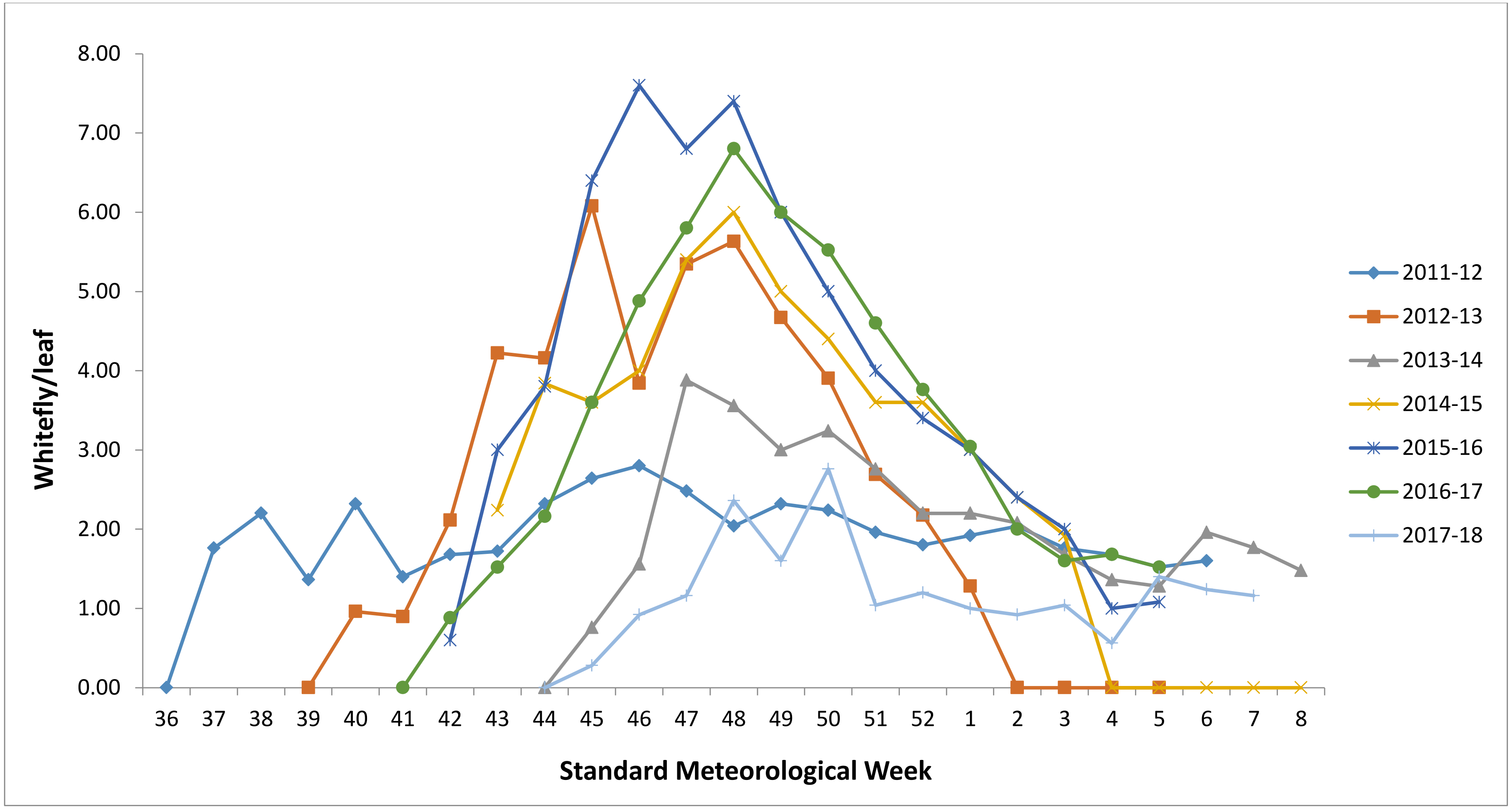

Fig. 5. Population dynamics of whitefly during 2011-12 to 2017-18 in rabi season

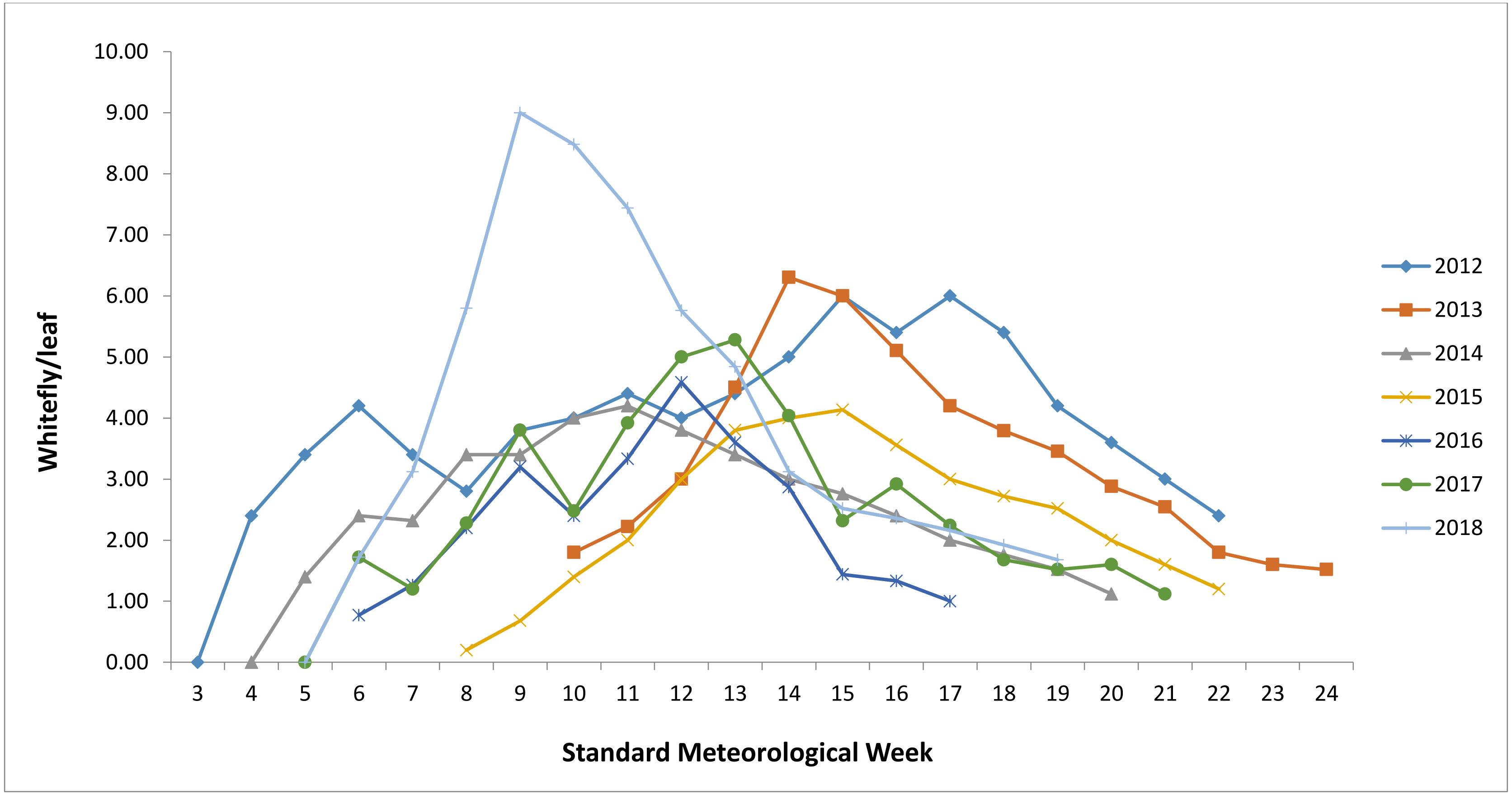

Fig. 6. Population dynamics of whitefly during 2012 to 2018 summer season

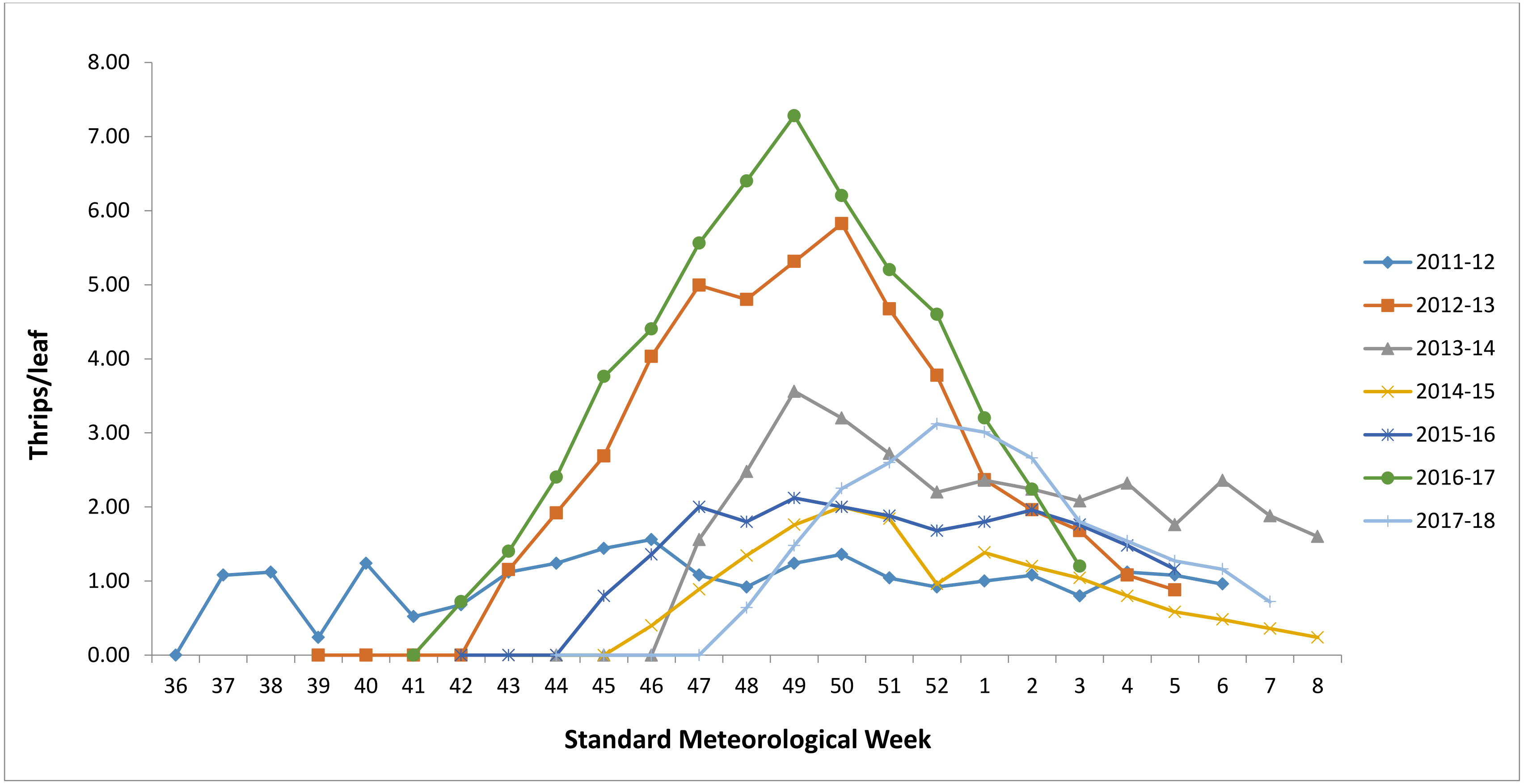

Fig. 7. Population dynamics of thrips during 2011-12 to 2017-18 in rabi season

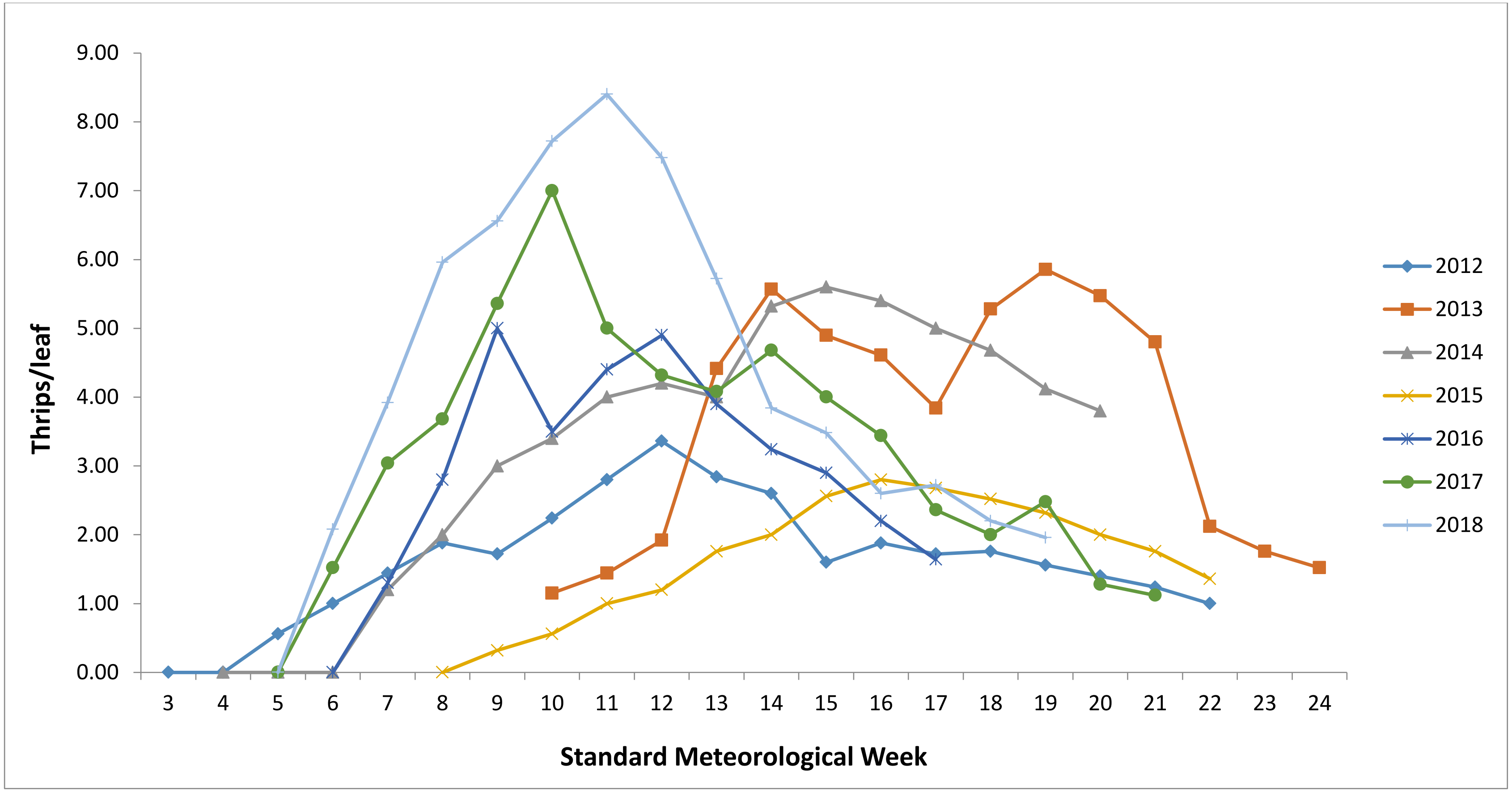

Fig. 8. Population dynamics of thrips during 2012 to 2018 in summer season

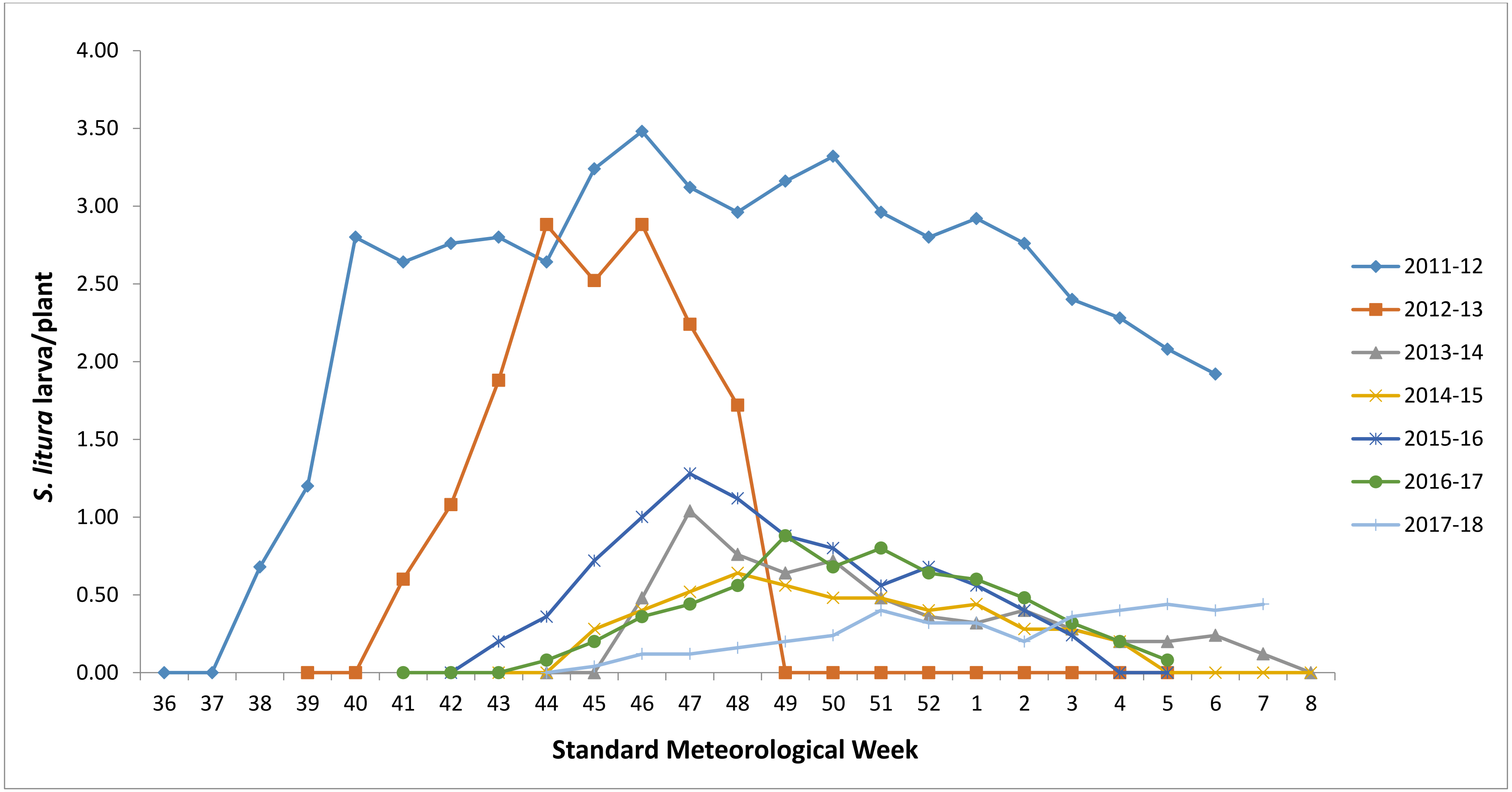

Fig. 9. Population dynamics of *S. litura* during 2012 to 2018 in rabi season

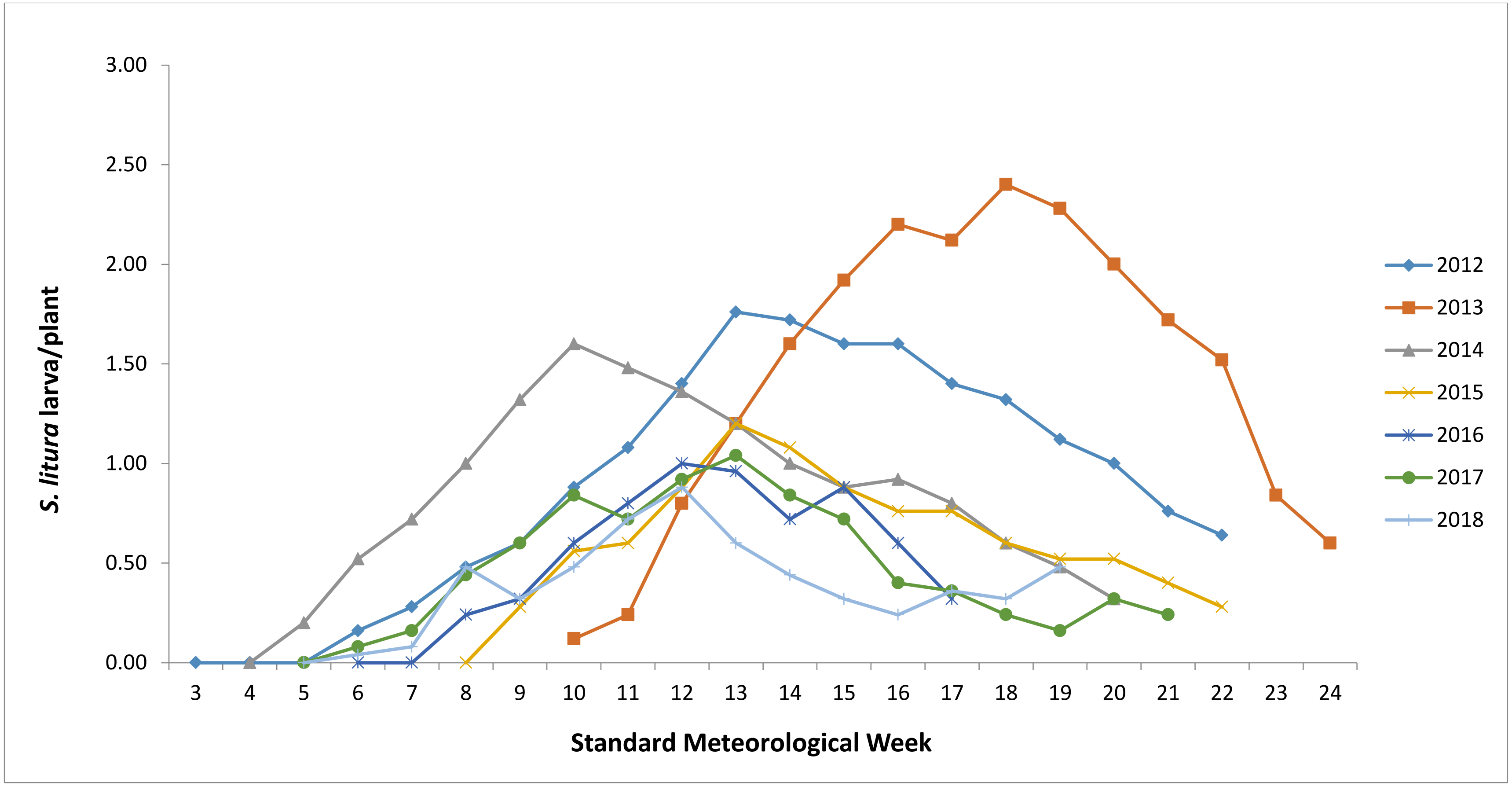

Fig. 10. Population dynamics of *S. litura* during 2012 to 2018 in summer season

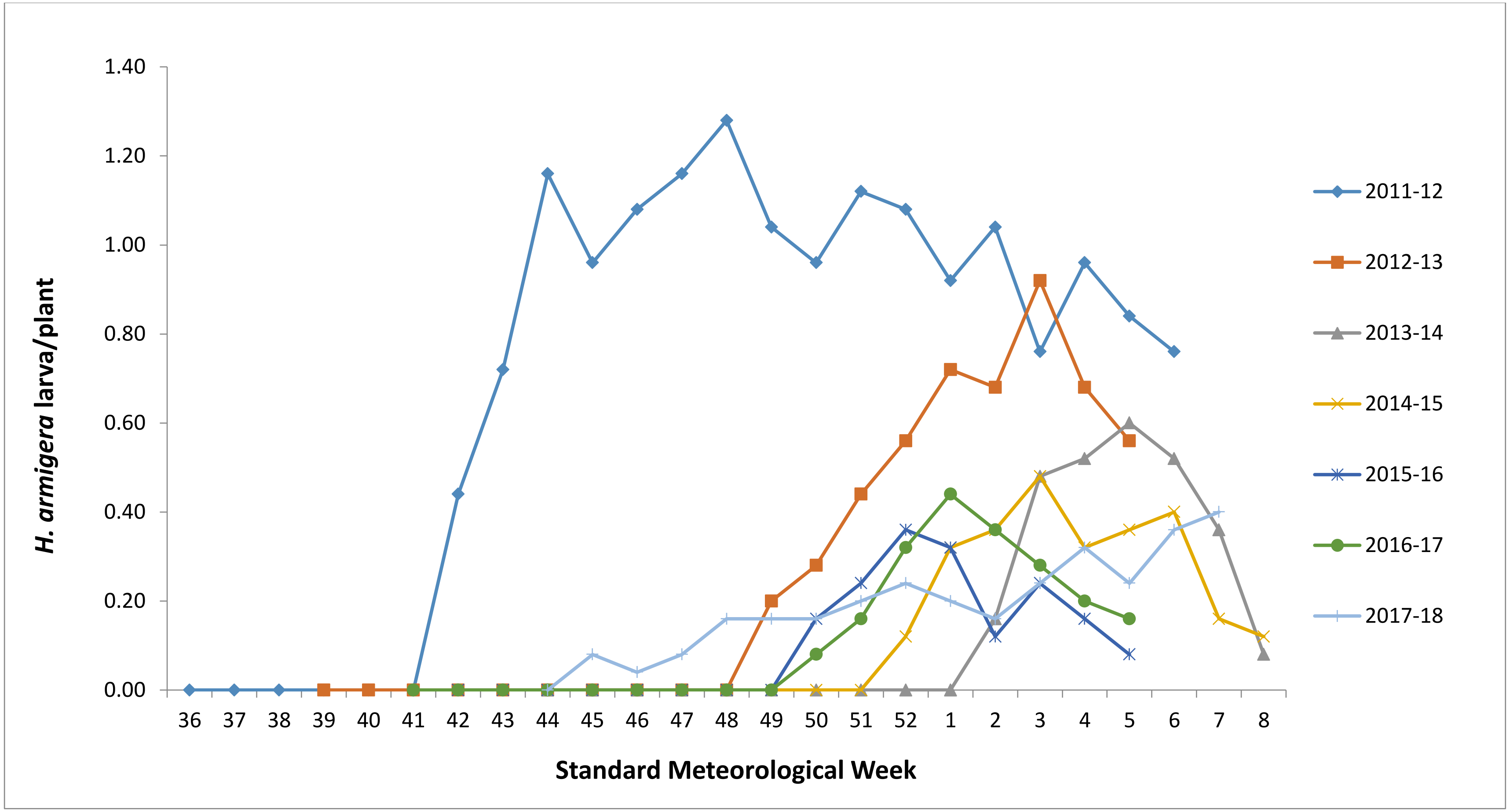

Fig. 11. Population dynamics of *H. armigera* during 2011-12 to 2017-18 in rabi season

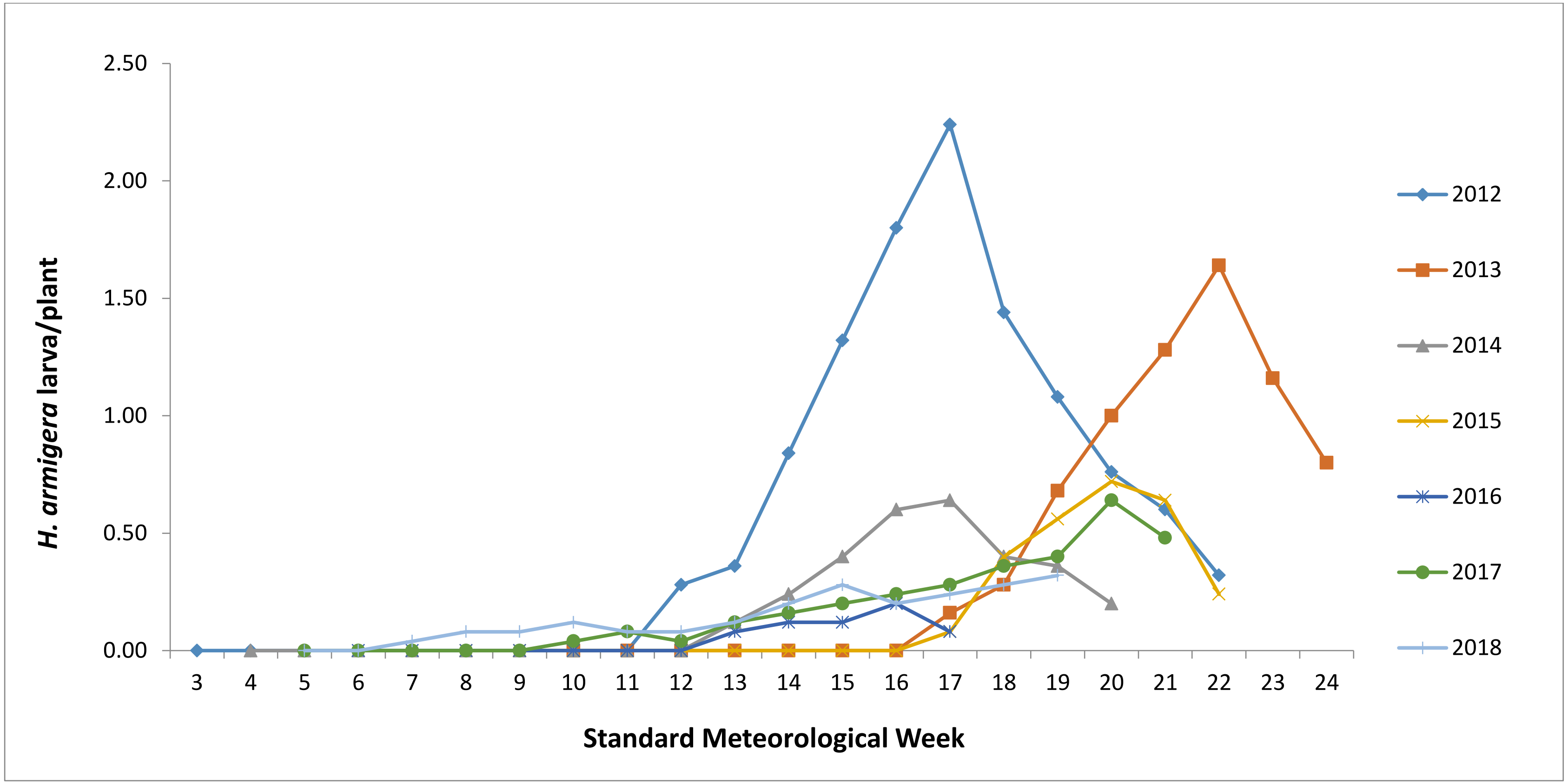

Fig. 12. Population dynamics of *H. armigera* during 2012 to 2018 in summer season

Plate 1. Views of different farmers' fields

Plate 2. Experimental plot at C-Block Farm, BCKV, Kalyani

Leaf miner infestation

Leaf miner (*L. trifolii*) adult

Whitefly (*Bemisia tabaci*)

Aphids (*Myzus persicae*)

Plate 3. Insect pests of tomato at Experimental plot in C-Block Farm, Kalyani

Thrips

Spodoptera litura

Helicoverpa armigera

Plate 3. Insect pests of tomato at Experimental plot in C-Block Farm, Kalyani

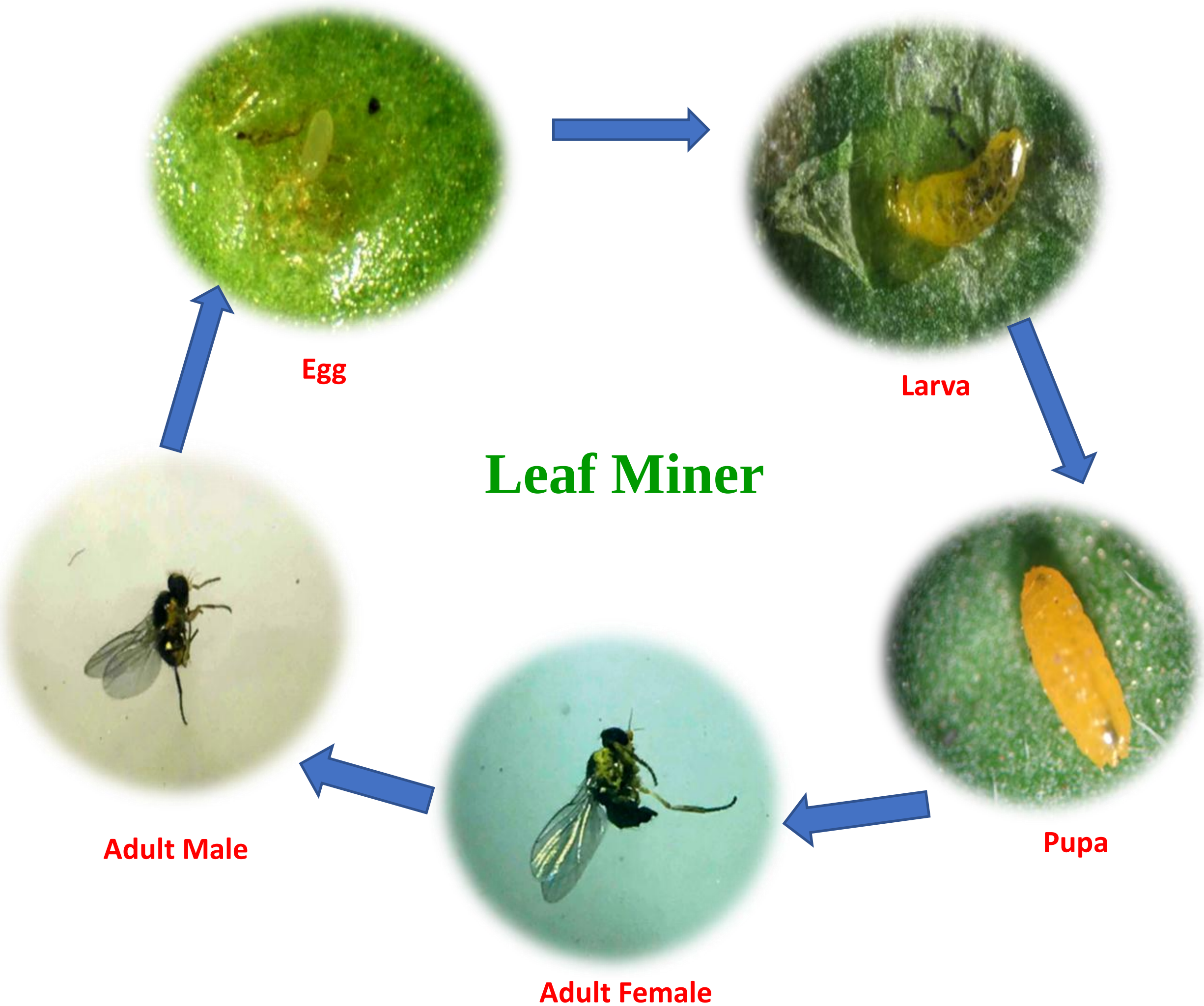

Plate 4. Life cycle of *L. trifolii* on tomato

Tomato field for Management module

Harvested Tomato Fruits

Plate 5. Management field at C-Block Farm, BCKV, Kalyani

a. White Crab Spider

b. *Neoscona* sp.

c. Male *Oxyopes* sp.

d. Female *Oxyopes* sp.

Plate 6. Natural Enemies - Spiders

a. *Coccinella transversalis*

b. *Menochilus sexmaculatus*

c. *Harmonia axyridis*

d. *Micraspis discolor*

Plate 7. Natural Enemies - Coccinellids

In loving memories of Aiee……