INTEGRATED PEST MANAGEMENT AND MOLECULAR CHARACTERIZATION OF MAJOR INSECT PESTS OF TOMATO (*Solanum lycopersicum* L.)

Thesis

submitted to

NAGALAND UNIVERSITY

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of

Doctor of Philosophy

in

ENTOMOLOGY

by

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DECLARATION

I, Arensungla Pongen, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Entomology

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CERTIFICATE – I

This is to certify that the thesis entitled "**Integrated Pest Management and Molecular Characterization of Major Insect Pests of Tomato (*Solanum lycopersicum* L.)"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Entomology is the record of research work carried out by Ms. Arensungla Pongen Registration No. Ph.D/ENT/00240 under my personal supervision and guidance.

The result of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN ENTOMOLOGY

This is to certify that the thesis entitled **"Integrated Pest Management and Molecular Characterization of Major Insect Pests of Tomato (*Solanum lycopersicum* L.)"** submitted by Arensungla Pongen, Admission No. 252/18 Registration No. Ph.D/ENT/00240 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Entomology has been examined by the Advisory Board and External examiner on 10th February 2023.

The performance of the student has been found**Satisfactory/Unsatisfactory.**

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Dated: *(ARENSUNGLA PONGEN)*

LIST OF ABBREVIATIONS / SYMBOLS

%	Per cent
/	Per
°C	Degree Centigrade
etc.	*et cetera*
et al.	*Et alli* (and other)
viz.	videlicet (namely)
msl	Mean sea level
Fig.	Figure
DNA	Deoxyribonucleic acid
mtDNA	mitochondrial DNA
gDNA	genomic DNA
AT	Adenine, Thymine
GC	Guanine, Cytosine
COI	Cytochrome oxidase subunit I
Spp/sp.	Species
rRNA	ribosomal Ribonucleic acid
rpm	Revolutions per minute
PCR	Polymerase Chain Reaction
RFLP	Restriction Fragment Length Polymorphism
Pvt.ltd	Private limited
Cyt b	Cytochrome b
Bp	base pair
ng/ µl	Nanogram per microlitre
SDS	Sodium dodecyl sulphate

Mm	MilliMolar
EDTA	Ethylene-di-amine-tetra acetic acid
TAE	Tris-acetate-EDTA
Tris- HCl	Tris- Hydrochloride
dNTP	deoxyribonucleoside-triphosphate
Ml	millilitre
M	Molar
TE	Tris Ethylene-di-amine-tetra acetic acid
µl	Microlitre
µ	Micron
Rpm	Revolutions Per Minute
G	Gram
Ng	Nanogram
UV	Ultra Violet
V	Volt
NCBI	National Centre for Biotechnology Information
NBAIR	National Bureau of Agricultural Insect Resources
BLASTN	Basic Local Alignment Search Tool
ORF	Open Reading Frames
IBIn	Insect Barcode Informatica
BOLD	Barcode of Life Data
MEGA	Molecular Evolutionary Genetic Analysis
ICAR	Indian Council of Agricultural Research

ABSTRACT

The negative impacts of insecticides havecompelled the development of integrated approaches to manage tomato pests complex. The objective of this research study was to evaluate the impact of integrated pest management on the population dynamics of insect pests and natural enemies in tomato crop. The treatments used were readily available methods i.e. three different dates of planting, five different tomato varieties and use of biopesticides. All these methods proved efficient to control the insect pest to some extent. The research commenced on September 2019 - April 2020 and September 2020 - April 2021. The major insect pests and natural enemies recorded from tomato ecosystem were tomato green looper (*Chrysodeixis eriosoma*), green citrus aphid (*Aphis spiraecola*),fruit borer (*Helicoverpa armigera*),seven-spot ladybird (*Coccinellaseptempunctata*), transverse ladybird(*Coccinella transversalis*),parasitic wasp(*Glyptapanteles* sp.)and predatory spider (*Oxyopes* sp.). The early planting of tomato (transplanted on 23rd October) recorded the least aphid infestation (7.28 aphid/plant) whereas the last date of planting (transplanted on 23rd November) observed minimum fruit infestation of 2.51% in tomato crop. Crop varieties viz., pusa rohini, pusa sheetal, rocky, sakata-914 andlocal cultivar were tested for their possible resistance against insect pests of tomato. Experimental findings reveal that the local cultivar used in the present study was comparably more resistant to aphid (5.63 aphid/plant) and fruit borer infestation (2.71%) as compared to other varieties. The adoption of IPM technology in tomato using biopesticides viz., marigold (trap crop), multineem (0.03%), emamectin benzoate (5% SG), spinosad45% SC, *Beauveria bassiana* and *Pongamia pinnata*, out of which emamectin benzoate (5% SG) recorded highest reduction of*Aphis spiraecola* and *Helicoverpa armigera.* Studies on field evaluation of biopesticides revealed no significant reduction on predator population i.e. coccinellid beetlesand spider. Lastly, molecular identification was successfully done for6 major insect species (pests + natural enemies) and DNA barcodes were successfully developed by sequencing partial Cytochrome oxidase I (COI) gene of mitochondrial DNA. The molecular identity of the insect species was established through BLAST NCBI and identification of 5 insects were done upto species level whereas the remaining 1 was

identified upto genus level due to absence of matching molecular data at NCBI. All the analyzed sequences have been deposited to International GeneBank (NCBI)with accession numbers ON460288, ON460289, ON461368, ON461370, ON489304 and ON496461. The comprehensive information on the integrated pest management and molecular database developed could be used as diagnostic guide at both morphological and molecular level and aid in developing better pest management strategies.

Keywords: Vegetable, insect pests, natural enemies, IPM, biopesticides, DNA barcoding, COI gene

CHAPTER I
INTRODUCTION

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important commercial vegetable grown and occupies the second position among vegetables in area and production in the world (Anonymous, 2018). It belongs to the family Solanaceae and is said to be the native of South America. Tomato is grown widely both for fresh market and processing. The fruits can be eaten either raw or cooked and is a major source of vitamins (A, B, C) and minerals (Bose and Som, 1990). Large quantities are processed into stable products like ketchup, sauce, pickles, paste, chutney, juice etc (Thompson and Kelly, 1983). It is universally treated as 'Protective Food' because of its special nutritive value as the pulp and juice, which are easily digestible, have mild aperients, promoter of gastric secretion and blood purifier. Tomato thrives best in moderate climatic conditions but have the potential to grow in all kinds of climatic conditions *viz*., temperate, tropical and subtropical due to its high adaptive quality. The crop requires warm weather and abundant sunshine for best growth and development. The plant grows best when provided with uniform moisture and well drained soil.

India ranks second in tomato production in the world after China. Bihar, Karnataka, Orissa, Maharashtra and Andhra Pradesh are the major tomato growing states in India contributing maximum share in area and production. In India, tomato is cultivated in an area of 789.2 thousand hectares with a production of about 19759.3 thousand million tonnes. While in Nagaland scenario, the tomato is grown in an area of 3.13 thousand hectare with a production of 22.47 thousand million tonnes (Anonymous, 2018).

In the present day context, tomato farming requires adequate protection from principal enemies such as insects, weeds, fungus and mites for profitable return. Among these enemies, insect pests are major constraint because all parts of the plant offer food, shelter and reproduction site for insects. Insects can

cause unthrifty growth or death of the tomato plant and damage to fruits in the form of scarring tissue destruction and aberration in shape or colour. Insects can also introduce decay organisms into the fruit or can act as vector for many viruses and several mycoplasmas that cause growth disorders, deshaping of fruits or sometimes death of the plant.

Tomato is devastated by a wide array of insect pests like cutworms and tobacco caterpillar (*Agrotis ipsilon* and *Spodoptera litura*), aphids (*Myzus ornatus* and *Myzus persicae*), thrips (*Ceratothripoides calaratis*), cabbage loopers, white flies (*Bemisia tabaci* and *Trialeurodes vaporiorum*), tomato fruit borer (*Helicoverpa armigera*), leaf miners (*Liriomyza trifolii* and *Liriomyza bryoni*), flea beetles (*Chalaenosoma metallicum*), potato tuber moth (*Phthorimaea operculella),* leaf bug (*Nesidiocoris tenuis*), green bug (*Nezara viridula)* mealy bug (*Pseudococcus cryptus*), Lunate fly *(Eumerus species*), spotted beetle (*Henosepilachna vigintioctopunctata*), tobacco hornworms and Colorado potato beetles. The monetary loss due to these pests in India has been estimated over rupees one thousand corers per year (Jayraj *et al*. 1994). Among these insect pests, fruit borer cause considerable damage to the crop. Tomato fruit borer, *H. armigera* is a polyphagous pest with host range of over 360 plant species including cultivated crops of economic importance (Duraimurugan and Regupathy, 2005). It alone causes the loss in tomato yield to the tune of 50 to 80 per cent (Tewari and Krishnamoorthy, 1984). The extent of damage to crop and the consequent loss in yield due to this pest vary considerably amongst crops, regions and locations, and seasons (Fitt, 1989; Wakil *et al*. 2010). Besides, several natural enemies also harbour in tomato ecosystem which maintain the pest population at certain level. In nature, there is a balance between the pest and natural enemy populations. These natural enemies help the farmers by keeping the harmful pests under check (Gul *et al*. 2017). The presence of a variety of natural enemies of agro ecosystems would reduce the cost of cultivation by cutting down on the pesticide usage. Natural enemies build up their population

by consuming their prey/hosts (pests) and regulate them. The natural enemies are naturally occurring and provide outstanding regulation in reducing the level of pest populations below those causing economic injury level. Therefore, the importance of natural enemies in preventing invertebrate pest outbreaks is well recognised (Chambers and Adams, 1986).

To control the insect pests and to save the crop, pesticides are being used in large quantities. The use of insecticides has become indispensable because of its rapid effect, ease of application and availability. The chemical insecticides significantly curtailed the insect pests in the past but in due course it resulted in the development of resistance to insecticides in insects, environmental degradation and increase in the cost of cultivation. To overcome these unfavourable situations, Integrated Pest Management (IPM) strategies are being advocated. The concept of IPM is becoming a practicable and acceptable approach over the world. The idea is to maintain the pest below economic threshold rather than eradicate it. This approach advocates an integration of all possible or at least some of the known natural means of control (cultural control, physical control, biological control, mechanical control etc.) with or without insecticides so that the best insect management in terms of economics and maintenance of pest population below threshold level.

With millions of species and their different life stages, correct identification becomes a challenge for taxonomy. Pest management tools depend on proper identification of arthropod species, which are usually classified relying on morphological keys. However, the shortcomings and limitations of the conventional taxonomical identification methods highlighted the need for new and simple methods of pest identification. Due to the advances in science, it is now possible to complete the identification of new or invasive taxonomically difficult species very quickly and reliably using various molecular techniques (Behere *et al*. 2008). Besides other molecular techniques, DNA barcoding is getting more attention in identification of taxonomically difficult species, it is a

taxonomic method that uses a short genetic marker in an organisms DNA as to identify it as belonging to a particular species. DNA barcoding is a universal typing system to ensure rapid and accurate identification of a broad range of biological specimens. It allows the species characterization of organisms using a short DNA sequence from a standard and agreed-upon position in the genome (Hebert *et al*., 2004). Comprehensive molecular information is not available, especially on pests and natural enemies of tomato ecosystem in Nagaland. Therefore, considering all these facts, this research aims to study the use of all management techniques and methods available in a compatible manner to ensure sustainable agriculture. Hence, the present study "Integrated Pest Management and Molecular Characterization of Major Insect Pests of Tomato (*Solanum lycopersicum* L.)" was undertaken with following objectives:

1. Influence of date of planting and varieties on the insect pest complex and their natural enemies in tomato ecosystem

2. To evaluate the efficacy of some biopesticides and trap crop against major insect pests and its impact on natural enemies of tomato

3. Molecular characterization of major insect pests and their natural enemies in tomato

CHAPTER II
REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1. Pest complex of Tomato

Tomato (*Solanum lycopersicum* L.), is the most popular and important vegetable crop, which is susceptible to insect attack from seedling to harvesting stage. Salasy (1992) recorded *Liriomyza* spp. as major pest in tomato. Srinivasan (1993) reported white fly and fruit borers were major threat to tomato crop. Dhamdhere and Bhonsle (1995) reported *Bemisia tabaci* and *Helicoverpa armigera* were the regular pests in tomato cultivation. Similarly Naik *et al.* (2005) also observed *H.armigera*, *B. tabaci* and *Liriomyza trifolii*as the major insect pests of tomato in India.

A total of 41 species of insect pests belonging to 21 different families from tomato ecosystem have been recorded in India, which includes mainly sucking pests *viz*., *B. tabaci*, *Aphis gossypii*, *M. persicae* and *N. viridula.* Other insect pests like *Spodoptera litura, Monolepta andrawesi, Poekilocerus pictus, Atractomorphacrenu lata, L. trifolii, H. armigera, Othreis fullonica* (*Eudocima fullonica*) were also recorded (Reddy and Kumar, 2004).

Tomato fruit borer has been identified as a major pest of tomato in many countries of the world. In India, 181 cultivated and uncultivated host plant species belonging to 45 families were susceptible to *H. armigera* alone (Mustafiz *et al*. 2015). Bouhachem *et al.* (2007) stated that the tomato fruit borer, *H. armigera* is a major threat in the processing tomato crops in Tunisia.

Blister beetles belonging to the family Meloidae can be considered as serious agricultural pests, and cause economic damages to variety of vegetables including tomato (Ghoneim, 2013). Tomato crop were the hosts for many kinds of insects, since all parts of the plant offer food, shelter, and reproduction sites for insects. In case of screen house condition, two major pests whitefly

Trialeurodes vaporariorum and two spotted spider mite *Tetranychus urticae* tends to be predominant (Lange and Bronson, 1981).European tomato crops were affected by a diversity of insect pests and diseases. Among which, two whitefly species *B.tabaci* and *T. vaporariorum* were widespread and problematic for tomato cultivation (Arno *et al*. 2008).

Azad Thakur *et al*. (2012) reported that, the cultivation of tomato crop is very limited in Meghalaya. The occurrence of high rainfall does not permit its successful cultivation due to high incidence of pests and diseases. The crop in Meghalaya is infested by fruit borer (*H. armigera*), aphid (*M. persicae*), cutworm(*A. ipsilon*), jassids (*Amrasca bigutulla bigutulla*) and white fly (*B. tabaci*). Of which, fruit borer is a major pest causing severe damage to the fruits thereby resulting in low yield.

From transplanting to fruiting stage, a total of 14 insect species were found to be associated with tomato plants in Ghana, whereas the highest number of insect pests were recorded at the fruiting stage of the plant (Ofori *et al.* 2014). Oda *et al.* (2012) observed the prevalence of various insect pests such as aphid, thrips, whitefly, leaf miner in tomato ecosystem in Thailand. Chaudhuriand Senapati (2001) reported that, aphid (*A. gossypii*), whitefly (*B. tabaci*), tingid bug (*Urentius hystricellus*), leaf miner (*L. trifolii*), and fruit borer (*H. armigera*) were found to be major pests of tomato in terai region of West Bengal.

A field experiment was conducted to study the occurrence and distribution of insect pests attacking solanaceous vegetables in semi-arid region of central Gujarat, India (Khajuria*et al*., 2014). The experimental result revealed that, tomato crop was found to be damaged by fruit borer (*H. armigera*), leaf caterpillar (*S. litura*), aphid (*A. gossypii*), white fly (*B. tabaci*), Serpentine leaf miner (*L. trifolii*), and mealy bug (*Pseudococcus virgata*).

The tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) is a major insect pest infesting tomato crops in countries of the

Mediterranean basin, causing major yield and economic losses (Desneux *et al.* 2011; Balzan and Moonen, 2012; Garzia *et al.*, 2012). Because of high biotic potential, multi-voltine character, short generation time, and increased resistance to insecticides, it attains the key pest status even in the new habitats and poses a serious threat for successful tomato production systems across the world (Desneux *et al.*, 2011). Sharma and Gavkwere (2017) reported that, this pest is notorious and feeding on tomato leaves, flower buds, apical shoots and fruits in sub-temperate mid-hills of Himachal Pradesh, India.

2.2. Natural enemies in tomato ecosystem

Many insects cause serious damage to agricultural crops and reduce the crop yield. However, some insects were acting as natural enemies of the pests which check the harmful pests under control (Anbalagan *et al.*, 2016).

Lokhande (1986) reported six spotted lady bird beetle, *Menochilus sexmaculatus* and dipteran predator, syrphid fly were the predominant natural enemies found to be feeding on aphids in the chilli ecosystem.*Coccinella transversalis* and *Micraspis discolor* were the most dominant predator species observed throughout the *Capsicum chinense* cropping season in Jorhat, India (Begam *et al.* 2016). Chintkuntlawwer*et al.* (2011) recorded 2 species of coccinellid predator and 1 braconid parasitoid in chilli ecosystem of Jabalpur, India.

Coccinellids were the most commonly known of all beneficial insects, the family includes about 3000 species of beetles, distributed across the world. Total of 36 species of true aphidiphagous coccinellids have been reported in Indian subcontinent (Agarwala and Ghosh, 1988). Mayadunnage *et al.* (2007) studied the coccinelllids diversity in different vegetable crops in Sri Lanka, total of fifteen species from 12 genera belonging to sub-families Coccinellinae, Chilocorinae and Scymninae were reported. Among the coccinellids, the species *Micraspis discolor* were found to be dominant.

Similarly, *Nesidiocoris tenuis* is the mirid predator that is effective in the control of whitefly population on tomato crops. It is common in tropical and subtropical wereas, feeds mainly on whiteflies, but also on other pests such as spider mites, leafminers and early instars of Lepidoptera (Carnero *et al.*,2000; Urbaneja *et al.* 2009).

Arno *et al.* (2005) demonstrated that, *Eretmocerus mundus* (Hymenoptera: Aphelinidae) is a solitary ecto and endo parasitoid found to be effective against whitefly nymph in greenhouse tomatoes in Spain. Among the predators of whiteflies in greenhouse solanaceous crops, *Macrolophus pygmaeus* (Hemiptera: Miridae) and *M. melanotoma* (*M. caliginosus*), were considered to be principal one showed more predation rate on *T. vaporariorum* on tomato and eggplant in Greece (Perdikis and Lykouressis, 2002).

Leaf miners were one of the important pests of vegetable crops especially, tomato. Leaf miners have several natural enemies, which were mostly parasitoids. Those parasitoid species were, *Diglyphus isaea* (Hymenoptera: Eulophidae), *Dacnusa sibirica* and *Opius palipes* (Hymenoptera: Braconidae).The species, *Diglyphus isaea* is an ectoparasitoid, which lays its eggs in the mine, beside the leaf miner larva (Ode and Heinz, 2002). Likewise, the predatory mirid bug, *D. hersperus*can reduce the population of *Frankliniella occidentalis* on greenhouse tomatoes. However, this predator may cause damage to the tomato fruit when the thrips population is low (Shipp and Wang, 2006).

Ladybird beetles were considered as beneficial, because their predatory activity helps in regulating pest population of soft bodied insects like aphids, jassids etc. Khan *et al*. (2007) studied the biodiversity and species composition of lady bird beetles (Coleoptera:Coccinellidae) from Pakistan. A total of 51species from 6 subfamilies of coccinellids were recorded from the study area.

Aphid population were suppressed by a high number of predators in solanaceous and other vegetable crops, the predatory midges (Diptera:

Cecidomyiidae), chrysopids (Neuroptera: Chrysopidae), coccinellids (Coleoptera: Coccinellidae) and mirids (Hemiptera: Miridae) were some of the natural enemies controls the aphid population effectively (Perdikis *et al*. 2008). In addition to these, the predatory bugs *Anthocoris nemoralis*, *Anthocoris nemorum* (Hemiptera: Anthocoridae) and *Orius similis* also effectively control the aphids in the vegetable ecosystem (Meyling*et al., 2*003; Sengonca *et al*., 2008).

Insect predators belonging to the genus *Orius* (Hemiptera: Anthocoridae), were common on vegetable crops. The species *O. majuscules* and *O. laevigatus* were found to be effective against *B. tabaci and F. occidentalis* in solanaceous crops (Arno *et al.* 2008).

Singh *et al*. (2011) studied the biodiversity, distribution and host range of the genus *Ephedrus* sp. (Hymenoptera: Aphidiidae) in Manipur, India. The authors recorded 13 species of aphid parasitoids belonging to the genus *viz*. *Ephedrus brevis, E. cerasicola, E. dioscorae, E.lacertosus, E. minor, E. nacheri, E. niger, E. orientalis, E. persicae, E. plagiator, E. srinagwerensis, Ephedrus*sp.a and *Ephedrus*sp.b from the aphid host infesting crops including Solanaceous crops ecosystem. *Ephedrus persicae* (Hymenoptera: Braconidae: Aphidiinae) represents a biologically complex parasitoid species group that parasitizes more than150 aphid species worldwide, including many pests in different agroecosystems (Hurd, 2009).

A total of 129 species of predatory and parasitic insects were recorded from vegetable crops (brinjal, okra and tomato) in Tamil Nadu (Anbalagan *et al.* 2016). The predatory insects comprised of dragonflies and damselflies (Odonata), assassin bugs, mirid bugs, anthocorid bugs (Hemiptera), ground beetle, rover beetle and lady bird beetles (Coleoptera) ant and wasp (Hymenoptera), predatory syrphid fly (Diptera) and ant lion and owl fly (Neuroptera).

2.3. Influence of date of planting and varieties on the insect pest complex and their natural enemies in tomato ecosystem.

2.3.1. Influence of date of planting

Kaur and Singh (2001) carried out a research work in the year 1992-94 in Ludhiana, Punjab on the effect of cultivars (Punjab Kesri, Naveen, Punjab Chhuhara and Punjab Tropic) and planting dates (23rd& 26th November and 21st& 22nd December) on the population of *H. armigera* in tomato. The authors reported the cultivar Punjab Kesri had the lowest level of egg and larval population; Punjab Chhuhara and Naveen fell in mid category; and Punjab Tropic showed the highest egg and larval population.

Rashid *et al.* (2008) conducted an experiment to detect the effect of different dates of planting on the prevalence of tomato Yellow Leaf Curl Virus (TYLCV) and whitefly in tomato fields in Bangladesh. The percentage of TYLCV incidence in different dates of planting time (one year from mid-October, 2000 to mid-September, and 2001) of tomato cv. Bari was evaluated. The highest TYLCV incidence (%) was observed at 75 DAP during the period of March and April, 2001 planting followed by May, 2001 planting, but the lowest TYLCV incidence (%) was found in November, 2000 planting followed by December, 2000 planting. A strong correlation was obtained between the incidence of TYLCV and number of whitefly in tomato plants

Alfreen *et al.* (2017) conducted an experiment at the Sher-e-Bangla Agricultural University, Dhaka during rabi season 2013-14 to study the effects of different planting dates and mechanical support for the management of insect pest in tomato. The authors reported that the tomato planted at 10th December with the method of horizontal mechanical support was more effective for reduction of insect pest of tomato.

Harshita *et al.* (2018) noticed the incidence of fruit borer on the month of January 2016 with a mean population of 0.9 larva/plant and observed peak infestation of *H. armigera* during March of 2015-16 and 2016-17.

The findings of Harshita *et al.* (2019) reported that the peak population was observed during the month of February and March. A similar observation was also made by Mondal *et al.* (2019); the authors report the highest lady bird population during the 13th standard week (i.e. fourth week of March).

Madhu *et al.* (2020), reported peak spider population in tomato ecosystem in the month of January and also recorded spider population from the first week after transplantation to the end of the harvest. Similarly Khokhar and Rolania (2021) conducted an extensive study on spider population in tomato and reported predatory spiders were present throughout the crop period from 9th SMW to 22nd SMW.

2.3.2. Influence of different genotypes

Sharma *et al.* (2001) also evaluated thirty one advance generation lines of tomato derived from 13 inter varietal crosses against *H. armigera* and reported that none of the tomato genotypes was immune to its attack but four cultivars, *viz.* 2546-1-2-1, 4237-11 B (Bulk), 0245-1-1 and 0247-1-3-1 were the most promising.

Selvanarayanan and Muthukumaran (2005) carried out an extensive study in Tamil Nadu, India during 1996-2004. An exhaustive germplasm comprising 321 tomato accessions including cultivars, wild lines, landraces, tribal/native tomatoes was gathered from various sources and screened for resistance against the major pest namely fruit worm, *H. armigera.* In the field screening, larval population and fruit damage was evaluated, while in the glasshouse, foliage and fruit damage was assessed and ten promising accessions were selected. Based on further laboratory studies on the various mechanisms and bases of resistance, four accessions namely, Varushanadu Local, Seijima Jeisei, Ac 238 and Roma were selected and 22 subjected to inter-crossing by conventional hybridization, which yielded three viable hybrids. The resistance potentials of these hybrids against the fruit worm, *H. armigera,* leaf caterpillar, *S. litura,* leaf miner, *L. trifolii* and whitefly, *B. tabaci* were probed both in

thefield and glasshouse along with their respective parents. The hybrids exerted lesser feeding and ovipositional preference and higher antibiotic effects on insect stages. The density of three types of non-glandular and two types of glandular trichomes and phenol content in the foliage, lycopene and ascorbic acid content in the fruits were the major factors of resistance. Based on these studies, Hybrid 3 (Ac 238 x Roma) and its derivatives were deemed as potential accessions possessing insect tolerance

Amutha and Manisegaran (2006) carried out a field trial in Madurai, Tamil Nadu, India, in 2004 to screen 44 tomato cultivars, comprising 26 from NBPGR (New Delhi), 3 from llHR (Bangalore) and 15 from TNAU (Coimbatore), against *H. armigera.* Only one accession (LE 228) was found to be resistant, which had fruit damage of 2.4% compared to 33.6% in the susceptible genotype (LE 4). Twelve cultivars were found to be moderately resistant, with percentage damage ranging from 11.2% (EC 398704) to 19.1% (LE 526). Thirty cultivars were categorized as moderately susceptible, with 20-30% fruit damage.

Sharma *et al.* (2006) evaluated eleven tomato genotypes for susceptibility to the greenhouse whitefly, *T. vaporariorum*. Genotype Rodade-1 proved to be the least susceptible with negligible infestation at both the locations, whereas, BL-333-3 and PTOM-9802-3 were relatively less susceptible to the pest than rest of the germplasm.

Sahu *et al.* (2006) conducted a field experiment and screened thirteen tomato genotypes against tomato leaf miner, *L.trifolii* during spring summer season of 2001-2002. Lowest affected leaves by leaf miner were recorded in NS 101 followed by Punjab Keshri and Manimaker in upper and in middle leaves but genotype S-22 had least infestation on lower leaves. Maximum infestation in lower leaves was found in genotypes Pusa Ruby, Sadabahar, Ganpati and Paras Dadi.

Singh *et al*. (2013) studied the relative performance of 13 tomato hybrid varieties against the fruit borer, *H.armigera* infestation during 2010-2011. Two varieties, viz., NS-538 (Namdhari seed) and Shaktiman were least infested and classified as resistant varieties. Nine varieties viz., NS-501 (Namdhari seed), Lakshmi, Shahenshah, NS-815 (Namdhari seed), All-rounder, Manithoibi, Manileima, Ms (Marglobe supreme) and American Apple were graded as moderately resistant. Two varieties viz., Dev and Manikhumnu were rated as moderately susceptible. The study indicated that the varieties as promising source of resistance may be incorporated in the integrated pest management.

Usman *et al*. (2013) studied on fourteen commercially available tomato genotype *viz.* Mission 102, Sultan, 027, Chinar, GS 5575, Sourabh, T 7008, R 165, RK 101, Riogrande, Roma, Bambino, Super Classic and Roma VF were tested for resistance against *H.armigera* infestation under field conditions at the New Developmental Farm (NDF), University of Agriculture, Peshawar during 2009 and 2010. The result revealed that the genotypes Chinar, Sourabh and Sultan had minimum fruit weight loss (18.98%, 21. 01% and 21.89%, respectively) as well as minimum number of infested fruits (21.40%, 23.87% and 25.43%, respectively).

Bugti (2016) carried out an investigation to record insect pests and predators on three tomato varieties namely, Zatooni, Moon star and Hybrid-1000. He concluded that the variety Hybrid-1000 was found more resistant to the insect pest and suggested for better production.

Mac *et al*. (1972), in their study on spider reported architectural structure and plant canopy as components for habitat selection while others, Harwood *et al*. (2004) Thevenard *et al*. (2004) and Gesraha *et al*. (2019), concluded that the abundance of spider is associated with their preferable insect pest (prey) availability and did not relate to a certain plant.

2.4. To evaluate the efficacy of some biopesticides and trap crop against major insect pests and its impact on natural enemies of tomato.

Hussain and Bilal (2007) evaluated the effect of marigold as a trap crop with various combinations of tomato to show the differential response of fruit borer and the resulted fruit damage by this pest. The authors observed the lowest larval reduction (81.0-88.89%) and significantly better management in 3:1 combination than other treatments

Boica*et al*. (2007) experimented on the spraying of the neem oil (1.2% of azadirachtin) at a concentration of 0.5%. The IPM and IPM-neem control techniques were efficient in controlling the late pest of the tomato cultivar. The conventional control technique, IPM and IPM-neem promoted bigger tomato production with increments of up to 74%. The number of sprayings was reduced up to77% with the IPM and IPM-neem techniques, when compared to the conventional method. The neem product may be a promising alternative to the late pest control in the tomato field that adjusts to the IPM.

Man (2010) in an extensive study reported the effects of tobacco leaf extract, tea extract, neem (*Azadirachta indica*) leaf extract (NLE), neem seed kernel extract (NSKE), jatropha (*Jatropha* sp.) leaf extract, jatropha kernel extract, karanj (*Pongamia pinnata*) leaf extract, karanj kernel extract, tulsi (*Ocimum tenuiflorum*) leaf extract (TLE), onion-garlic bulb extract (OGBE) and chilli fruit extract (CFE) on the performance of tomato and incidence of fruit borer (*Helicoverpa* sp.) in Allahabad, Uttar Pradesh, India, during 2005-06. NSKE resulted in the greatest fruit yield (36.98 t/ha) and the lowest incidence of fruit borer infestation (5.84%) and fruit damage (7.37%).

Nzanza and Mashela (2012) reported that the whitefly and aphid on tomato(*Solanum lycopersicum* L.) were economically important insect pests that were difficult to manage due to their resistance to a wide range of chemical pesticides. Field experiments were conducted to assess the effects of fermented plant extracts of neem (*A. indica*) leaf and wild garlic (*Tulbaghia violacea*) on

whitefly and aphid population. The population of both insect pests showed two different patterns with higher counts observed during summer than winter monitoring. During both seasons, numbers of whiteflies and aphids increased regardless of the treatment, but the numbers remained significantly lower within treated than untreated plots. The mixture of neem and wild garlic was more effective in reducing population densities of whitefly and aphid than either plant extract applied alone.

Karabhanthanal and Awalnavar (2012) conducted an experiment to test the efficacy of HaNPV, *Metarhizium anisopliae*, *Beauveria bassiania*, *Nomuraea rileyi* and *Steinernema* sp. against *H. armigera* on tomato. The lowest fruit damage (14.5%) and the highest marketable yield (166.4 qt/ha) and net profit (14390 Rupee/ha) was obtained with *Nomuraea rileyi*, which was less effective than the chemical treatment but as effective as HaNPV.

Muniz *et al*. (2014) studied on the pathogenicity of entomopathogens against insect pests of tomato. The results indicated that psyllids, thrips and whiteflies were susceptible to the entomopathogens such as *B.bassiana* and *M. anisopliae*. Klieber and Reinke (2016) also reported that the entomopathogen *B.bassania* has epiphytic and endophytic activity against tomato leaf miner, *T. absoluta.*

Dhar and Bhattacharya (2015) reported that the treatment with one time spray of imidacloprid 17.8% SL followed by twice spray of spinosad 45% SC gave the best result for management of pest viz., whitefly and fruit borer and disease incidence of Yellow Vein Mosaic Virus and Tomato Leaf Curl Virus on okra and tomato respectively.

Kichaoui *et al.* (2016) reported the use of biopesticide as one of the best solutions and safer approach for management of pests leading to reduce cost of pests control, preserves human health and environment from pollution. He also reported that *B. bassiana* exhibited satisfactory efficacy against *T. absoluta* larva compared to chemical treatment.

Singh and Tripathi (2017) worked in an extensive on farm trials on cultivation of marigold on field bunds of tomato crop for additional income as well as component of insect pest management. The authors recorded yield advantage of 505, 221% and 200% with the improved varieties of marigold viz. Namdhari, Orange 900 and Pusa narangi in comparison to local varieties during the year 2012-13, 2013-14 and 2014-15, respectively. Trap cropping of marigold with tomato also found effective in controlling fruit borer, *H. armigera* infestation with increased population of coccinellid predators.

Wagh *et al*. (2017) reported emamectin benzoate 5% SG, cypermetrin 25 EC and abamectin 1.9 EC emerged as most effective treatment to reduce aphid population in tomato ecosystem. Similarly, Khalequzzaman and Nahar (2008) studied on the biopesticidal action of azadirachtin, imidacloprit, malathon, carbosulfan and cymbush to control *Aphis craccivora*.

Agale *et al*. (2019) in an extensive study observed that the bio-pesticide treatment with neem based products was found the safest to coccinellid beetles. In addition, the entomopathgogenic fungi, *B. bassiana* which proved to be non toxic to coccinellids (Thungrabeab & Tongma 2007 and Sayed *et al.*, 2021)

2.5. Molecular characterization of major insect pests and natural enemies in tomato.

Insects were the most abundant of all life on earth and have evolved into a tremendous range of different forms. With millions of species and their different life stages, correct identification becomes a challenge for taxonomy. DNA based identification by using mitochondrial gene Cytochrome oxidase subunit I (COI) helps in resolving the problem (Hebert *et al*., 2003). The Cytochrome oxidase I (COI) gene is most widely applied as a molecular barcode for the identification of species of animal species with very high accuracy (Hebert *et al*., 2003; Hulcr *et al*., 2007). The insect mitochondrial genome (mitogenome) consists of a circular, two-stranded genome of 14,000-19,000 bp length, which contains 37 genes, including 13 protein coding genes (PCGs)

(Behere *et al*. 2016). Among 13 protein coding genes, a fragment of the COI gene has been selected as the standard barcoding region for animals (Wang *et al.* 2015). Advances in DNA-sequencing technologies have enabled researchers studying about arthropod pests by means of simple, cost-effective and rapid DNA analyses. The molecular approaches provide powerful tools to identify species and investigate phylogenetic relationships in insects (Gariepy *et al.*, 2007).

DNA barcoding using COI gene was undertaken for studying the global genetic diversity of *H. armigera* and its evolutionary relationship to *H. zea* (Behere *et al.*,2007). Using multiple specimens of *H. armigera* from all the continents, the single species status of *H. armigera* was successfully established which otherwise was very difficult using phenotypic characters (Behere *et al*. 2007). Chen *et al.* (2011) discriminated the two sibling species of Noctuidae moth i.e. *H.armigera* and *H. assulta* by simple polymerase chain reaction amplification experiment with the help of DNA markers.

Behere *et al*. (2008) successfully utilized partial regions of the mitochondrial DNA (mtDNA), cytochrome oxidase subunit I (COI), cytochrome *b* (Cyt*b*) genes and molecular markers to discriminate the four significant pest species in the *H.* genus (*H. armigera, H. assulta*, *H. punctigera* and *H. zea*) irrespective to their life stages.

In recent years, DNA-based methods have been used to identify natural enemies of pest species where morphological differentiation is problematic (Jenkins *et al*., 2012). Identifications using molecular data help in elucidating the relationships of morphologically variable individuals of the same species, such as individuals in different developmental stages, castes in social animals and sexually dimorphic individuals (Miller *et al*., 2005; Johnson *et al*., 2009). DNA barcoding also helps to identify specimens in various developmental stages, which were difficult or impossible to identify morphologically due to a lack of reliable characteristics (Pieterse *et al.,* 2010). DNA barcoding is

inseparably linked to taxonomy, the integration of various types of data, such as morphological, ecological, physiological and molecular data, including DNA barcodes, will improve new species discovery and description processes (Waugh, 2007; Padial *et al*., 2010).

Chen *et al.* (2012) reported that, the Cytb gene is an effective marker for the study of aphid population genetics due to its high sequence diversity. Nagoshi *et al.* (2011) has developed the DNA barcodes to identify invasive armyworm *Spodoptera* species in Florida using COI gene. This molecular approach makes the valuable complement to the morphological methods currently used for the monitoring of invasive *Spodoptera* and other Lepidopteran pests in the United States.

Rebijith *et al.* (2012) developed the species-specific markers using existing nucleotide differences in the COI partial sequences of both *A. gossypii* and *M. persicae*. They reported that these species-specific markers have proved to be adequate for the molecular identification of these species. The species identification of aphids through DNA barcodes using mitochondrial COI gene has been done to discriminate over 300 species of aphids from more than 130 genera (Foottit *et al.* 2008). Similarly, DNA barcodes using mitochondrial COI gene were also been studied to discriminate 142 individuals representing 32 cryptic aphids species from India (Rebijith *et al.* 2013).

Rebijith *et al.* (2012) measured the usefulness of COI for the species discrimination of mirids *viz*., *Helopeltis antoni*, *H. thievora*, *H. bradyi* and *Pachypeltis maesarum* in their various life stages in India. A less than 1% intraspecific divergence for all four species examined was reported, whereas the interspecific distances ranged from 7 to 13 percent. This study showed that the DNA barcode and species-specific markers will aid in quick identification of mirids in India. Bhau *et al*. (2014) conducted the morphological and genetic diversity study among populations of tea mosquito bug, *Helopeltis theivora* from Assam, India. Here, both the marker (morphological and molecular)

systems indicated that genetic variability within populations examined was significantly high.

Rebijith *et al.* (2014) employed COI gene sequences for discriminating 151 species of thrips in India. Identification of the thrips is difficult because of high intraspecific variation among the population. Kadirvel *et al.* (2013) used partial COI gene sequences to study the phylogenetic relationship among thrips populations. Higher intraspecific genetic variation was observed in *S. dorsalis* and *T. palmi* followed by *T. tabaci* and *F. occidentalis*. The authors reported that, the COI gene could be useful in grouping different thrips species and genera that coexist in a particular cropping system.

Behere *et al.* (2014) sequenced and characterized the complete mitochondrial genome of phytophagous ladybird beetle *Henosepilachna pusillanima*in India, the complete mitochondrial genome of these species determined to be 16, 216 bp long. Similarly, Kim *et al*. (2012) sequenced the complete mitochondrial genome of*Coccinella septempunctata*. Kobayashi *et al.* (1998) determined the molecular phylogeny of twelve Asian species of Epilachniae ladybird beetles using COI gene.

Raupac *et al*. (2014) employed DNA barcoding technique for identification of Heteropteran true bugs in central Europe. A total of 457 species comprising 39 families DNA barcodes was analyzed which includes Pentatomidae, Anthocoridae, Miridae, and Lygaeidae. Tembe *et al.* (2014) employed DNA barcoding method for identification of true bugs in Western Ghats of India. Totally, 80 COI sequences representing 43 species and 35 genera belonging to 5 superfamilies; Aradoidea, Coreoidea, Pentatomoidea, Pyrrhocoroidea and Lygaeoidea were obtained.

Chang *et al.* (2014) examined the population genetic diversity and structure of *L. orbonalis* based on eight populations collected from six different countries of Southeast Asia, by using mitochondrial COI gene sequences. The

results indicated no correlation between genetic diversity and geographic distance among the population.

Molecular characterization of *Leucinodes orbonalis* in nine geographic locations of India was carried out by using COI gene, which revealed no significant molecular diversity in *L. orbonalis*. Genetic diversity and phylogenetic analysis based on barcoding gene COI indicate that, *L. orbonalis* similarities in between populations of *L. orbonalis* collected from different geographic regions of the India (Shashank *et al.* 2015).

Wang *et al.* (2016) reported that the two genes, mitochondrial cytochrome oxidase I (COI) and large ribosomal subunit gene (28S) could be used for species identification of 54 mealybug species that commonly occur in China. Also, partial nucleotide sequences of nuclear and mitochondrial (COI) genes were used for species characterization of *Phenacoccus* mealy bug in Pakistan (Ashfaq *et al.* 2010).

DNA barcoding using COI gene was undertaken to study the evolutionary lineage of 15 insect pests of horticultural crops including brinjal in South India (Karthika *et al.* 2016). The results revealed that among the 15 sequences studied, seven species *viz*., *Aulacophora foveicollis*, *A. cincta*, *Leptocentrus taurus*, *Cletus punctiger*, *Heterorrhina elegans*, *Gametis versicolor* and *Sphenarches caffer* were novel and represented first time records. The authors conclude that the DNA barcoding using COI genes is an effective method for screening insect pests and aid in improving Integrated Pest Management in Asian countries.

Yong (2016) studied the complete mitochondrial genome and their phylogenetic implications of three Bactrocera fruit flies *viz*., *Bactrocera latifrons, Bactrocera melastomatos and Bactrocera umbrosa.* The complete mitogenome sequence would serve as a useful dataset for studying the genetics, systematics and phylogenetic relationships of the many species of the *Bactrocera* genus.

Sl. No.	*2019-2020*						*2020-2021*					
	Month	*Temperature (ºC)*		*Relative humidity (%)*		*Rainfall (mm)*	*Month*	*Temperature (ºC)*		*Relative humidity (%)*		*Rainfall (mm)*
		Max.	*Min.*	*Max.*	*Min.*			*Max.*	*Min.*	*Max.*	*Min.*	
1	7 December 2019	24.94	11.40	97.00	60.14	0.00	7 December 2020	26.07	11.69	97.00	54.00	0.00
2	22 December 2019	22.63	10.87	97.14	67.14	0.00	22 December 2020	23.26	9.06	97.00	53.71	0.00
3	6 January 2020	20.50	10.89	96.57	73.43	17.30	6 January 2021	24.86	7.37	95.71	42.86	0.00
4	21 January 2020	21.49	7.64	97.00	52.43	0.00	21 January 2021	22.84	9.60	96.71	62.71	3.40
5	5 February 2020	23.83	9.99	96.00	48.57	0.00	5 February 2021	24.73	8.13	96.43	45.29	0.00
6	20 February 2020	26.64	12.14	96.57	54.86	0.00	20 February 2021	29.24	11.30	93.14	36.86	0.00
7	6 March 2020	26.26	13.73	95.71	53.00	10.60	6 March 2021	27.71	14.29	93.86	57.14	18.80
8	21 March 2020	29.94	13.34	95.29	38.29	6.70	21 March 2021	32.99	15.84	90.43	28.86	0.00
9	5 April 2020	24.94	11.40	97.00	60.14	0.00	5 April 2021	32.59	15.77	87.57	34.14	14.60

Table 3.1. Meteorological observations during the period of study (December 2019 to April 2020 and December 2020 to April 2021)

CHAPTER III
MATERIALS AND METHODS

MATERIALS AND METHODS

3.1. Experimental site:

The present study entitled "Integrated Pest Management and Molecular Characterization of Major Insect Pests of Tomato (*Solanum lycopersicum* L.)" was carried out in the experimental cum research farm of School of Agricultural Sciences and Rural Development, Nagaland, University, Medziphema campus, situated at 25^0 45' 53" N latitude and 93^0 53' 04" E longitudes at an elevation of 310 meters above sea level.

3. 2. Climatic condition and weather

The experimental farm lies in humid and sub-tropical region with an average rainfall ranging from 2000-2500 mm annually. The mean temperature ranges from 21^0 to 32^0C during summer and rarely goes below 8^0C in winter. The climate is subtropical. The soil is sandy loam, acidic in nature with pH ranging from 4.5 to 6.5. The meteorological data during the period of study was obtained from Indian Council of Agricultural Research – Regional Centre for NEH Region, Nagaland Centre, Medziphema (Table 3.1)

3.3. Influence of date of planting and varieties on the insect pest complex and their natural enemies in tomato ecosystem.

3.3.1. Design and layout

The experiment was laid out in split plot design with three replications, keeping sowing dates in the main plots and varieties in the sub-plot. The main plots were separated from each other with a passage of 1 meter and the sub-plots with a passage of 50 cm wide.

Crop : Tomato

Number of replications : 3

Experimental design : Split Plot Design

Spacing:-

a. Row to Row : 60 cm

b. Plant to Plant : 40 cm

c. Interspacing between blocks : 1 m

d. Interspacing between main plots : 1 m

e. Interspacing between sub-plots : 50 cm

Number of planting dates : 3

Number of varieties : 5

Total number of plots : 45

Total number of plants : 540

Size of sub-plots :1.20m x 2.40 m

Number of plants/ sub-plot :12(twelve).

Number of plants/ row : 180

Gross Experimental area : 280 m^2

Net cropped area : 129.60 m^2

3.3.2. Treatment details:

3.3.2.1. Main factor:

Three different dates of sowing at fifteen days interval was selected and assigned to the main plots. The nursery bed was prepared and the seeds were sown on 23rd September, 8th October and 23rd October and transplanted to the main plots after 30 days of sowing from each respective date of sowing. Thus, the following symbols were given against the three dates of sowing:

Date of sowing	Date of transplanting	Symbol
23rd September	23rd October	D_1
8th October	8th November	D_2
23rd October	23rd November	D_3

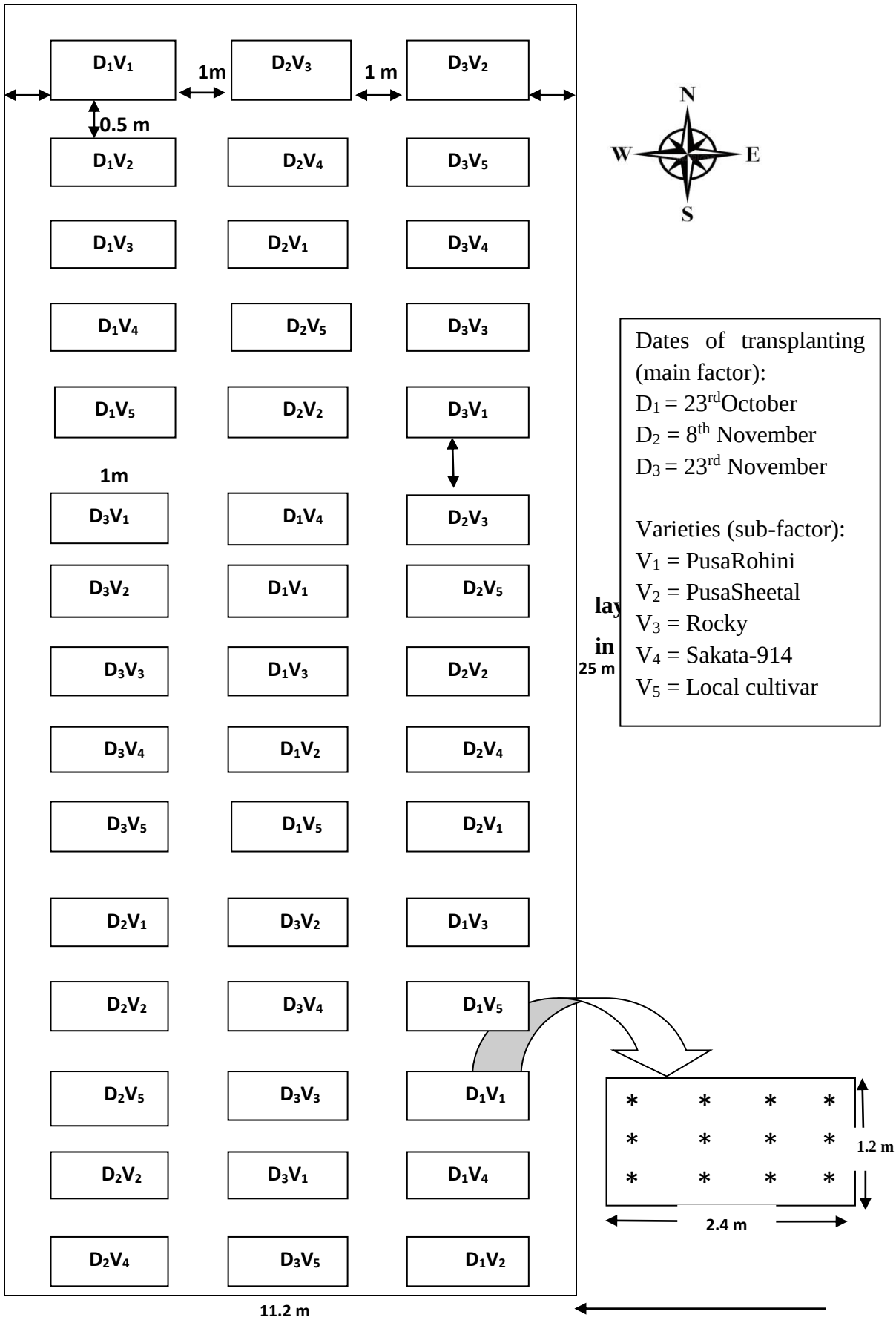
3.3.2.2. Sub factor: (Varieties/Cultivar)

Five different tomato varieties viz., Pusa Rohini, Pusa Sheetal, Rocky, Sakata-914 and one Local Cultivar was selected for the research study. The seeds of the varieties Pusa Rohini and Pusa Sheetal were procured from IARI, New Delhi; for the varieties Rocky and Sakata-914 the seeds were procured from Sunrise enterprise, Chumukedima, Nagaland; and the local cultivar from the local market, Medziphema.

Variety	Symbol
Pusa Rohini	V_1
Pusa Sheetal	V_2
Rocky	V_3
Sakata-914	V_4
Local cultivar	V_5

3.3.2.3. Treatment combinations:

D_1V_1	Pusa Rohini was planted on 23rd October 2019
D_1V_2	Pusa Sheetal was planted on 23rd October 2019
D_1V_3	Rocky was planted on 23rd October 2019
D_1V_4	Sakata-914 was planted on 23rd October 2019
D_1V_5	Local cultivar was planted on 23rd October 2019
D_2V_1	Pusa Rohini was planted on 8th November 2019
D_2V_2	Pusa Sheetal was planted on 8th November 2019
D_2V_3	Rocky was planted on 8th November 2019
D_2V_4	Sakata-914 was planted on 8th November 2019
D_2V_5	Local cultivar was planted on 8th November 2019
D_3V_1	Pusa Rohini was planted on 23rd November 2019
D_3V_2	Pusa Sheetal was planted on 23rd November 2019
D_3V_3	Rocky was planted on 23rd November 2019
D_3V_4	Sakata-914 was planted on 23rd November 2019
D_3V_5	Local cultivar was planted on 23rd November 2019


D1V1
1m
D2V3
1 m
D3V2
0.5 m
D1V2
D2V4
D3V5
D1V3
D2V1
D3V4
D1V4
D2V5
D3V3
D1V5
D2V2
D3V1
1m
D3V1
D1V4
D2V3
D3V2
D1V1
D2V5
D3V3
D1V3
D2V2
D3V4
D1V2
D2V4
D3V5
D1V5
D2V1
D2V1
D3V2
D1V3
D2V2
D3V4
D1V5
D2V5
D3V3
D1V1
D2V2
D3V1
D1V4
D2V4
D3V5
D1V2
11.2 m
N
W
E
S
lay
in
25 m
Dates of transplanting (main factor):
D1 = 23rdOctober
D2 = 8th November
D3 = 23rd November
Varieties (sub-factor):
V1 = PusaRohini
V2 = PusaSheetal
V3 = Rocky
V4 = Sakata-914
V5 = Local cultivar
1.2 m
2.4 m

3.3.3. Nursery raising and cultivation:-

The varieties viz., Pusa Rohini, Pusa Sheetal, Rocky, Sakata-914 and one Local Cultivar was selected for the research purpose and was sown in three different dates at an interval of fifteen (15) days in the nursery. Seeds were sown in parallel lines with a spacing of 2.5 cm row to row in the plot and a thin layer of fine sand was sprayed uniformly on the surface to cover the seeds properly. The nursery beds were watered twice a day and weeding was done at regular intervals till the plants were ready for transplanting. To prevent damping off of seedlings, Bavistin @ 2g/litre was sprayed.

3.3.4. Transplanting:-

30 days old tomato plants was selected for transplanting in the main field. All tomato varieties were transplanted on 3 different dates as mentioned earlier, at a spacing of 60 cm between the rows and 40 cm between plants.

3.3.5 Agronomical practices:-

3.3.5.1. Field preparation:

The experimental field was carefully selected and prepared by ploughing it three times. The field was made free from clods and weeds. During plot preparation, Farm Yard Manure was incorporated.

3.3.5.2. Gap filling:-

In order to maintain optimum plant population, gap filling of the damaged and missing plants was done at early stage.

3.3.5.3. Irrigation:-

Light irrigation was given after the tomato plants were transplanted. Irrigation was done every day when the plants were in its initial stage and afterwards at every alternate day.

3.3.5.4 Harvesting:-

Harvesting was done when the fruits attained its maturity but not completely ripe.

3.3.6. Sampling and data collection:-

A number of pests and natural enemies were observed during the experimental period, hence different sampling techniques best suitable for different insects was adopted for estimating their population/infestation.

3.3.6.1. Sap suckers:

Observation of the aphid population began from the incidence of pests and was recorded at 15 days interval. Count of aphid population was taken from 3 leaves of top, middle and bottom per plant from five randomly selected plants in each plot.

3.3.6.2. Green garden looper:

Direct count of insect pest was taken from five randomly selected plants and reading was taken at 15 days interval.

3.3.6.3. Fruit borer:

Total fruits and damaged fruits were recorded per five plants during harvesting time of each variety. Percent fruit infestation was calculated by the following formula (Wakil *et al*., 2009).

Fruit infestation percentage = B/A x 100

Where A = Total fruits (damaged + undamaged), and

B = Damaged fruits

The insect pest of tomato i.e. whitefly and leaf miner infestation was negligible and non-significant, hence data was not obtained.

3.3.6.4. Natural enemies:

Natural enemies associated with tomato ecosystem such as coccinellid beetles, spiders, parasitoids etc. was also be recorded side by side along with the pests. For coccinellid and spiders direct count of the predator was taken but for parasitoid the formula given below was used to calculate the abundance in percentage of natural enemy available,

$$\text{Abundance (\%)} = \frac{\text{Number of parasitized caterpillars}}{\text{Total number of caterpillars}} \times 100$$

3.3.7. Statistical analysis:-

3.3.7.1 Transformation of data

The data recorded on the pest population was tabulated and subjected to the square root transformation by applying the formula $\sqrt{X + 0.5}$ where "X" denotes the individual pest population under observation.The data on per cent leaf and fruit infestation was subjected to arcsine or angular transformation before analysing statistically (Dhamu and Ramamoorthy, 2008).

3.3.7.2 Analysis of variance:

The transformed values were subjected to Fisher' method of analysis of variance 'F test' to determine the significant or non-significance between two means and in case 'F' test is significant, the critical difference (CD) was then calculated for comparison.

3.4. To evaluate the efficacy of some biopesticides and trap crop against major insect pests and its impact on natural enemies of tomato.

3.4.1. Design and layout

The layout of the experiment was laid out in Randomised Block Design (RBD) with 6 treatments including the untreated control each replicated thrice. The treatments were randomly distributed within the different plots.

3.4.2. Experiment details

Experimental design	Randomised Block Design
Crop	Tomato
Cultivar	Sakata-914
Number of replications	3
Plot size	1.8 m x1.8 m
Spacings:	

- Row to Row	60 cm
- Plant to Plant	45 cm
- Interspacing between plots	1 m
- Interspacing between replication	1 m
Number of treatments	7
Number of plants per plot	12
Total No. of plots	21
Total No. of plants	252
Gross area	164.64 m^2

3.4.3. Treatment details

The experiment was conducted with 5 commercial formulations of bio-pesticides, 1 trap crop and an untreated control (water spray) as standard to evaluate their efficacy against major insect pests and their natural enemies in tomato ecosystem. The details of the treatments are as follows:

Treatments	Common name	Trade name	Dose
T_1	Marigold (*Pusa Narangi*)	-	-
T_2	Neem (0.03%)	Multineem	3ml/lit of water
T_3	Emamectin benzoate (5% SG)	Pocket	0.3g/lit. of water
T_4	Spinosad	Spintor	0.5ml/lit. of water
T_5	*Beauveria bassiana*($1x10^7$ conidia/ml)	Bio-sona	1.5ml/lit. of water
T_6	*Pongamia pinnata*	AGB-Insigon	3ml/lit. of water
T_7	Control	-	-

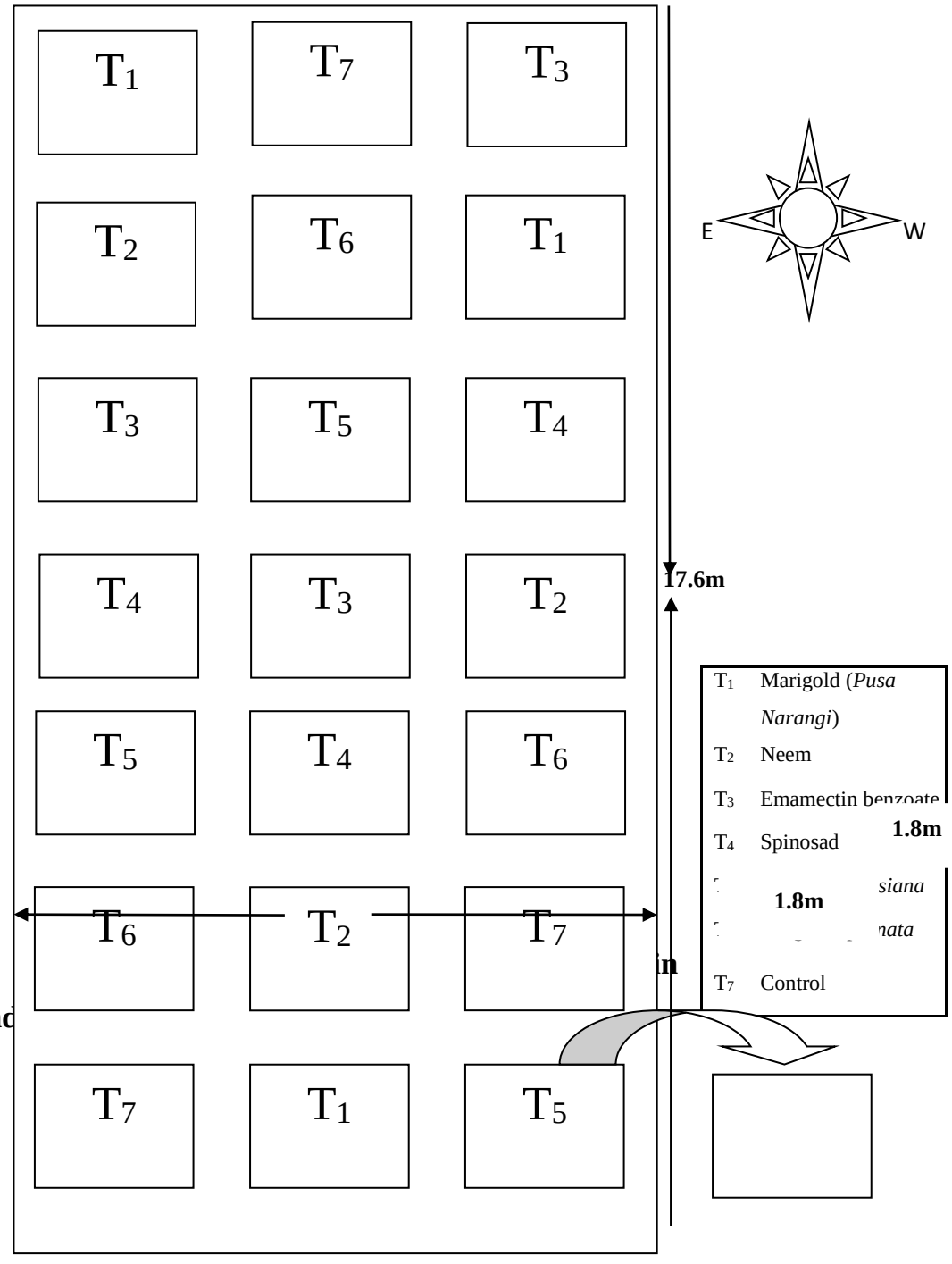

T1
T7
T3
T2
T6
T1
T3
T5
T4
T4
T3
T2
T5
T4
T6
T6
T2
T7
T7
T1
T5
E
W
17.6m
1.8m
1.8m
T1 Marigold (Pusa Narangi)
T2 Neem
T3 Emamectin benzoate
T4 Spinosad
T7 Control

Fig **in**

Rand

3.4.4. Nursery raising and cultivation

The cultivar Sakata-914 was selected for the research purpose because it is highly popular, easy to grow and is one of the most widely grown cultivar in India. Farmyard manure was incorporated into the soil before sowing. Seeds were sown in parallel lines with a spacing of 2.5 cm row to row in the plot and a thin layer of fine sand was sprayed uniformly on the surface to cover the seeds properly. The nursery beds were watered twice a day and weeding was done at regular intervals till the plants were ready for transplanting. To prevent damping off of seedlings, Bavistin @ 2g/litre was sprayed.

The trap crop (*Pusa Narangi*) was sown in polythene bags and was transplanted on the bunds around the plot (T_1) after 30 days of sowing.

3.4.5. Transplanting

Transplanting was carried out after 30 days of sowing, when the plants attained 10-15 cm height. Healthy and vigorous seedlings that have produced five leaves was used for planting in the main field maintaining a spacing of 60 cm between rows and 45 cm between plants within rows.

3.4.6. Agronomic practices

The agronomic practices were same as previously described in section 3.3.5.of materials and method chapter.

3.4.7. Sampling and data collection:-

The sampling and data collection was same as previously described in section 3.3.6. of materials and method chapter.

3.4.8. Efficacy of biopesticides against major insect pests and natural enemies of tomato.

First spray of the insecticide was initiated when there was high pest population and the second spraying was carried out after 30 days. Observations on the efficacy of different insecticides were recorded as pre and post treatment. The pre-treatment count of the pest and natural enemies population was recorded one day before the application of treatments and the dates of the post

treatments was recorded at 3, 5, and 7 days after each treatment to access the efficacy of each treatment, the per cent reduction was calculated using the following formula.

$$\text{Percent (\%) Reduction} = \frac{\text{Pre treatment count} - \text{Post treatment count}}{\text{Pre treatment count}} \times 100$$

The pre-treatment count of T_7 (control) was used for T_1 (Marigold as trap crop) to calculate the percent reduction.

3.4.10. Statistical analysis:-

The statistical analysis preformed is same as previously described in section 3.3.7.of materials and method chapter.

3.5. Molecular characterization of major insect pests and natural enemies in tomato.

The lab work for this research was conducted in the Molecular Entomology Laboratory, Division of Crop Protection of ICAR Research Complex for North Eastern Hills (NEH) Region, Umiam, Meghalaya while different experimental cum research farm of School of Agricultural Sciences and Rural Development, Nagaland, University, Medziphema campus, supported the field work. The major pests and natural enemies of tomato was collected, documented and preserved at 70% ethanol during the experimental period. DNA barcodes of major insect pests and natural enemies of tomato ecosystem was developed by using Cytochrome oxidase sub unit I (COI) of mitochondrial DNA (mtDNA).

3.5.1 Extraction of Deoxyribonucleic acid (DNA) from insect

DNA extraction was done following modified phenol: chloroform protocol (Behere*et al*. 2007).The preserved specimens was taken out from the vials with the help of sterilized forceps and air dried on blotting paper at room temperature for an hour for evaporation of ethanol. This was followed by extraction of DNA from single leg or antennae (in case of large insect) and whole insect (in case of small insects).

Materials and equipmentsused

- Insect sample
- Latex or Nitrile gloves
- Eppendorf Tubes (1.5ml)
- Micro pestle
- Micro pipettors and tips
- Digital Heat Block
- Vortex machine
- Micro-centrifuge (Eppendorf, Model No.:5430)
- Deep freezer (-4 and -20°C)

Reagents used

- Homogenization buffer: pH 8.0 (stored at 4°C)

0.1M NaCl

0.2M Sucrose

0.1M EDTA

0.03M Tris base

- Lysis buffer: pH 9.2

0.025M EDTA

2.5% SDS

- TE buffer

10mM TrisHCl

1mM EDTA

- Potassium acetate (pH 8.0)

3.5.2. Development of DNA barcodes by using COI gene

3.5.2.1 PCR amplification

Materials and Equipmentsused

- Sterile disposable micro-centrifuge tubes (1.5ml and 200µl capacity)

- Pipettes and tips
- Micro centrifuge
- Vortex machine
- PCR machine (Eppendorf Master Cycler Nexus Gradient)
- Latex or Nitrile gloves

Reagents used

- Diluted DNA
- PCR Master mix (2X)
- Molecular biology grade water
- Primers

For COI gene based barcoding, two pairs of primers have been considered as standard barcoding primers for insect DNA barcoding work. The details of the primers are as follows:

Primers	**Sequence (5'-3')**	**Primer length**	**Reference**
LepF1	ATTCAACCAATCATAAAGATATTGG	5bp	Folmer, 1994
LepR1	TAAACTTCTGGATGTCCAAAAAATCA	6bp	
LCO	GGTCAACAAATCATAAAGATATTGG	5bp	Hebert *et al*., 2004
HCO	TAAACTTCTGGATGTCCAAAAAATCA	6bp	

PCR reaction was carried out using LCO (Forward) and HCO (Reverse) primer. The samples which failed to amplify with LCO/HCO were further amplified with LepF1 (Forward) andLepR1 (Reverse) primer.

PCR reaction mixture

PCR amplifications were carried out in the thermal cycler (Eppendorf, India) to test the amplifications of all the samples with two standard DNA barcoding primers. The reaction mixture contain 2µl of gDNA (~40-50 ng), 0.5µl each of forward and reverse primers, 5µl of ready to use EmeraldAmp®

MAX PCR Master Mix (2x) (Takara) and 2µl of molecular biology grade water. This premix master mix has composition of 5µl of 2mM dNTPs, 1.5 µlof 50 mM MgCl2, 0.25µl of 5U *Taq*DNA polymerase and 5µl of 10X PCR buffer.

PCR cycles

PCR profile consist of initial denaturation at 94°C for 2 minutes, followed by 5 cycles of denaturation at 94°C for 30 seconds, annealing at 45°C for 40 seconds and extension for 1 minute at 72°C, again followed by 35 cycles of denaturation at 94°C for 30 seconds, annealing at 51°C for 40 seconds and extension for 1 minute at 72°C. A final extension was allowed for 10 minutes at 72°C and samples was allowed to hold at 10°C in PCR machine after completion of all the cycles and then stored in -20°C for further use.

3.5.2.2 Gel electrophoresis and documentation

Procedure

1. The amplified 10 µl of PCR products was subjected to electrophoresis on agarose gel.
2. The gel was prepared by adding 1.5g of agarose in 100ml 1X TAE buffer in a wide mouthed conical flask.
3. The mixture was heated in a microwave oven for few minutes, until the agarose melted. Then the flask was gently removed from the oven and kept into a water bath to cool down.
4. After which, 2µl of ethidium bromide was added to stain the gel. The gel solution was mixed thoroughly before pouring into the tank.
5. The amplified PCR products (10µl) was loaded serially into the wells along with 100bp DNA ladder (4µl) as a molecular marker in the first well and the control loaded into the last well, in order to see any contamination in the PCR product.
6. The samples were allowed to run at 160V for 20-30 minutes.
7. After completion, the gel was visualized under UV trans-illuminator and gel was documented in gel documentation system (Care stream Gel Logic 212

Pro). The presence or absence of amplification for each of the sample was recorded.

3.5.3. Sequencing of PCR amplicons of COI gene for pests and natural enemies in tomato ecosystem.

For sequencing, PCR reactions was carried out with universal LCO/HCO primer and samples which failed to amplify with LCO/HCO primer was amplified with LepF1/LepR1 primers for sequencing.A total volume 50µl of PCR reaction was carried out. The PCR profile is similar as described in the previous section. After completion of PCR amplification 10µl of each PCR product was used for gel electrophoresis and documentation. The remaining 40µl of post PCR product of each species was transferred into 1.5ml sterilized eppendorf tubes and the tubes was packed properly and sent for sequencing in frozen condition to Eurofins Genomics India Pvt. Ltd, Bangalore. Sequencing was performed for all the samples from both the ends (5' and 3').

3.5.4. Bioinformatics Analysis

- The molecular biology software STADEN Package was used for Nucleotide sequence analysis/assembling (Staden *et al*. 2000). The messy 5' and 3' end of the sequences was trimmed.
- Sequence alignment was done by using softare Clustal-X (Thompson *et al.*1997).
- The final analyzed sequences were submitted to National Center for Biotechnology Information (NCBI) for accession numbers.

CHAPTER IV
RESULTS AND DISCUSSION

Plate 1: General view of the experimental field

A

C

Plate 2: Morphological characteristics of tomato varieties: A) Pusa Rohini: B) Pusa Sheetal: C) Rocky: D) Sakata-914: E) Local cultivar

Plate 3: Aphidinfestation on tomato inflorescence

RESULTS AND DISCUSSION

The present chapter deals with the experimental findings obtained during the course of investigation entitled "Integrated pest management and molecular characterization of major insect pests of tomato (*Solanum lycopersicum* L.)" As a first line of pest control, IPM works to manage the crop and prevent pests from becoming a threat. The negative impacts of insecticides have necessitated the development of integrated approaches to manage tomato pests complex so as to ensure increased and sustainable production. In recent years, one promising combination identified is the use of host plant resistance and planting dates alongside use of biopesticides has proven to be very effective, cost efficient and present little to no risk to the people or the environment. The results obtained from present study are interpreted and presented in the following headings.

4.1. Influence of date of planting and varieties on the insect pests complex and their natural enemies in tomato ecosystem

Field experiments were conducted to study the effectiveness of three tomato planting dates (23rd September; 8th October and 23rd October) and five varieties (Pusa Rohini, Pusa Sheetal, Rocky, Sakata-914 and Local Cultivar) on the population densities of *Aphis spiraecola, Chrysodeixis eriosoma, Helicoverpa armigera, Glyptapanteles* sp., coccinellids and spiders during 2019-2020 and 2020-2021.

4.1.1. Influence of date of planting and varieties against aphid, *Aphis spiraecola*

The data on the incidence of aphid, *A. spiraecola* are tabulated in Table 4.1- 4.4 and illustrated in Figure 4.1 and 4.2. It is evident from the data obtained (Table 4.1)that all the three different planting dates showed significant influence on aphid population. The highest incidence of *A. spiraecola*

Table 4.1: Effect of date of planting and varieties on abundance of aphid (*Aphis spiraecola*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of aphid *(Aphis spiraecola)* / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D_1	4.53 (2.23)	6.13 (2.55)	6.61 (2.65)	7.12 (2.73)	8.24 (2.93)	8.99 (3.06)	8.09 (2.92)	7.10	5.04 (2.34)	6.45 (2.61)	7.01 (2.72)	7.40 (2.79)	8.50 (2.98)	9.33 (3.12)	8.45 (2.97)	7.45
D_2	5.48 (2.42)	6.63 (2.66)	7.28 (2.78)	8.11 (2.92)	8.76 (3.02)	9.35 (3.12)	8.24 (2.94)	7.69	6.05 (2.55)	6.94 (2.72)	7.67 (2.85)	8.40 (2.97)	9.11 (3.08)	9.61 (3.17)	8.51 (2.98)	8.04
D_3	5.99 (2.53)	8.93 (3.04)	8.81 (3.04)	9.79 (3.19)	10.36 (3.28)	10.88 (3.36)	9.89 (3.21)	9.23	6.49 (2.62)	9.53 (3.15)	9.28 (3.11)	10.15 (3.24)	10.75 (3.34)	11.25 (3.42)	10.27 (3.27)	9.67
SEm±	*0.03*	*0.04*	*0.03*	*0.04*	*0.04*	*0.03*	*0.05*		*0.04*	*0.04*	*0.04*	*0.03*	*0.03*	*0.03*	*0.04*	
CD (P= 0.05)	*0.10*	*0.17*	*0.13*	*0.14*	*0.14*	*0.10*	*0.20*		*0.17*	*0.14*	*0.15*	*0.11*	*0.12*	*0.13*	*0.15*	
Varieties																
V_1	6.92 (2.72)	9.20 (3.10)	8.93 (3.07)	10.69 (3.33)	11.31 (3.43)	11.96 (3.52)	10.69 (3.33)	9.96	7.36 (2.80)	9.52 (3.16)	9.51 (3.16)	10.98 (3.38)	11.61 (3.47)	12.24 (3.56)	11.04 (3.38)	10.32
V_2	3.96 (2.10)	6.02 (2.54)	6.31 (2.59)	6.71 (2.67)	7.89 (2.88)	8.58 (3.00)	7.47 (2.81)	6.71	4.51 (2.23)	6.33 (2.60)	6.71 (2.67)	7.00 (2.72)	8.18 (2.93)	8.96 (3.06)	7.76 (2.86)	7.06
V_3	6.11 (2.57)	7.76 (2.86)	8.22 (2.95)	9.11 (3.09)	10.29 (3.28)	10.71 (3.35)	9.78 (3.20)	8.85	6.59 (2.66)	8.22 (2.94)	8.53 (3.00)	9.36 (3.14)	10.62 (3.33)	11.07 (3.40)	10.04 (3.24)	9.20
V_4	6.20 (2.58)	8.49 (2.99)	9.09 (3.09)	9.62 (3.18)	10.09 (3.25)	10.64 (3.34)	9.64 (3.18)	9.11	6.71 (2.68)	9.02 (3.07)	9.47 (3.15)	9.96 (3.23)	10.47 (3.31)	10.98 (3.39)	10.04 3.25)	9.52
V_5	3.48 (1.99)	4.69 (2.26)	5.29 (2.40)	5.56 (2.45)	6.02 (2.55)	6.80 (2.70)	6.13 (2.57)	5.42	4.13 (2.14)	5.10 (2.36)	5.71 (2.49)	5.96 (2.54)	6.38 (2.62)	7.09 (2.75)	6.49 (2.64)	5.84
SEm±	*0.04*	*0.04*	*0.03*	*0.04*	*0.04*	*0.04*	*0.02*		*0.03*	*0.03*	*0.03*	*0.03*	*0.03*	*0.04*	*0.06*	
CD (P= 0.05)	*0.11*	*0.12*	*0.09*	*0.11*	*0.13*	*0.11*	*0.07*		*0.10*	*0.08*	*0.10*	*0.10*	*0.08*	*0.12*	*0.16*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Table 4.2: Interaction between date of planting and varieties on abundance of aphid *(Aphis spiraecola)* population in tomato ecosystem during 2019-2020 and 2020-2021

Treatments	**Number of aphid *(Aphis spiraecola)* / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	5.67 (2.48)	8.20 (2.95)	8.47 (2.99)	8.80 (3.05	9.27 (3.12)	9.93 (3.23)	8.47 (2.99)	8.40	6.47 (2.64)	8.57 (3.01)	9.00 (3.08)	9.13 (3.10)	9.57 (3.17)	10.47 (3.31)	8.93 (3.05)	8.88
D_1V_2	3.20 (1.92)	4.67 (2.27)	4.87 (2.31)	5.07 (2.36	6.73 (2.69)	7.87 (2.88)	7.00 (2.74)	5.63	3.93 (2.11)	4.93 (2.33)	5.13 (2.37)	5.20 (2.39)	7.00 (2.74)	8.27 (2.94)	7.13 (2.75)	5.9
D_1V_3	5.20 (2.39)	6.80 (2.70)	7.60 (2.85)	8.33 (2.97	10.73 (3.35)	11.20 (3.42)	10.40 (3.30)	8.61	5.80 (2.51)	7.13 (2.76)	8.07 (2.93)	8.60 (3.02)	11.07 (3.40)	11.47 (3.46)	10.67 (3.34)	8.97
D_1V_4	5.40 (2.43)	7.33 (2.80)	7.80 (2.88)	8.93 (3.07	9.47 (3.15)	9.87 (3.22)	8.87 (3.06)	8.24	5.47 (2.44)	7.60 (2.85)	8.20 (2.95)	9.20 (3.11)	9.60 (3.18)	10.20 (3.27)	9.47 (3.16)	8.5
D_1V_5	3.17 (1.91)	3.67 (2.04)	4.33 (2.20)	4.47 (2.23	5.00 (2.35)	6.07 (2.56)	5.73 (2.49)	4.63	3.53 (2.01)	4.00 (2.12)	4.67 (2.27)	4.87 (2.32)	5.27 (2.40)	6.27 (2.60)	6.07 (2.56)	4.95
D_2V_1	7.27 (2.79)	8.07 (2.93)	8.27 (2.96)	10.33 (3.29	11.33 (3.44)	12.07 (3.54)	11.40 (3.45)	9.82	7.27 (2.79)	8.40 (2.98)	8.67 (3.02)	10.60 (3.33)	11.67 (3.49)	12.20 (3.56)	11.53 (3.47)	10.05
D_2V_2	3.53 (2.00)	5.53 (2.46)	5.73 (2.49)	6.47 (2.64	7.20 (2.77)	7.80 (2.88)	6.20 (2.59)	6.07	4.00 (2.12)	5.87 (2.52)	6.27 (2.60)	6.73 (2.69)	7.33 2.79)	8.00 (2.92)	6.53 (2.65)	6.39
D_2V_3	6.87 (2.71)	6.73 (2.69)	7.93 (2.90)	8.67 (2.02	9.33 (3.13)	9.60 (3.18)	8.33 (2.97)	8.21	7.20 (2.77)	7.00 (2.74)	8.13 (2.94)	8.87 (3.06)	9.67 (3.19)	10.07 (3.25)	8.60 (3.01)	8.51
D_2V_4	6.00 (2.55)	7.73 (2.87)	8.87 (3.06)	9.27 (3.12	9.73 (3.19)	10.53 (3.32)	9.33 (3.13)	8.78	6.87 (2.71)	8.20 (2.95)	9.20 (3.11)	9.60 (3.17)	10.20 (3.27)	10.80 (3.36)	9.67 (3.19)	9.22
D_2V_5	3.73 (2.06)	5.07 (2.36)	5.60 (2.47)	5.80 (2.51	6.20 (2.59)	6.73 (2.69)	5.93 (2.54)	5.58	4.93 (2.33)	5.23 (2.39)	6.07 (2.56)	6.20 (2.59)	6.67 (2.68)	7.00 (2.74)	6.20 (2.59)	6.04
D_3V_1	7.83 (2.88)	11.33 (3.44)	10.07 (3.25)	12.93 (3.66	13.33 (3.72)	13.87 (3.79)	12.20 (3.56)	11.65	8.33 (2.97)	11.60 (3.47)	10.87 (3.37)	13.20 (3.70)	13.60 (3.75)	14.07 (3.82)	12.67 (3.63)	12.05
D_3V_2	5.13 (2.36)	7.87 (2.89)	8.33 (2.97)	8.60 (3.02	9.73 (3.20)	10.07 (3.25)	9.20 (3.11)	8.42	5.60 (2.47)	8.20 (2.95)	8.73 (3.04)	9.07 (3.09)	10.20 (3.27)	10.60 (3.33)	9.60 (3.18)	8.86
D_3V_3	6.27 (2.60)	9.73 (3.20)	9.13 (3.10)	10.33 (3.29	10.80 (3.36)	11.33 (3.44)	10.60 (3.33)	9.74	6.77 (2.68)	10.53 (3.32)	9.40 (3.15)	10.60 (3.33)	11.13 (3.41)	11.67 (3.49)	10.87 (3.37)	10.14
D_3V_4	7.20 (2.77)	10.40 (3.30)	10.60 (3.33)	10.67 (3.34	11.07 (3.40)	11.53 (3.47)	10.73 (3.35)	10.31	7.80 (2.88)	11.27 (3.43)	11.00 (3.39)	11.07 (3.40)	11.60 (3.48)	11.93 (3.53)	11.00 (3.39)	10.81
D_3V_5	3.53 (2.01)	5.33 (2.39)	5.93 (2.54)	6.40 (2.62	6.87 (2.71)	7.60 (2.85)	6.73 (2.69)	6.06	3.93 (2.10)	6.07 (2.56)	6.40 (2.63)	6.80 (2.70)	7.20 (2.77)	8.00 (2.92)	7.20 (2.77)	6.51
SEm±	*0.07*	*0.07*	*0.05*	*0.06*	*0.07*	*0.07*	*0.04*		*0.06*	*0.05*	*0.06*	*0.06*	*0.05*	*0.07*	*0.10*	
CD (P= 0.05)	*0.19*	*0.21*	*0.15*	*0.19*	*0.22*	*0.20*	*0.13*		*0.17*	*0.14*	*0.17*	*0.17*	*0.14*	*0.21*	*0.28*	

Note:Figures in the table are mean values and those in parenthesis are square root transformed values

recorded in the year 2019-2020 was at 120 DAT (Days after transplanting) with 10.88 aphid/plant in D_3 *i.e.* fourth week of March and also the highest total mean population of 9.23 aphid population was observed in D_3, whereas the lowest population with 4.53 aphid/plant was recorded at 45 DAT in D_1 *i.e.* first week of December with the least total mean population of 7.10 numbers of aphid population in D_1.The same trend was also recorded in the second trial (2020-2021) where the highest mean population of 11.25 aphid/plant was recorded at 120 DAT in D_3 with the highest total mean population of 9.65 number of aphid population in D_3 while the lowest was observed in D_1 with 5.04 aphid/plant and the least overall mean was observed at D_1 with 7.45 number of aphid population. The finding also reveals that the aphid population persisted throughout the season in an increasing trend. The pooled data (Table 4.3) reveals that all three different planting dates had significant effect on the incidence of *A. spiraecola* and the pest incidence was observed from 45 DAT which gradually increased in numbers attaining its highest peak number at 120 DAT with11.07 aphid/plant in D_3 and lowest number with 4.71 aphid/plant at 45 DAT in D_1. The overall mean was observed highest in the third date of planting (D_3) with 9.46 aphid/plant and the least number of 7.28 aphid population was observed in the first date of planting (D_1). It can therefore be concluded that aphid infestation was recorded highest during the late planting date (D_3) 28th October and the lowest number of aphid population was recorded during the early planting of tomato crop (D_1) *i.e.* 23rd September. The present finding get support from the observations of Meena *et al*. (2002) and Kumari and Yadav (2004) who reported that early sown crop are less infested by aphid and gave higher yield in comparison to late sown crop. The present investigaton is also in alignment with Aheer *et al*. (2007), Iqbal *et al*. (2008) and Wains *et al.* (2010); the authors reported the highest aphid population during the period of March.

Table 4.3: Pooled data on the effect of date of planting and varieties on abundance of aphid (*Aphis spiraecola*)population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of aphid (*Aphis spiraecola*) /plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	4.78 (2.28)	6.29 (2.58)	6.81 (2.68)	7.26 (2.76)	8.37 (2.95)	9.16 (3.09)	8.27 (2.94)	7.28
D_2: 8th October 2019	5.77 (2.48)	6.78 (2.69)	7.47 (2.81)	8.25 (2.94)	8.93 (3.05)	9.48 (3.14)	8.37 (2.96)	7.86
D_3: 23rd October 2019	6.24 (2.57)	9.23 (3.10)	9.05 (3.08)	9.97 (3.22)	10.55 (3.31)	11.07 (3.39)	10.08 (3.24)	9.46
SEm±	*0.02*	*0.03*	*0.03*	*0.02*	*0.02*	*0.02*	*0.03*	
CD (P= 0.05)	*0.08*	*0.09*	*0.08*	*0.07*	*0.08*	*0.07*	*0.10*	
Varieties								
V_1: Pusa Rohini	7.14 (2.76)	9.36 (3.13)	9.22 (3.11)	10.83 (3.36)	11.46 (3.45)	12.10 (3.54)	10.87 (3.36)	10.14
V_2: Pusa Sheetal	4.23 (2.16)	6.18 (2.57)	6.51 (2.63)	6.86 (2.70)	8.03 (2.91)	8.77 (3.03)	7.61 (2.84)	6.88
V_3: Rocky	6.35 (2.61)	7.99 (2.90)	8.38 (2.98)	9.23 (3.12)	10.46 (3.31)	10.89 (3.37)	9.91 (3.22)	9.03
V_4: Sakata-914	6.46 (2.63)	8.76 (3.03)	9.28 (3.12)	9.79 (3.20)	10.28 (3.28)	10.81 (3.36)	9.84 (3.21)	9.32
V_5: Local Cultivar	3.81 (2.07)	4.89 (2.31)	5.50 (2.44)	5.76 (2.49)	6.20 (2.58)	6.94 (2.72)	6.31 (2.61)	5.63
SEm±	*0.03*	*0.02*	*0.02*	*0.03*	*0.03*	*0.03*	*0.03*	
CD (P= 0.05)	*0.07*	*0.07*	*0.06*	*0.07*	*0.07*	*0.08*	*0.09*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

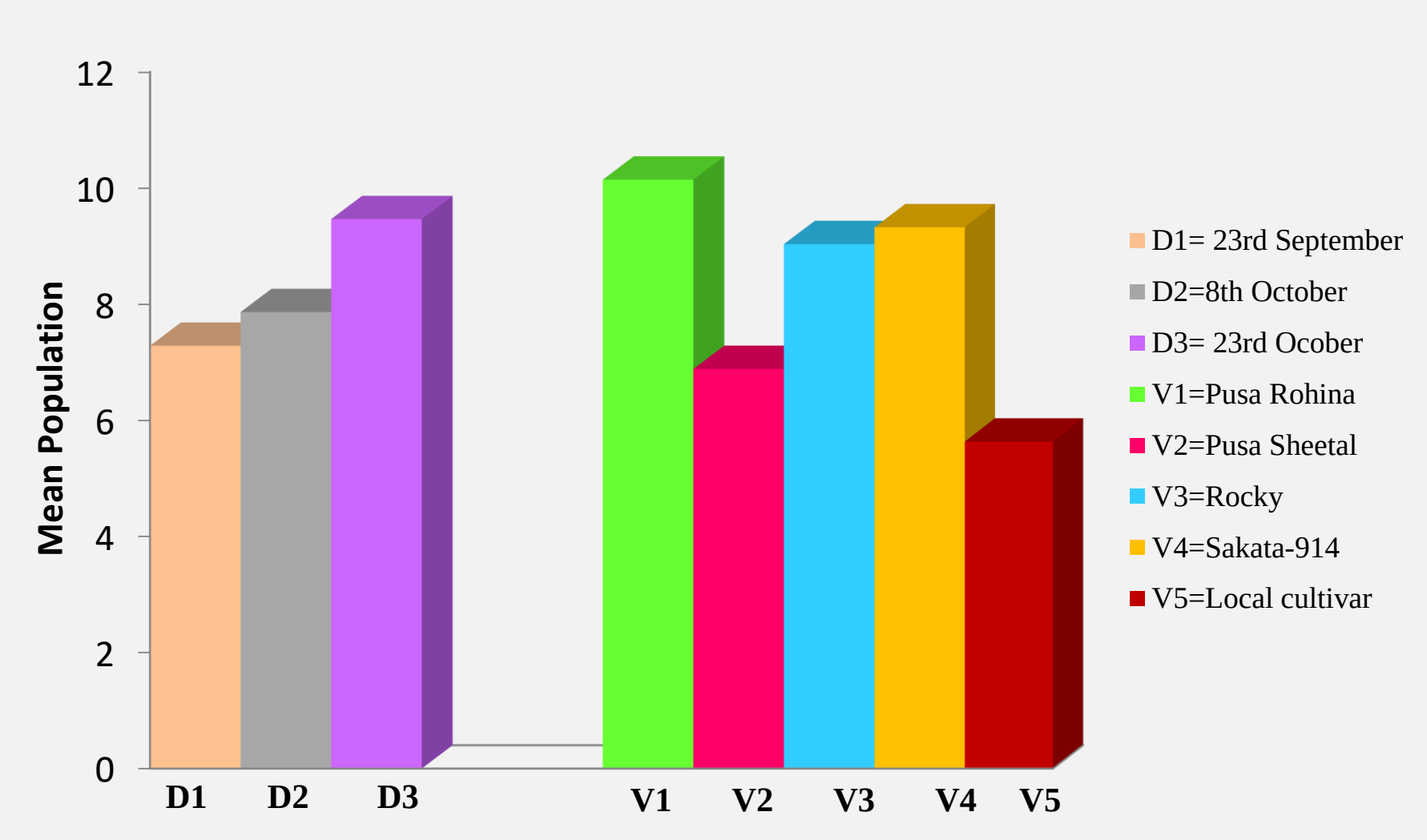


Fig **4.1. Pooled data on effect of date of planting and varieties on abundance of aphid population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.4: Pooled data on the interaction effect of date of planting and varieties on abundance of aphid(*Aphis spiraecola*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of aphid *(Aphis spiraecola)* / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	6.07 (2.56)	8.38 (2.98)	8.73 (3.04)	8.97 (3.08)	9.42 (3.15)	10.20 (3.27)	8.70 (3.02)	8.64
D_1V_2	3.57 (2.01)	4.80 (2.30)	5.00 (2.34)	5.13 (2.37)	6.87 (2.71)	8.07 (2.91)	7.07 (2.75)	5.79
D_1V_3	5.50 (2.45)	6.97 (2.73)	7.83 (2.89)	8.47 (2.99)	10.90 (3.37)	11.33 (3.44)	10.53 (3.32)	8.79
D_1V_4	5.43 (2.44)	7.47 (2.82)	8.00 (2.91)	9.07 (3.09)	9.53 (3.17)	10.03 (3.25)	9.17 (3.11)	8.39
D_1V_5	3.35 (1.96)	3.83 (2.08)	4.50 (2.24)	4.67 (2.27)	5.13 (2.37)	6.17 (2.58)	5.90 (2.53)	4.79
D_2V_1	7.27 (2.79)	8.23 (2.95)	8.47 (2.99)	10.47 (3.31)	11.50 (3.46)	12.13 (3.55)	11.47 (3.46)	9.93
D_2V_2	3.77 (2.06)	5.70 (2.49)	6.00 (2.55)	6.60 (2.66)	7.27 (2.78)	7.90 (2.90)	6.37 (2.62)	6.23
D_2V_3	7.03 (2.74)	6.87 (2.71)	8.03 (2.92)	8.77 (3.04)	9.50 (3.16)	9.83 (3.21)	8.47 (2.99)	8.36
D_2V_4	6.43 (2.63)	7.97 (2.91)	9.03 (3.09)	9.43 (3.14)	9.97 (3.23)	10.67 (3.34)	9.50 (3.16)	9.00
D_2V_5	4.33 (2.19)	5.15 (2.38)	5.83 (2.51)	6.00 (2.55)	6.43 (2.63)	6.87 (2.71)	6.07 (2.56)	5.81
D_3V_1	8.08 (2.93)	11.47 (3.46)	10.47 (3.31)	13.07 (3.68)	13.47 (3.74)	13.97 (3.80)	12.43 (3.60)	11.85
D_3V_2	5.37 (2.42)	8.03 (2.92)	8.53 (3.00)	8.83 (3.05)	9.97 (3.23)	10.33 (3.29)	9.40 (3.15)	8.64
D_3V_3	6.52 (2.64)	10.13 (3.26)	9.27 (3.12)	10.47 (3.31)	10.97 (3.39)	11.50 (3.46)	10.73 (3.35)	9.94
D_3V_4	7.50 (2.83)	10.83 (3.36)	10.80 (3.36)	10.87 (3.37)	11.33 (3.44)	11.73 (3.50)	10.87 (3.37)	10.56
D_3V_5	3.73 (2.05)	5.70 (2.48)	6.17 (2.58)	6.60 (2.66)	7.03 (2.74)	7.80 (2.88)	6.97 (2.73)	6.29
SEm±	*0.04*	*0.04*	*0.04*	*0.04*	*0.04*	*0.05*	*0.05*	
CD (P= 0.05)	*0.12*	*0.12*	*0.11*	*0.12*	*0.13*	*0.14*	*0.15*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

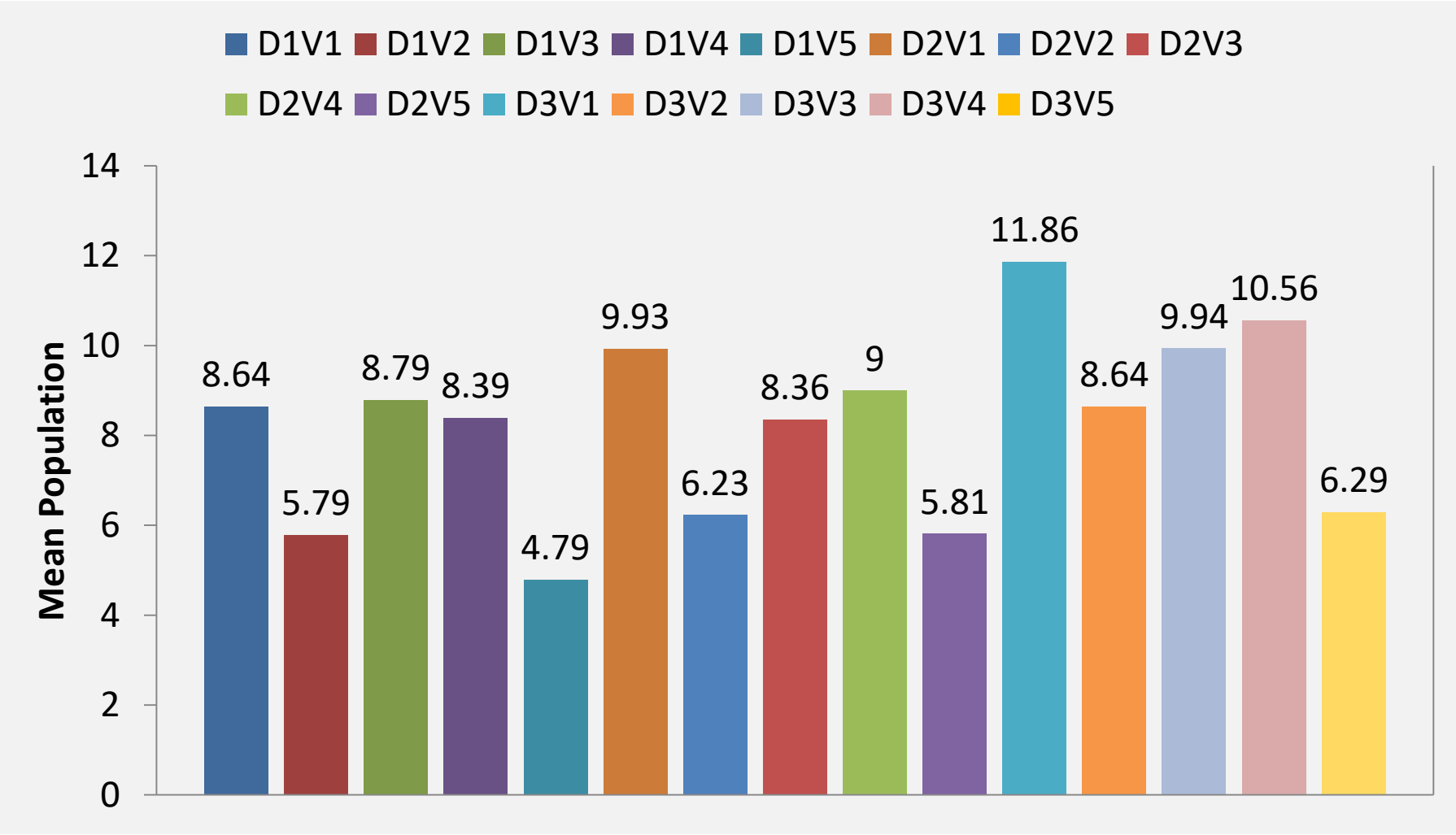


Fig **4.2: Pooled data on the interaction effect of date of planting and varieties on abundance of aphid population in tomato ecosystem during 2019-2020 and 2020-2021**

Incidence of insect pests on different tomato varieties had significant influence on aphid population throughout the crop growth. All the varieties under study were affected by aphid, *A. spiraecola* population to some degree. The highest aphid population was observed on the variety Pusa Rohini (V_1) at 120 DAT with 11.96 aphid/plant (2019-2020) and 12.24 aphid/plant (2020-2021) while the lowest was observed in Local cultivar (V_5) with 3.48 aphid/plant (2019-2020) and 4.13 aphid/plant (2020-2021). In both the years of experimental trials *i.e.* 2019-2020 and 2020-2021, Local cultivar (V_5) registered the lowest mean population of 5.42 and 5.84 aphid/plant respectively while the highest mean population of 9.96 and 10.32 aphid/plant respectively was recorded in the variety Pusa Rohini (V_1). Significantly lower aphid population was also recorded in the variety Pusa Sheetal (V_2) with mean population of 6.71 and 7.06 aphid/plant in the year 2019-2020 and 2020-2021 respectively. The resistance of the different varieties under study to aphid, *A.spiraecola* population may also be attributed to the morphological characteristics of the host plant *i.e.* presence of trichomes which conferred resistance against the insect pest (Plate 2). It was observed that little to no trichomes were present for the varieties Pusa Rohini and Sakata-914 while Pusa Sheetal, Local cultivar and Rocky had densely populated trichomes present which may have ultimately resulted in the number of *A. spiraecola* population on the tomato plant. Trichome density is one of the main traits of particular focus in plant protection as it prevents pest attachment and limit movement on crops. Trichomes tend to be more effective against insects that are smaill relative to trichome size; additionally, trichomes tend to deter sap feeding or leaf chewing to a greater extent than those feeding within plant tissues (Tian *et al*. 2012; Figueiredo *et al*. 2013). Pooled data (Table 4.3) also showed that all the varieties have significant effect on the incidence of *A. spiraecola* population. It can be revealed that the highest mean population in the pooled data was observed at 120 DAT with 12.10 aphid /plant in Pusa rohini (V_I) and the

lowest at 45 DAT with 3.81aphid/plant in local cultivar (V_5). The varying degree of total mean population was recorded highest in Pusa Rohini (10.14 aphid/plant) followed by Sakata-914 (9.32 aphid/plant), Rocky (9.03 aphid/plant), Pusa Sheetal (6.88 aphid/plant) and the least population was seen in the Local cultivar (5.63 aphid/plant). The research study was undertaken to record the varieties that are more resistant to the insect-pests of tomato crop. Similar research of screening of varieties for insect pest resistance of tomato crop were also conducted by Bustos *et al.* 2004; Naik *et al.* 2005 andBaldin *et al.* 2005. The morphological characters of the Local variety used in this study match with the reports of Kok (1978), the author reported that wild species of tomato with erect, small leaved, densely pubescent with glandular hairs were resistant to aphids, ultimately resulting in less infestation. In another similar finding by Chaudhuri *et al*. (2000), the author reported that hybrids were more susceptible to pests than high yielding open pollinated varieties.

The interaction between different planting date and varieties (Table 4.2) showed significant effect on all dates of observation. The treatment combination of Pusa Rohini planted on 23rd October (D_3V_1) harboured the maximum mean aphid population on both the experimental trials with 11.65 and 12.05 aphid/plant respectively. Whereas, the minimum aphid population was observed on Local cultivar planted on 23rd September (D_1V_5) with 4.63 and 4.95 aphid/ plant respectively. Pooled data on the interaction between planting data and varieties against *A. spiraecola* (Table 4.4) exhibited significant effect on all dates of observations. Similar results were also obtained from the pooled data *i.e.* the treatment combination of Pusa Rohini planted on 23rd October (D_3V_1) harboured the maximum mean aphid population of 11.81 aphid/plant while the lowest observed on Local cultivar planted on 23rd September (D_1V_5) with 4.79 aphid/plant. The highest mean observation was recorded at 120 DAT (13.97 aphid/plant) in D_3V_1 and the lowest was recorded at 45 DAT (3.35 aphid/plant) in D_1V_5.

Correlation co-efficient worked out to find the relationship between aphid population with abiotic factors (Table 4.13) during 2019-2020 revealed that aphid population exhibited positive and significant interaction with maximum temperature ($r = 0.855$, $p< 0.01$) on D_3 whereas, significant negative correlation with maximum relative humidity on D_2 ($r = -0.700$, $p< 0.05$) and minimum relative humidity on D_3 ($r = -0.797$, $p< 0.05$). Similarly, during the second year (2020-2021) data pertaining to correlation revealed that there was a significant positive correlation with minimum temperature ($r = 0.811$, $p< 0.01$) on D_3 and significant negative correlation with maximum relative humidity ($r = -0.757$, $p< 0.05$) on D_1. Aphid population on all varieties under study showed non-significant correlation with all abiotic factors (Table 4.14) during the first year of research (2019-2020) whereas for the second research period (2020-2021), aphid population showed significant and negative correlation with maximum relative humidity on variety Pusa Sheetal ($r = -0.708$, $p <0.05$), Rocky ($r = -0.669$, $p <0.05$), Sakata-914 ($r = -0.598$, $p <0.05$) and Local cultivar ($r = -0.763$, $p <0.05$). Other parameters exhibited non-correlation at both 5% and 1% level of significance. Our findings is comparable with the findings of Pavan *et al.* (2019), the authors reported correlation studies of aphid population showed non- significant positive correlation with temperature (minimum, average) and bright sunshine hrs while significant negative correlation with relative humidity (maximum, minimum, average). Sharma *et al.* (2013) also reported that the aphid population was positive but non-significantly correlated with the maximum, minimum temperature („r"=0.576; 0.215) but exhibited negative but non-significant correlation with relative humidity (maximum and minimum) (r= –0.506; –0.381) and rainfall (r= –0.613).

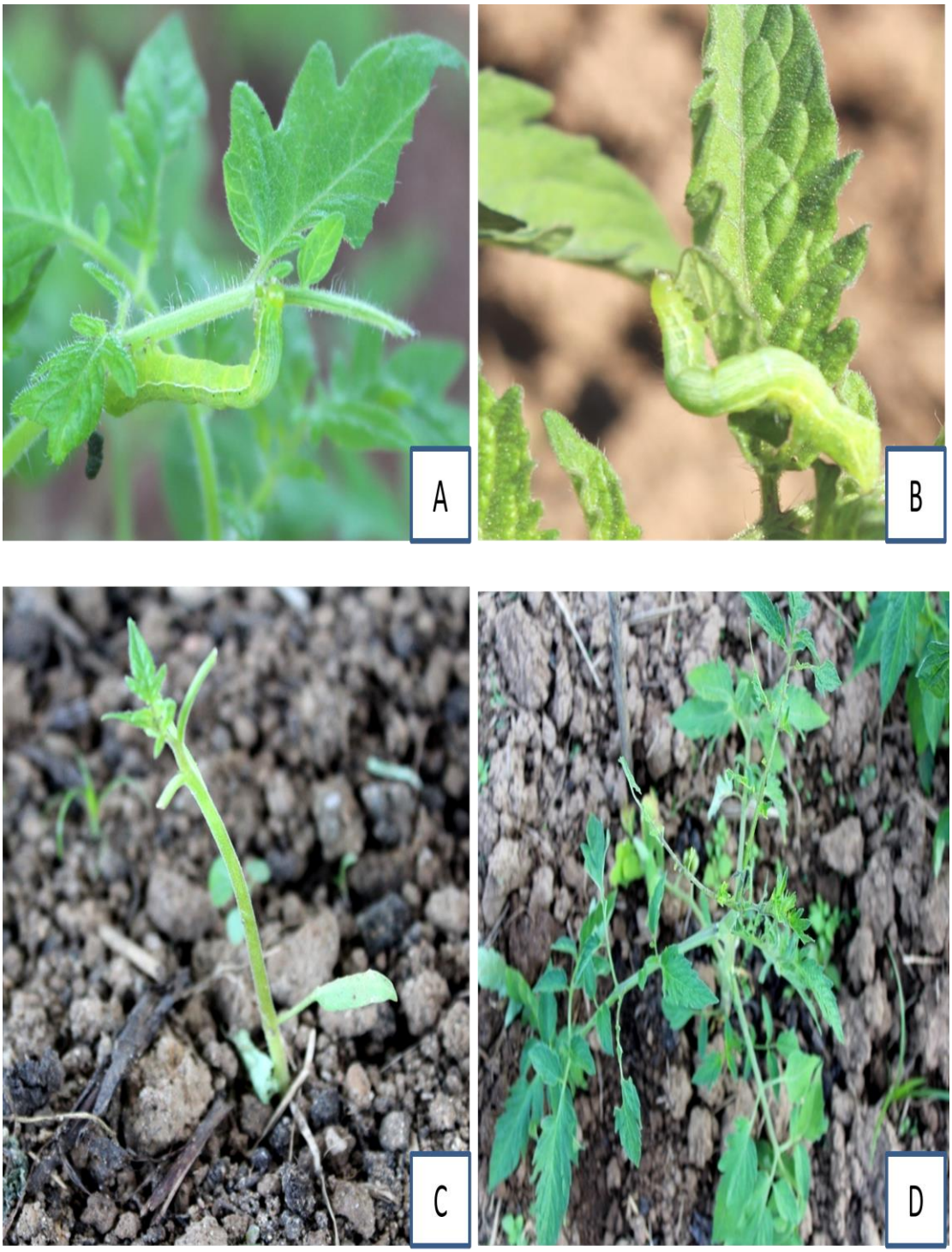


Plate 4. A-B. Larva of tomato green looper, *Chrysodeixis eriosoma*
C-D. *Damaged symptoms of C*. *eriosoma*

4.1.2. Influence of date of planting and varieties against green garden looper, *Chrysodeixis eriosoma*

The influence of planting date against green garden looper, *C. eriosoma* population are presented in Tables 4.5 - 4.8 and illustrated as histograms in Figure 4.3 and 4.4. Analysis of data revealed from the two years experimental trials that all three dates of planting had significant influence on all dates of observation except at 105 DAT and 120 DAT in the year 2020-2021. In both the years of experimental trial the incidence of *C. eriosoma* was recorded right from the beginning of data observation *i.e.* 45 DAT, 60 DAT and from 90 DAT the pest showed a gradual decline in population. In the first experimental year, the highest incidence of 0.32 number of larva/plant was recorded at 45 DAT in D_1*i.e.* first week of December, whereas the lowest pest incidence of 0.01 larva/plant was recorded at 135 DAT (D_2) *i.e.* fourth week of march. The maximum mean population was observed in D_1 (23^{rd}September) with 0.14 larva/plant and the minimum mean population of 0.11 larva/plant was recorded in D_2 (8^{th} October). In the second year of experimental trial (2020-2021), the highest incidence of 0.33 larva/plant was observed at 45 DAT in D_1 and D_2 (*i.e.* first and fourth week of December respectively); also the highest mean population was recorded in D_2 with 0.15 larva/plant. Similarly the lowest pest incidence of 0.01 larva/plant was recorded on 135 DAT in D_2 and the least mean population of 0.12 larva/plant was seen in D_3. From the analysed data for both the years, we see a pattern of the pest population where it shows an initial high pest population accompanied by an immediate decrease then a gradual appearance of the pest which is ultimately followed by a steady decrease; this may be due to the presence of an endoparasitoid wasp, *Glyptapanteles* sp. which was actively present in the field. The pooled data (Table 4.7) represents that all planting dates have significant effect on the incidence of green garden looper, *C. eriosoma*. The pest incidence was recorded highest during the initial date of observation at 45 DAT with 0.33 larva/plant in $D_1$and also the highest

Table 4.5: Effect of date of planting and varieties on abundance of green garden looper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of green garden looper (*Chrysodeixis eriosoma*) / *plant***															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D_1	0.32 (0.90)	0.28 (0.88)	0.09 (0.77)	0.03 (0.72)	0.05 (0.74)	0.13 (0.79)	0.08 (0.76)	0.14	0.33 (0.90)	0.31 (0.89)	0.13 (0.79)	0.01 (0.72)	0.04 (0.73)	0.05 (0.74)	0.07 (0.75)	0.13
D_2	0.19 (0.82)	0.28 (0.88)	0.15 (0.80)	0.08 (0.76)	0.00 (0.71)	0.11 (0.78)	0.01 (0.72)	0.11	0.33 (0.91)	0.29 (0.89)	0.16 (0.80)	0.11 (0.78)	0.05 (0.74)	0.11 (0.77)	0.01 (0.72)	0.15
D_3	0.15 (0.80)	0.23 (0.85)	0.13 (0.79)	0.19 (0.82)	0.09 (0.77)	0.05 (0.74)	0.00 (0.71)	0.12	0.25 (0.87)	0.27 (0.87)	0.17 (0.81)	0.13 (0.79)	0.04 (0.73)	0.03 (0.72)	0.00 (0.71)	0.12
SEm±	*0.02*	*0.02*	*0.01*	*0.02*	*0.004*	*0.008*	*0.005*		*0.01*	*0.01*	*0.02*	*0.01*	*0.005*	*0.014*	*0.009*	
CD (P= 0.05)	*0.08*	*0.06*	*0.05*	*0.06*	*0.017*	*0.031*	*0.020*		*0.03*	*0.06*	*0.08*	*0.04*	*NS*	*NS*	*0.034*	
Varieties																
V_1	0.27 (0.87)	0.40 (0.95)	0.07 (0.75)	0.20 (0.83)	0.09 (0.76)	0.18 (0.82)	0.07 (0.75)	0.18	0.36 (0.92)	0.44 (0.97)	0.04 (0.74)	0.13 (0.79)	0.07 (0.75)	0.04 (0.74)	0.04 (0.74)	0.16
V_2	0.18 (0.81)	0.31 (0.90)	0.11 (0.78)	0.04 (0.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.09	0.33 (0.91)	0.38 (0.94)	0.22 (0.85)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.14
V_3	0.13 (0.78)	0.22 (0.85)	0.29 (0.88)	0.13 (0.79)	0.00 (0.71)	0.13 (0.79)	0.07 (0.75)	0.4	0.40 (0.95)	0.31 (0.90)	0.40 (0.95)	0.16 (0.81)	0.00 (0.71)	0.11 (0.78)	0.07 (0.75)	0.21
V_4	0.42 (0.95)	0.38 (0.93)	0.16 (0.81)	0.11 (0.78)	0.16 (0.81)	0.18 (0.82)	0.02 (0.72)	0.20	0.33 (0.91)	0.29 (0.89)	0.09 (0.76)	0.07 (0.75)	0.13 (0.79)	0.16 (0.80)	0.02 (0.72)	0.16
V_5	0.09 (0.76)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.01	0.11 (0.78)	0.02 (0.72)	0.02 (0.72)	0.00 (0.71)	0.02 (0.72)	0.00 (0.71)	0.00 (0.71)	0.02
SEm±	*0.03*	*0.01*	*0.02*	*0.01*	*0.008*	*0.012*	*0.012*		*0.01*	*0.02*	*0.02*	*0.01*	*0.006*	*0.018*	*0.010*	
CD (P= 0.05)	*0.09*	*0.04*	*0.06*	*0.04*	*0.023*	*0.034*	*0.035*		*0.04*	*0.04*	*0.05*	*0.04*	*0.019*	*0.051*	*0.030*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values; NS: Non significant at 5% level of significance

Table 4.6: Interaction effect of date of planting and varieties on abundance of green garden looper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of green garden looper (*Chrysodeixis eriosoma*) / *plant***															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.13 (0.79)	0.40 (0.95)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.20 (0.84)	0.13 (0.79)	0.12	0.20 (0.84)	0.53 (1.02)	0.20 (0.84)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.07 (0.75)	0.12
D_1V_2	0.40 (0.95)	0.33 (0.91)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.11	0.53 (1.02)	0.40 (0.95)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.15
D_1V_3	0.40 (0.94)	0.20 (0.84)	0.20 (0.83)	0.00 (0.71)	0.00 (0.71)	0.27 (0.87)	0.20 (0.84)	0.18	0.53 (1.02)	0.27 (0.88)	0.27 (0.87)	0.00 (0.71)	0.00 (0.71)	0.13 (0.79)	0.20 (0.84)	0.20
D_1V_4	0.53 (1.02)	0.47 (0.98)	0.20 (0.83)	0.13 (0.79)	0.27 (0.87)	0.20 (0.84)	0.07 (0.75)	0.27	0.40 (0.95)	0.33 (0.91)	0.13 (0.79)	0.07 (0.75)	0.20 (0.84)	0.13 (0.79)	0.07 (0.75)	0.19
D_1V_5	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.02	0.13 (0.79)	0.00 (0.71)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.03
D_2V_1	0.33 (0.91)	0.33 (0.91)	0.00 (0.71)	0.13 (0.79)	0.00 (0.71)	0.20 (0.84)	0.07 (0.75)	0.15	0.47 (0.98)	0.33 (0.91)	0.00 (0.71)	0.20 (0.84)	0.00 (0.71)	0.00 (0.71)	0.07 (0.75)	0.15
D_2V_2	0.00 (0.71)	0.33 (0.91)	0.27 (0.87)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.10	0.27 (0.87)	0.40 (0.95)	0.27 (0.87)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.15
D_2V_3	0.00 (0.71)	0.33 (0.91)	0.40 (0.95)	0.13 (0.79)	0.00 (0.71)	0.13 (0.79)	0.00 (0.71)	0.14	0.33 (0.91)	0.40 (0.95)	0.33 (0.91)	0.20 (0.84)	0.00 (0.71)	0.20 (0.83)	0.00 (0.71)	0.20
D_2V_4	0.53 (1.01)	0.40 (0.95)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.20 (0.84)	0.00 (0.71)	0.17	0.47 (0.98)	0.33 (0.91)	0.00 (0.71)	0.00 (0.71)	0.20 (0.84)	0.33 (0.91)	0.00 (0.71)	0.19
D_2V_5	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.01	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.01
D_3V_1	0.33 (0.91)	0.47 (0.98)	0.20 (0.84)	0.47 (0.98)	0.27 (0.87)	0.13 (0.79)	0.00 (0.71)	0.27	0.40 (0.95)	0.47 (0.98)	0.07 (0.75)	0.20 (0.84)	0.20 (0.84)	0.13 (0.79)	0.00 (0.71)	0.21
D_3V_2	0.13 (0.79)	0.27 (0.87)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.06	0.20 (0.84)	0.33 (0.91)	0.27 (0.87)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.12
D_3V_3	0.00 (0.71)	0.13 (0.79)	0.27 (0.87)	0.27 (0.87)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.10	0.33 (0.91)	0.27 (0.87)	0.40 (0.95)	0.27 (0.87)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.18
D_3V_4	0.20 (0.84)	0.27 (0.87)	0.20 (0.84)	0.20 (0.84)	0.20 (0.84)	0.13 (0.79)	0.00 (0.71)	0.17	0.13 (0.79)	0.20 (0.84)	0.13 (0.79)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.08
D_3V_5	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.01	0.20 (0.84)	0.07 (0.75)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.04
SEm±	*0.05*	*0.03*	*0.03*	*0.02*	*0.014*	*0.020*	*0.021*		*0.03*	*0.03*	*0.03*	*0.03*	*0.011*	*0.030*	*0.018*	
CD (P= 0.05)	*0.16*	*0.08*	*0.10*	*0.07*	*0.040*	*0.059*	*0.061*		*0.07*	*0.08*	*0.09*	*0.07*	*0.033*	*0.089*	*0.051*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

mean population of 0.14 numbers of *C. eriosoma* was recorded in D_1 whereas, the lowest pest incidence of 0.01 larva/plant was recorded on 135 DAT in D_2 with the least mean population also observed in D_3. The present finding is also in partial compliance with that of Roberts (1979), where the author reported the incidence of *C. eriosoma* to be in considerable numbers in January and February but only sporactically in the months of May to October.

A thorough analysis of the data revealed that the influence of different varieties had significant effect against green garden looper, *C. eriosoma* population on all dates of observation. The variety Sakata-914 (V_4) at 45 DAT (0.42 larva/plant) was found to be more susceptible to *C. eriosoma* during the first experimental year also the highest mean population was recorded in this variety (0.20 larva/plant) while Pusa Rohini (V_1) at 60 DAT (0.44 larva/plant) had maximum pest incidence during the second year and the maximum mean population was observed in the variety Rocky (V_3) with 0.21 number of larva per plant. Throughout the crop growth in both experimental years, significantly low population of this pest was recorded on Pusa Sheetal (V_2), while the least number of *C. eriosoma* population was found on the Local cultivar. The pooled data for this pest (Table 4.7) also showed a significant influence on all dates of observation. The highest incidence of 0.42 larva/plant was recorded in the variety Pusa Rohini at 60 DAT while the total mean for all the varieties registered infestation ranging between 0.02 to 0.18 larva/plant. The total mean population recorded were 0.02 larva/plant in Local cultivar, followed by Pusa Sheetal (0.12 larva/plant), Rocky (0.17 larva/plant), Pusa Rohini (0.17 larva/plant) and Sakata-914 (0.18 larva/plant). The Local tomato cultivar had significantly least incidence (0.02 larva/plant) and the rest were at par.

Table 4.7: Pooled data on the effect of date of planting and varieties on abundance of green garden looper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of green garden looper (*Chrysodeixis eriosoma*) / *plant***							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	0.33 (0.90)	0.29 (0.88)	0.11 (0.78)	0.02 (0.72)	0.05 (0.74)	0.09 (0.77)	0.07 (0.75)	0.14
D_2: 8th October 2019	0.26 (0.86)	0.29 (0.88)	0.15 (0.80)	0.09 (0.77)	0.03 (0.72)	0.11 (0.77)	0.01 (0.72)	0.13
D_3: 23rd October 2019	0.20 (0.83)	0.25 (0.86)	0.15 (0.80)	0.16 (0.81)	0.07 (0.75)	0.04 (0.73)	0.00 (0.71)	0.12
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.003*	*0.008*	*0.005*	
CD (P= 0.05)	*0.03*	*0.04*	*0.04*	*0.03*	*0.011*	*0.026*	*0.016*	
Varieties								
V_1: Pusa Rohini	0.31 (0.90)	0.42 (0.96)	0.06 (0.74)	0.17 (0.81)	0.08 (0.76)	0.11 (0.78)	0.06 (0.74)	0.17
V_2: Pusa Sheetal	0.26 (0.86)	0.34 (0.92)	0.17 (0.81)	0.06 (0.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.12
V_3: Rocky	0.27 (0.87)	0.27 (0.87)	0.34 (0.92)	0.14 (0.80)	0.00 (0.71)	0.12 (0.78)	0.07 (0.75)	0.17
V_4: Sakata-914	0.38 (0.93)	0.33 (0.91)	0.12 (0.79)	0.09 (0.76)	0.14 (0.80)	0.17 (0.81)	0.02 (0.72)	0.18
V_5: Local Cultivar	0.10 (0.77)	0.01 (0.71)	0.01 (0.71)	0.00 (0.71)	0.01 (0.71)	0.00 (0.71)	0.00 (0.71)	0.02
SEm±	*0.02*	*0.01*	*0.01*	*0.01*	*0.005*	*0.011*	*0.008*	
CD (P= 0.05)	*0.05*	*0.03*	*0.04*	*0.03*	*0.014*	*0.030*	*0.022*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

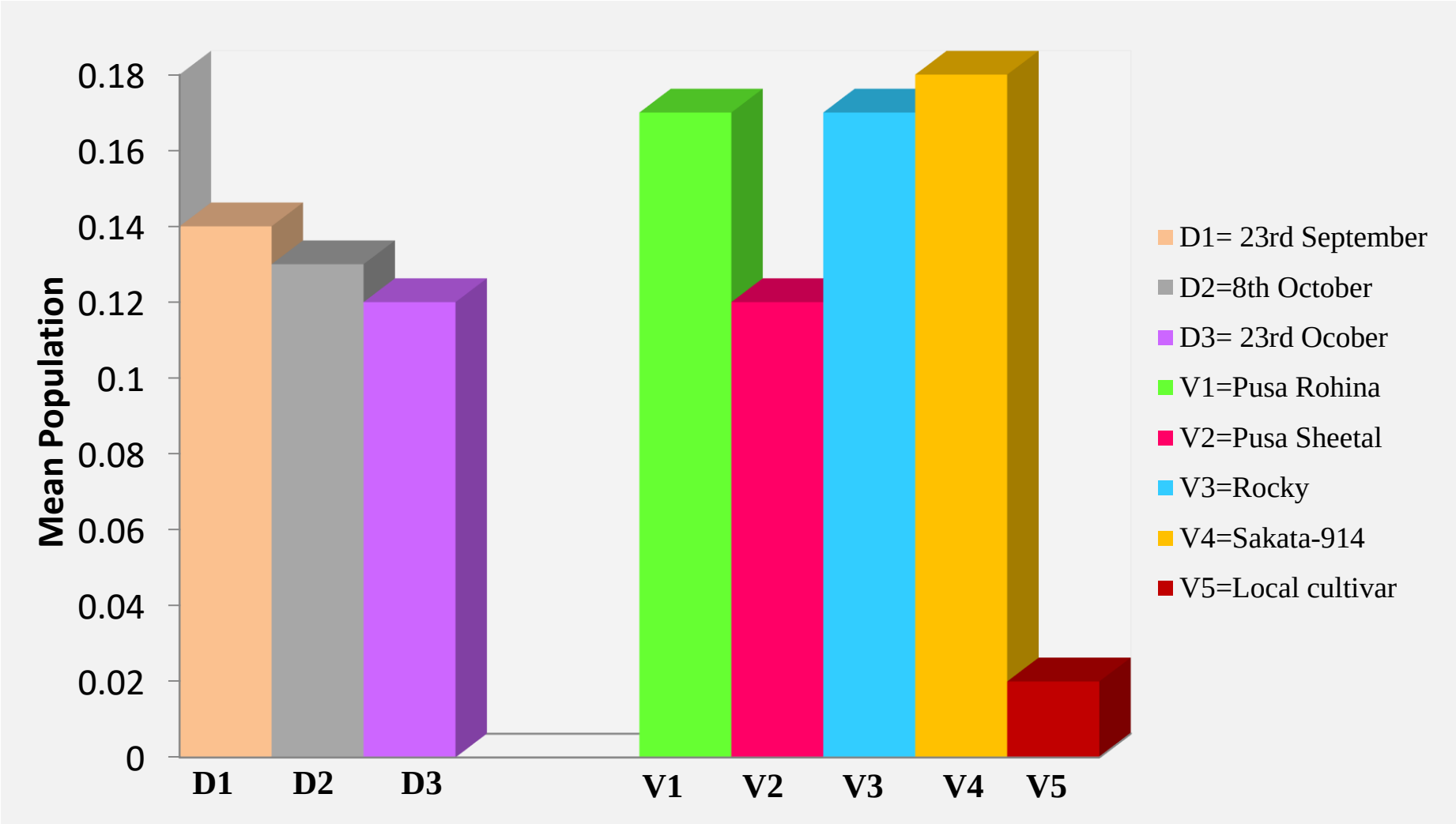


Fig **4.3. : Pooled data on the effect of date of planting and varieties on abundance of semilooper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2021**

Table 4.8: Pooled data on the interaction effect of date of planting and varieties on abundance of green garden looper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of green garden looper (*Chrysodeixis eriosoma*) / *plant***							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.17 (0.82)	0.47 (0.98)	0.10 (0.77)	0.00 (0.71)	0.00 (0.71)	0.10 (0.77)	0.10 (0.77)	0.13
D_1V_2	0.47 (0.98)	0.37 (0.93)	0.10 (0.77)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.13
D_1V_3	0.47 (0.98)	0.23 (0.86)	0.23 (0.85)	0.00 (0.71)	0.00 (0.71)	0.20 (0.83)	0.20 (0.84)	0.19
D_1V_4	0.47 (0.98)	0.40 (0.95)	0.17 (0.81)	0.10 (0.77)	0.23 (0.86)	0.17 (0.82)	0.07 (0.75)	0.23
D_1V_5	0.13 (0.79)	0.00 (0.71)	0.03 (0.73)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.01
D_2V_1	0.40 (0.94)	0.33 (0.91)	0.00 (0.71)	0.17 (0.82)	0.00 (0.71)	0.10 (0.77)	0.07 (0.75)	0.15
D_2V_2	0.13 (0.79)	0.37 (0.93)	0.27 (0.87)	0.13 (0.79)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.13
D_2V_3	0.17 (0.81)	0.37 (0.93)	0.37 (0.93)	0.17 (0.82)	0.00 (0.71)	0.17 (0.81)	0.00 (0.71)	0.17
D_2V_4	0.40 (0.95)	0.37 (0.93)	0.03 (0.73)	0.00 (0.71)	0.10 (0.77)	0.27 (0.87)	0.00 (0.71)	0.18
D_2V_5	0.03 (0.73)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.03 (0.73)	0.00 (0.71)	0.00 (0.71)	0.01
D_3V_1	0.47 (0.98)	0.47 (0.98)	0.13 (0.79)	0.33 (0.91)	0.23 (0.86)	0.13 (0.79)	0.00 (0.71)	0.25
D_3V_2	0.17 (0.81)	0.30 (0.89)	0.13 (0.79)	0.03 (0.73)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.09
D_3V_3	0.17 (0.81)	0.20 (0.83)	0.33 (0.91)	0.27 (0.87)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.14
D_3V_4	0.17 (0.82)	0.23 (0.86)	0.17 (0.82)	0.17 (0.82)	0.10 (0.77)	0.07 (0.75)	0.00 (0.71)	0.13
D_3V_5	0.13 (0.79)	0.03 (0.73)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.02
SEm±	*0.03*	*0.02*	*0.02*	*0.02*	*0.009*	*0.018*	*0.014*	
CD (P= 0.05)	*0.09*	*0.05*	*0.07*	*0.05*	*0.025*	*0.052*	*0.039*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

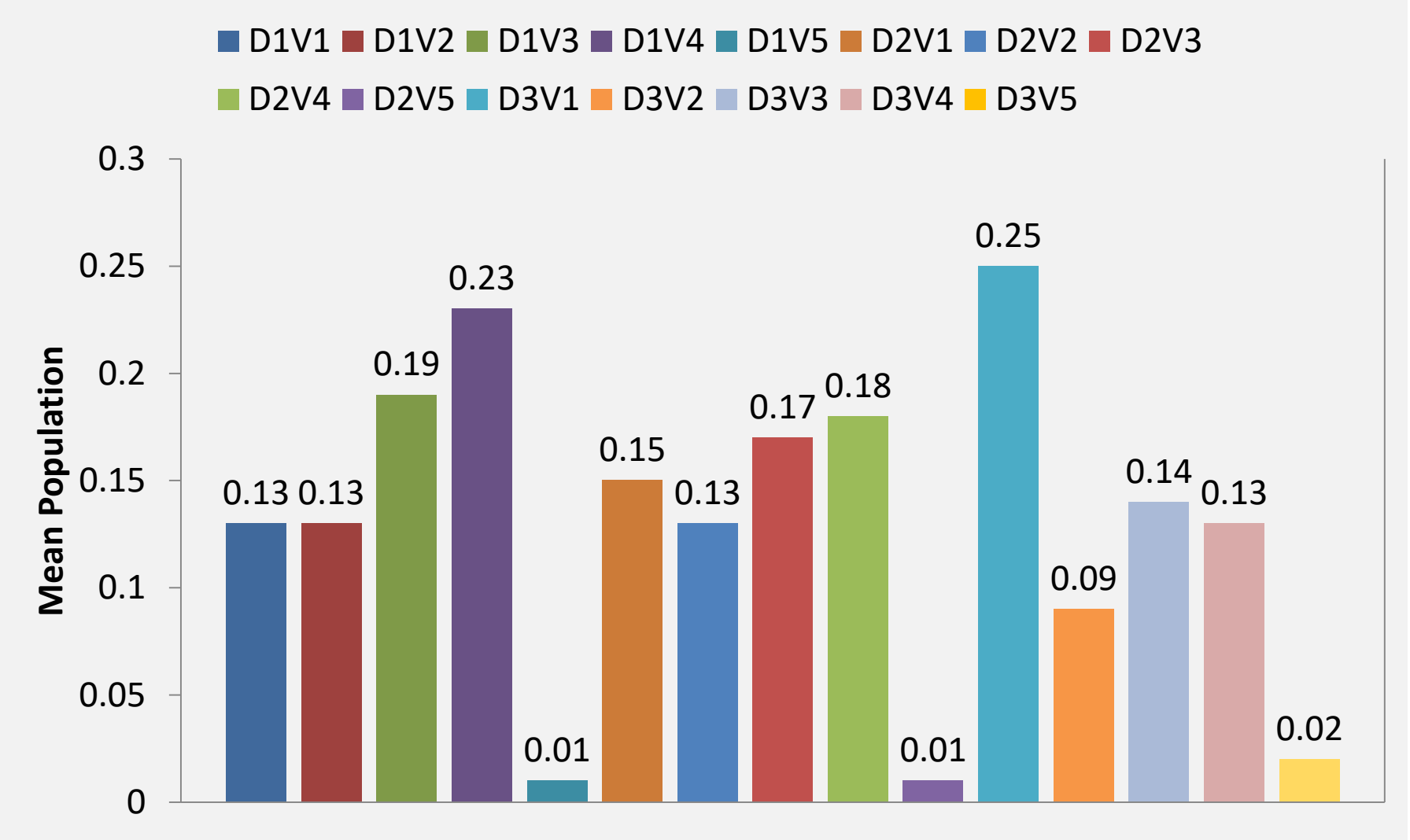


Fig **4.4: Pooled data on the interaction effect of date of planting and varieties on abundance of semilooper (*Chrysodeixis eriosoma*) population in tomato ecosystem during 2019-2020 and 2020-2021**

The interaction combinations of planting dates and varieties were found to be significant throughout the crop growth for both years of experimental trials (Table 4.6). The treatment combination of Pusa Rohini planted on 23rd October (D_3V_1) recorded the maximum mean population on both the experimental trials with 0.29 larva/plant and 0.21 larva/plant respectively. Whereas the minimum total mean population was observed on Local cultivar planted on 8th October (D_2V_5) with 0.01 larva/plant respectively. The pooled data (Table 4.8) also revealed a similar pattern of incidence with the maximum total mean population of 0.25 larva/plant observed at D_3V_1 (i.e Pusa Rohini planted on 23rd October) and the minimum mean of 0.01 larva/plant was observed on D1V5 (Local cultivar planted on 23rd September) and D_2V_5 (Local cultivar planted on 8th October). The data on the incidence of *C.eriosoma* against different varieties under study shows minimum incidence on the Local cultivar in all planting dates.

Correlation analysis indicated (Table 4.13) that *C. eriosoma* was negatively significant with maximum temperature ($r = -0.855$, $p < 0.01$) and positively significant with maximum relative humidity ($r = 0.838$, $p<0.01$) in D_2 during the first research trial (2019-2020). On the other hand, the correlation analysis for the second trial reveals significant negative correlation with maximum temperature on D_2 ($r = -756$, $p<0.05$) and D_3 ($r = -0.892$, $p<0.01$); minimum temperature on D_2 ($r = -695$, $p<0.05$) and D3 ($r = -0.927$, $p<0.01$); and positive significant correlation with maximum relative humidity in D_2 ($r = 0.742$, $p<0.05$) and D_3 ($r = 0.855$, $p<0.01$). The present research findings is in close accordance with Tripathi and Akhtar (1988), who reported optimum and significant build up of the noctuid *C.eriosoma* population with temperature and high relative humidity.

C. eriosoma population showed (Table 4.14) significant and positive correlation with maximum relative humidity on variety Pusa Rohini ($r = 0.805$, $p < 0.01$), Pusa Sheetal ($r = 0.712$, $p < 0.05$), and Sakata-914 ($r = 0.719$, $p < 0.05$); and minimum relative humidity on the varieties Pusa Sheetal ($r = 0.690$, $p < 0.05$), and Rocky ($r = 0.939$, $p < 0.01$) during the first experimental trial. However for the second research period, *C. eriosoma* population on all varieties exhibited non-significant correlation with all abiotic factors. Other parameters exhibited non-correlation at both 5% and 1% level of significance.

This pest was on the European and Mediterranean plant protection organization (EPPO) alert list between 2000 and 2007 (EPPO, 2007) and there is very limited study done on *C. eriosoma* infesting tomato crop in India and North east India. Hence this research will be the first of its kind and also the first time report of *C.eriosoma* from Nagaland.

4.1.3. Influence of date of planting and varieties against tomato fruit borer, *Helicoverpa armigera*

The data on the incidence of tomato fruit borer, *H. armigera*are tabulated in Table 4.9 – 4.12 and illustrated in Figure 4.5 and 4.6. The data reveals that planting date and varieties had significant effect on the incidence of *H.armigera* in both years. The collected data from the year 2019-2020 reveals that the incidence of tomato fruit borer, *H. armigera* was recorded from 75 DAT (0.56 % fruit damage) in D_1*i.e.* 23rd October planting date, 75 DAT (0.65 % fruit damage) in D_2*i.e.* 8th October planting date and 90 DAT (1.97 % fruit damage) in D_3*i.e.* 23rd October planting date. A comparable pattern was also observed during the second year (2020-2021) research period where the incidence of *H.armigera* was recorded from 75 DAT (0.91 % fruit damage) in D_1*i.e.* 23rd October planting date, 75 DAT (0.81 % fruit damage) in D_2*i.e.* 8th October planting date and 90 DAT (2.32 % fruit damage) in D_3*i.e.* 23rd October planting date. The present findings is supported by the work of

Plate 5. A. Larva of tomato fruit borer, *Helicoverpa armigera*
B. Pupa of *H. armigera*
C-F: Fruit damaged by *H. armigera*

Table 4.9: Effect of date of planting and varieties on abundance of tomato fruit borer (*Helicoverpa armigera*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Percent fruit infestation / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D_1	0.00	0.00	0.56 (0.97)	2.93 (1.82)	5.85 (2.50)	6.99 (2.72)	5.47 (2.42)	3.11	0.00	0.00	0.91 (1.13)	3.31 (1.93)	6.21 (2.58)	7.57 (2.83)	5.80 (2.49)	3.40
D_2	0.00	0.00	0.65 (1.00)	2.96 (1.85)	5.75 (2.50)	7.36 (2.80)	5.79 (2.50)	3.22	0.00	0.00	0.81 (1.05)	3.32 (1.95)	6.05 (2.56)	7.80 (2.88)	6.27 (2.60)	3.46
D_3	0.00	0.00	0.00 (0.71)	1.97 (1.55)	4.38 (2.19)	5.95 (2.52)	4.61 (2.24)	2.42	0.00	0.00	0.00 (0.71)	2.32 (1.66)	4.92 (2.31)	6.22 (2.58)	4.81 (2.29)	2.61
SEm±	-	-	*0.01*	*0.02*	*0.01*	*0.02*	*0.01*		-	-	*0.01*	*0.02*	*0.01*	*0.01*	*0.01*	
CD (P= 0.05)	-	-	*0.05*	*0.06*	*0.05*	*0.06*	*0.05*		-	-	*0.04*	*0.07*	*0.06*	*0.06*	*0.04*	
Varieties																
V_1	0.00	0.00	1.30 (1.27)	3.71 (2.05)	6.49 (2.64)	7.41 (2.81)	6.04 (2.55)	3.56	0.00	0.00	1.60 (1.37)	4.04 (2.13)	6.90 (2.72)	7.94 (2.90)	6.40 (2.62)	3.84
V_2	0.00	0.00	0.00 (0.71)	1.88 (1.53)	4.80 (2.29)	5.91 (2.52)	4.87 (2.31)	2.49	0.00	0.00	0.00 (0.71)	2.42 (1.70)	4.90 (2.31)	6.56 (2.65)	5.18 (2.38)	2.72
V_3	0.00	0.00	0.00 (0.71)	3.20 (1.92)	5.84 (2.52)	7.53 (2.83)	5.80 (2.51)	3.20	0.00	0.00	0.31 (0.87)	3.33 (1.95)	6.29 (2.60)	8.04 (2.92)	6.07 (2.56)	3.43
V_4	0.00	0.00	0.71 (1.07)	2.69 (1.77)	5.92 (2.53)	8.04 (2.92)	6.27 (2.60)	3.38	0.00	0.00	0.96 (1.16)	3.23 (1.92)	6.47 (2.64)	8.09 (2.93)	6.64 (2.67)	3.63
V_5	0.00	0.00	0.00 (0.71)	1.62 (1.44)	3.58 (2.01)	4.94 (2.32)	3.47 (1.97)	1.94	0.00	0.00	0.00 (0.71)	1.88 (1.52)	4.09 (2.14)	5.36 (2.41)	3.84 (2.07)	2.17
SEm±	-	-	*0.02*	*0.01*	*0.02*	*0.02*	*0.02*		-	-	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	
CD (P= 0.05)	-	-	*0.06*	*0.04*	*0.06*	*0.06*	*0.07*		-	-	*0.05*	*0.05*	*0.06*	*0.05*	*0.06*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Table 4.10: Interaction effect of date of planting and varieties on abundance of tomato fruit borer (*Helicoverpa armigera*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Percent fruit infestation / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.00	0.00	1.60 (1.44)	4.07 (2.14)	7.00 (2.73)	7.93 (2.90)	6.47 (2.64)	3.87	0.00	0.00	1.93 (1.56)	4.60 (2.26)	7.27 (2.78)	8.67 (3.03)	7.00 (2.73)	4.21
D_1V_2	0.00	0.00	0.00 (0.71)	2.17 (1.63)	5.87 (2.52)	6.20 (2.59)	5.27 (2.40)	2.79	0.00	0.00	0.00 (0.71)	2.87 (1.83)	6.00 (2.55)	6.87 (2.71)	5.67 (2.48)	3.06
D_1V_3	0.00	0.00	0.00 (0.71)	3.93 (2.11)	6.53 (2.65)	8.00 (2.92)	6.27 (2.60)	3.53	0.00	0.00	0.93 (1.20)	4.00 (2.12)	6.87 (2.71)	8.27 (2.96)	6.33 (2.61)	3.77
D_1V_4	0.00	0.00	1.20 (1.30)	3.27 (1.94)	6.87 (2.71)	8.27 (2.96)	6.53 (2.65)	3.73	0.00	0.00	1.67 (1.47)	3.50 (2.00)	7.20 (2.77)	8.87 (3.06)	6.73 (2.69)	4.00
D_1V_5	0.00	0.00	0.00 (0.71)	1.20 (1.30)	3.00 (1.87)	4.57 (2.25)	2.80 (1.82)	1.65	0.00	0.00	0.00 (0.71)	1.57 (1.44)	3.73 (2.06)	5.20 (2.39)	3.27 (1.94)	1.97
D_2V_1	0.00	0.00	2.30 (1.67)	3.87 (2.09)	6.27 (2.60)	8.20 (2.95)	6.67 (2.68)	3.90	0.00	0.00	2.87 (1.83)	4.00 (2.12)	6.87 (2.71)	8.73 (3.04)	7.00 (2.74)	4.21
D_2V_2	0.00	0.00	0.00 (0.71)	2.33 (1.68)	5.27 (2.40)	7.00 (2.74)	5.33 (2.42)	2.85	0.00	0.00	0.00 (0.71)	2.87 (1.83)	5.33 (2.42)	7.67 (2.86)	5.87 (2.52)	3.11
D_2V_3	0.00	0.00	0.00 (0.71)	2.87 (1.83)	6.00 (2.55)	7.33 (2.80)	5.67 (2.48)	3.12	0.00	0.00	0.00 (0.71)	3.00 (1.87)	6.67 (2.68)	8.00 (2.92)	6.20 (2.59)	3.41
D_2V_4	0.00	0.00	0.93 (1.19)	3.07 (1.89)	6.33 (2.61)	8.00 (2.92)	6.27 (2.60)	3.51	0.00	0.00	1.20 (1.30)	3.87 (2.09)	6.40 (2.63)	7.93 (2.90)	7.00 (2.74)	3.77
D_2V_5	0.00	0.00	0.00 (0.71)	2.67 (1.78)	4.87 (2.32)	6.27 (2.60)	5.00 (2.34)	2.69	0.00	0.00	0.00 (0.71)	2.87 (1.83)	5.00 (2.35)	6.67 (2.68)	5.27 (2.40)	2.83
D_3V_1	0.00	0.00	0.00 (0.71)	3.20 (1.92)	6.20 (2.59)	6.10 (2.57)	5.00 (2.34)	2.93	0.00	0.00	0.00 (0.71)	3.53 (2.01)	6.57 (2.66)	6.43 (2.63)	5.20 (2.39)	3.10
D_3V_2	0.00	0.00	0.00 (0.71)	1.13 (1.28)	3.27 (1.94)	4.53 (2.24)	4.00 (2.12)	1.85	0.00	0.00	0.00 (0.71)	1.53 (1.43)	3.37 (1.97)	5.13 (2.37)	4.00 (2.12)	2.00
D_3V_3	0.00	0.00	0.00 (0.71)	2.80 (1.82)	5.00 (2.34)	7.27 (2.78)	5.47 (2.44)	2.93	0.00	0.00	0.00 (0.71)	3.00 (1.87)	5.33 (2.42)	7.87 (2.89)	5.67 (2.48)	3.12
D_3V_4	0.00	0.00	0.00 (0.71)	1.73 (1.49)	4.57 (2.25)	7.87 (2.89)	6.00 (2.55)	2.88	0.00	0.00	0.00 (0.71)	2.33 (1.68)	5.80 (2.51)	7.47 (2.82)	6.20 (2.59)	3.11
D_3V_5	0.00	0.00	0.00 (0.71)	1.00 (1.22)	2.87 (1.83)	4.00 (2.12)	2.60 (1.76)	1.50	0.00	0.00	0.00 (0.71)	1.20 (1.30)	3.53 (2.01)	4.20 (2.17)	3.00 (1.87)	1.70
SEm±	-	-	*0.03*	*0.02*	*0.03*	*0.04*	*0.04*		-	-	*0.03*	*0.03*	*0.04*	*0.03*	*0.04*	
CD (P=0.05)	-	-	*0.10*	*0.07*	*0.10*	*0.11*	*0.12*		-	-	*0.09*	*0.08*	*0.11*	*0.09*	*0.11*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Harshita *et al*. (2018), the authors noticed the incidence of fruit borer on the month of January 2016 with a mean population of 0.9 larva/plant. The present findings in both years of experimental trial reveals that the insect pest was found to be higher at fruit maturing stage till the final harvest of the crop fruit, the damage varying from 0.56% (75 DAT) in D_1 (*i.e.* first week of January) to 7.36 % (120 DAT) in D_2 (*i.e.* second week of March) for the year 2019-2020 and 0.81%(75 DAT) in D_2 to 7.80% (120 DAT) in D_2 during the year 2020-2021. The highest total mean of 3.22 % (2019-2020) and 3.46 % (2020-2021) was observed in D_2 whereas the lowest was observed on D_3 with 2.42% (2019-2020) and 2.61% (2020-2021). The pooled data (Table 4.11) also indicated that all the planting dates have significant influence on the incidence of *H.armigera* and the pest incidence was observed from 75 DAT (0.72 % fruit damage) in D_1, 75 DAT (0.73% fruit damage) in D_2 and 90 DAT (2.15 % fruit damage) in D_3 which gradually increased and attained its peak fruit damage of 7.58 % at 120 DAT in D_2 and the lowest of 0.72% at 45 DAT in D_1. The overall mean was observed highest in second date of planting (D_2) with 3.34 % fruit damage and the least number of 2.51% fruit damage was observed in the third date of planting (D_3). The data recorded is in accordance with Harshita *et al*. (2018) who observed peak infestation of *H. armigera* during March of 2015-16 and 2016-17. The study conducted by Kharpuse (2005); Shinde *et al*. (2013) and Rishikesh *et al*. (2015) are also in alignment with the present findings where the authors observed peak period activity of fruit borer at fruit maturing stage *i.e.* March to April.

The findings of the present study revealed that tomato fruit borer *H. armigera* had significant effect on all tomato varieties under study throughout the study period (Table 4.9). The variety Sakata-914 (V_4) at 120 DAT was found to be more susceptible to *H. armigera* for both years of trials *i.e.* 8.04% and 8.09% respectively. In addition, the highest mean population of 3.56% (2019-2020) and 3.84% (2020-2021) was recorded in Pusa Rohini (V_1)

Table 4.11: Pooled data on theeffect of planting and varieties on abundance of tomato fruit borer(*Helicoverpa armigera*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Percent fruit infestation / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	0.00	0.00	0.72 (1.02)	3.12 (1.88)	6.03 (2.54)	7.28 (2.78)	5.63 (2.46)	3.26
D_2: 8th October 2019	0.00	0.00	0.73 (1.05)	3.14 (1.90)	5.90 (2.53)	7.58 (2.84)	6.03 (2.55)	3.34
D_3: 23rd October 2019	0.00	0.00	0.00 (0.71)	2.15 (1.60)	4.65 (2.25)	6.09 (2.55)	4.71 (2.27)	2.51
SEm±	-	-	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	
CD (P= 0.05)	-	-	*0.03*	*0.04*	*0.03*	*0.03*	*0.03*	
Varieties								
V_1: Pusa Rohini	0.00	0.00	1.45 (1.32)	3.88 (2.09)	6.69 (2.68)	7.68 (2.85)	6.22 (2.59)	3.70
V_2: Pusa Sheetal	0.00	0.00	0.00 (0.71)	2.15 (1.61)	4.85 (2.30)	6.23 (2.59)	5.02 (2.34)	2.61
V_3: Rocky	0.00	0.00	0.16 (0.79)	3.27 (1.94)	6.07 (2.56)	7.79 (2.88)	5.93 (2.54)	3.32
V_4: Sakata-914	0.00	0.00	0.83 (1.11)	2.96 (1.85)	6.19 (2.58)	8.07 (2.93)	6.46 (2.64)	3.50
V_5: Local Cultivar	0.00	0.00	0.00 (0.71)	1.75 (1.48)	3.83 (2.07)	5.15 (2.37)	3.66 (2.02)	2.06
SEm±	-	-	*0.01*	*0.01*	*0.01*	*0.01*	*0.02*	
CD (P= 0.05)	-	-	*0.04*	*0.03*	*0.04*	*0.04*	*0.04*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

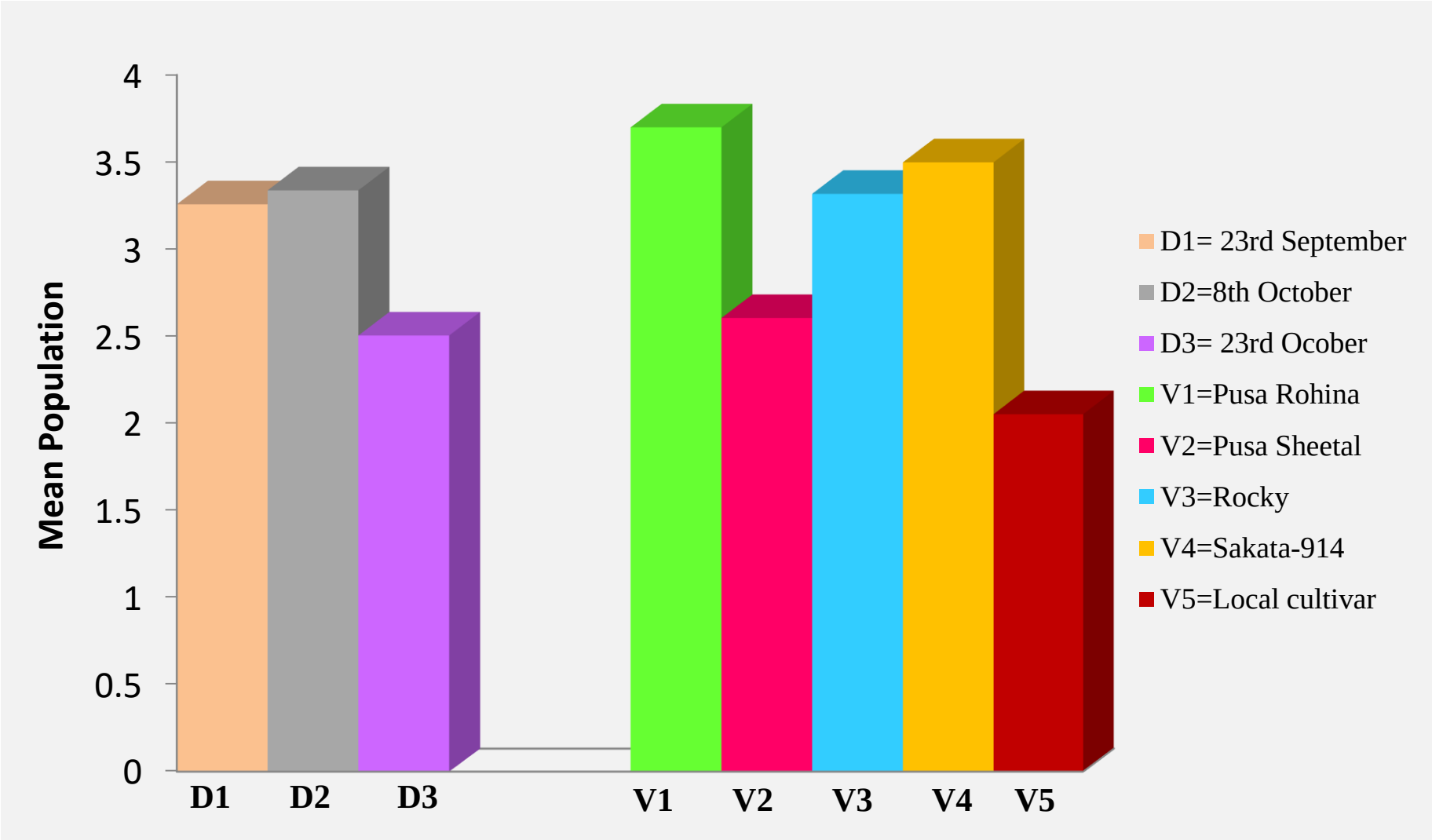


Fig **4.5: Pooled data on the effect of planting and varieties on abundance of *Helicoverpa armigera* population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.12: Pooled data on theinteraction effect of date of planting and varieties on abundance of tomato fruit borer (*Helicoverpa armigera*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Percent fruit infestation / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.00	0.00	1.77 (1.50)	4.33 (2.20)	7.13 (2.76)	8.30 (2.96)	6.73 (2.68)	4.04
D_1V_2	0.00	0.00	0.00 (0.71)	2.52 (1.73)	5.93 (2.54)	6.53 (2.65)	5.47 (2.44)	2.92
D_1V_3	0.00	0.00	0.47 (0.95)	3.97 (2.11)	6.70 (2.68)	8.13 (2.94)	6.30 (2.61)	3.65
D_1V_4	0.00	0.00	1.43 (1.39)	3.38 (1.97)	7.03 (2.74)	8.57 (3.01)	6.63 (2.67)	3.86
D_1V_5	0.00	0.00	0.00 (0.71)	1.38 (1.37)	3.37 (1.96)	4.88 (2.32)	3.03 (1.88)	1.81
D_2V_1	0.00	0.00	2.58 (1.75)	3.93 (2.11)	6.57 (2.66)	8.47 (2.99)	6.83 (2.71)	4.05
D_2V_2	0.00	0.00	0.00 (0.71)	2.60 (1.76)	5.30 (2.41)	7.33 (2.80)	5.60 (2.47)	2.98
D_2V_3	0.00	0.00	0.00 (0.71)	2.93 (1.85)	6.33 (2.61)	7.67 (2.86)	5.93 (2.54)	3.27
D_2V_4	0.00	0.00	1.07 (1.25)	3.47 (1.99)	6.37 (2.62)	7.97 (2.91)	6.63 (2.67)	3.64
D_2V_5	0.00	0.00	0.00 (0.71)	2.77 (1.81)	4.93 (2.33)	6.47 (2.64)	5.13 (2.37)	2.76
D_3V_1	0.00	0.00	0.00 (0.71)	3.37 (1.97)	6.38 (2.62)	6.27 (2.60)	5.10 (2.37)	3.02
D_3V_2	0.00	0.00	0.00 (0.71)	1.33 (1.35)	3.32 (1.95)	4.83 (2.31)	4.00 (2.12)	1.93
D_3V_3	0.00	0.00	0.00 (0.71)	2.90 (1.84)	5.17 (2.38)	7.57 (2.84)	5.57 (2.46)	3.03
D_3V_4	0.00	0.00	0.00 (0.71)	2.03 (1.59)	5.18 (2.38)	7.67 (2.86)	6.10 (2.57)	3.00
D_3V_5	0.00	0.00	0.00 (0.71)	1.10 (1.26)	3.20 (1.92)	4.10 (2.14)	2.80 (1.82)	1.60
SEm±	-	-	*0.02*	*0.02*	*0.03*	*0.02*	*0.03*	
CD (P= 0.05)	-	-	*0.06*	*0.05*	*0.07*	*0.07*	*0.08*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

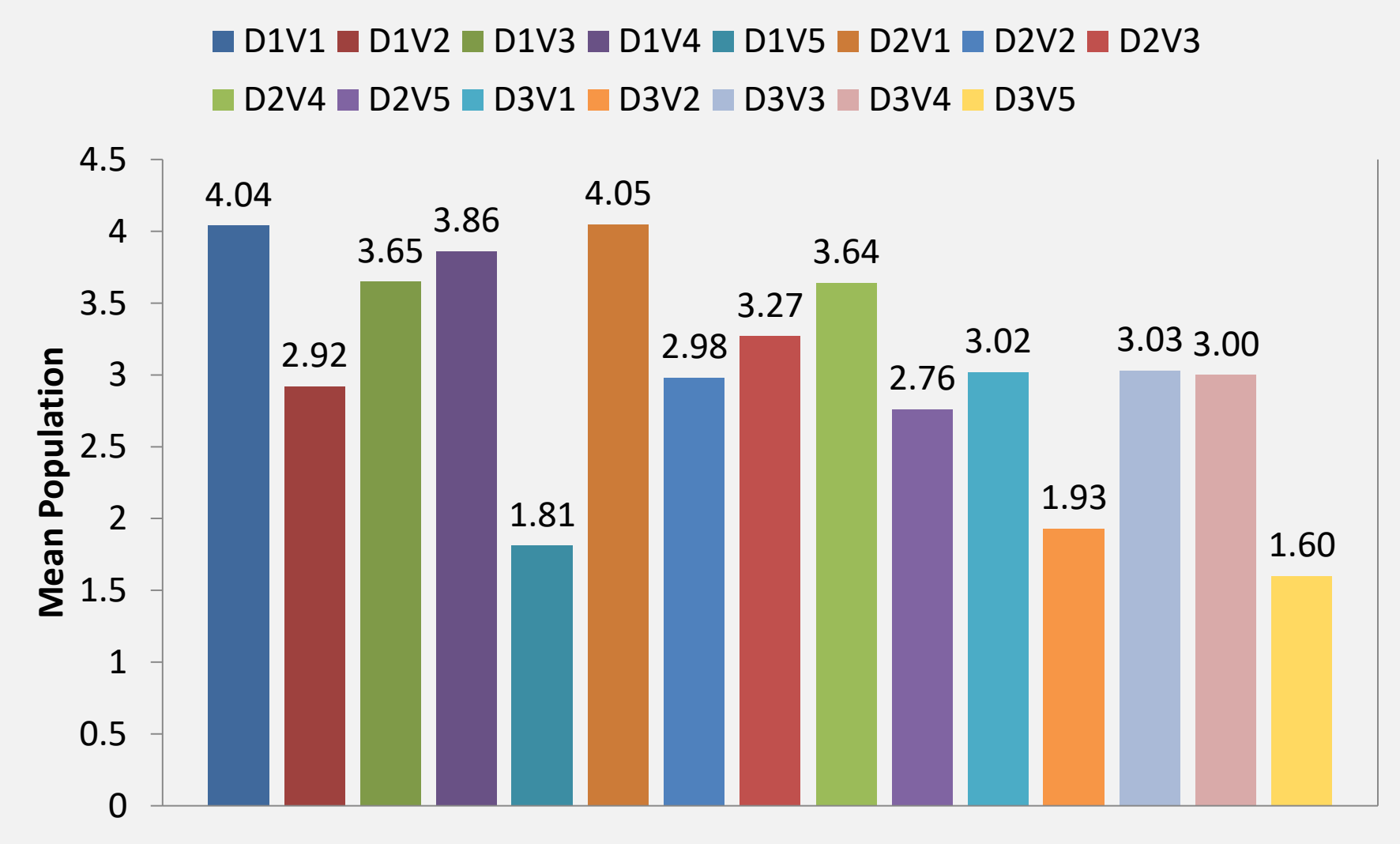


Fig **4.6: Pooled data on the interaction effect of date of planting and varieties on abundance of *Helicoverpa armigera* population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.13: Correlation coefficient (r) of pest complex on dates of sowing of tomato with abiotic factors during 2019-2020 and 2020-2021

Pearson correlation coefficient	Year 2019-2020								
	Aphid			Green garden looper			Tomato fruit borer		
	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)
Maximum temperature (ºC)	0.358	0.663	0.855**	0.180	-0.855**	-0.503	0.612	0.866**	0.838**
Minimum temperature (ºC)	0.164	0.505	0.478	0.276	-0.399	-0.592	0.241	0.770*	0.780*
Maximum relative humidity (%)	-0.644	-0.700*	-0.423	0.565	0.530	0.310	-0.695*	-0.761*	-0.492
Minimum relative humidity (%)	-0.539	-0.654	-0.797*	0.443	0.838**	0.134	-0.766*	-0.653	-0.453
Rainfall (mm)	0.032	0.051	-0.499	-0.303	0.501	-0.083	-0.151	0.043	0.025
Pearson correlation coefficient	**Year 2020-2021**								
	Aphid			**Green garden looper**			**Tomato fruit borer**		
	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)
Maximum temperature (ºC)	0.482	0.615	0.617	-0.180	-0.756*	-0.892**	0.595	0.796*	0.891**
Minimum temperature (ºC)	0.136	0.634	0.811**	0.003	-0.695*	-0.927**	0.319	0.829**	0.970**
Maximum relative humidity (%)	-0.757*	-0.602	-0.532	0.501	0.742*	0.855**	-0.734*	-0.776*	-0.822**
Minimum relative humidity (%)	-0.426	-0.210	-0.162	0.130	0.456	0.512	-0.353	-0.357	-0.469
Rainfall (mm)	0.304	0.542	0.379	-0.308	-0.166	-0.580	0.336	0.526	0.514

Note: df = (9-2) = 7 $r_{0.05} = 0.666$; $r_{0.01} = 0.798$

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

Those values in the table without assign any symbols are non-correlated at 5% and 1% level of significance respectively

Table 4.14: Correlation coefficient (r) of pest complex on varieties of tomato with abiotic factors during 2019-2020 and 2020-2021

Pearson correlation coefficient	Year 2019-2020														
	Aphid					Green garden looper					Tomato fruit borer				
	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)
Maximum temperature (ºC)	0.274	0.291	0.320	0.098	0.291	-0.069	-0.363	-0.587	-0.051	0.223	0.547	0.683	0.644	0.658	0.674
Minimum temperature (ºC)	-0.029	0.119	0.079	-0.035	0.146	-0.194	-0.075	-0.069	-0.059	0.105	0.196	0.327	0.242	0.327	0.288
Maximum relative humidity (%)	-0.505	-0.591	-0.632	-0.508	-0.608	0.805**	0.712*	0.597	0.719*	0.350	-0.710*	-0.714*	-0.658	-0.701*	-0.646
Minimum relative humidity (%)	-0.607	-0.483	-0.592	-0.408	-0.466	0.268	0.690*	0.939**	0.424	0.080	-0.755*	-0.761*	-0.787*	-0.717	-0.748*
Rainfall (mm)	-0.136	0.020	-0.017	0.085	0.112	-0.612	-0.129	0.449	-0.448	-0.248	-0.096	-0.161	-0.201	-0.109	-0.200
Pearson correlation coefficient	**Year 2020-2021**														
	Aphid					**Green garden looper**					**Tomato fruit borer**				
	Pusa Rohini: (V_1)	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**	**Pusa Rohini: (V_1)**	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**	**Pusa Rohini: (V_1)**	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**
Maximum temperature (ºC)	0.290	0.415	0.392	0.220	0.451	-0.427	-0.436	-0.273	-0.122	-0.042	0.557	0.641	0.609	0.628	0.631
Minimum temperature (ºC)	0.034	0.032	0.071	-0.097	0.108	-0.040	-0.257	-0.256	-0.087	0.054	0.282	0.413	0.362	0.365	0.368
Maximum relative humidity (%)	-0.611	-0.708*	-0.669*	-0.598	-0.763*	0.654	0.639	0.447	0.498	0.513	-0.720*	-0.756*	-0.734*	-0.764*	-0.737*
Minimum relative humidity (%)	-0.301	-0.467	-0.388	-0.359	-0.406	0.381	0.182	0.041	-0.047	0.093	-0.337	-0.318	-0.329	-0.347	-0.358
Rainfall (mm)	0.227	0.211	0.250	0.194	0.308	-0.327	-0.423	-0.408	-0.579	-0.340	0.347	0.380	0.343	0.384	0.321

Note: df = (9-2) = 7 $r_{0.05}$ = 0.666; $r_{0.01}$ = 0.798

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

whereas the lowest was recorded in Local cultivar (V_5) with 1.94% (2019-2020) and 2.17% (2020-2021) fruit damage. The pooled data for this pest (Table 4.11) also showed a significant influence on all dates of observation. The highest fruit infestation of 8.07% was recorded in the variety Sakata-914 (V_4) at 120 DAT while lowest was observed in Rocky (V_3) at 75 DAT with 0.16% fruit damage. The results revealed that none of the tomato varieties were found free from damage to fruit borer *H. armigera*,the total mean percentage fruit damage varied among various tomato varieties, Pusa Rohini, Sakata-914 and Rocky were all at par *i.e.* 3.70%, 3.50% and 3.32% respectively while the varieties Pusa Sheetal and Local cultivar recorded minimum per cent fruit damage *i.e.* 2.72% and 2.17% respectively. Sharma *et al.* (2001) also evaluated thirty one advance generation lines of tomato derived from 13 inter varietal crosses against *H. armigera* and reported that none of the tomato genotypes was immune to its attack but four cultivars, viz. 2546-1-2-1, 4237-11 B (Bulk), 0245-1-1 and 0247-1-3-1 were the most promising.

The interaction (Table 4.10) of planting date and varieties on the incidence of tomato fruit borer, *H. armigera* reveals that it is significant for all the date of observation in both years of research trial. The interaction combination of Pusa Rohini transplanted on 23rd October (D_1V_1) recorded the maximum mean population on the first experimental trial with 3.87% fruit damage whereas, Pusa Rohini transplanted on 23rd October (D_1V_1) and 8th November (D_2V_1) showed the highest mean for the second research trial. On the other hand, the minimum total mean population was observed on Local cultivar transplanted on 23th November (D_3V_5) for both the experimental years with 1.50% and 1.70% respectively. The pooled data (Table 4.12) also revealed a similar pattern of incidence with the maximum total mean population of 4.05% fruit damage observed at D_2V_1 (*i.e.* Pusa Rohini transplanted on 8th November) and the minimum mean of 1.60% was observed on D_3V_5 (Local cultivar transplanted on 23rd November).

The results obtained (Table 4.13) during the first experimental period (2019-2020) showed that *H.armigera* had positive and significant correlation with maximum temperature in D_2 ($r = 0.866$, $p<0.01$) and D3 ($r = 0.838$, $p<0.01$); minimum temperature in D_2 ($r = 0.770$, $p<0.05$) and D_3 ($r = 0.780$, $p<0.01$); negative significant correlation with maximum relative humidity on D_1 ($r = -0.695$, $p<0.05$) and D_2 ($r = -0.761$, $p<0.05$) and negative significant correlation with minimum relative humidity in D_1 ($r = -0.766$, $p<0.05$).A similar result was also seen during the second research period (2020-2021) where data obtained revealed a positive and significant correlation with maximum temperature in D_2 ($r = 0.796$, $p<0.05$) and D_3 ($r = 0.891$, $p<0.01$); minimum temperature on D_2 ($r = 0.829$, $p<0.01$) and D_3 ($r = 0.970$, $p<0.01$); and significant negative correlation with maximum relative humidity in D_1 ($r = -0.734$, $p<0.05$), D_2 ($r = -0.776$, $p<0.05$) and D_3 ($r = -0.833$, $p<0.01$) while other parameters on different date of planting were found to be non-significant.

H.armigera population on all varieties under study exhibited negative significant correlation with maximum relative humidity on variety Pusa Rohini ($r = -0.710$, $p<0.05$), Pusa Sheetal ($r = -0.714$, $p<0.05$) and Sakata-914 ($r = -0.701$, $p<0.05$); and negative minimum relative humidity on variety Pusa Rohini ($r = -0.755$, $p<0.05$), Pusa Sheetal ($r = -0.761$, $p<0.05$), Rocky ($r = -0.787$, $p<0.05$) and Local cultivar ($r = -0.748$, $p<0.05$) during the first year of research (2019-2020) whereas during the second research period (2020-2021), significant and negative correlation with maximum relative humidity was observed on all varieties under study *i.e.* Pusa Rohini ($r = -0.720$, $p<0.05$), Pusa Sheetal ($r = -0.756$, $p <0.05$), Rocky ($r = -0.734$, $p <0.05$), Sakata-914 ($r = -0.764$, $p <0.05$) and Local cultivar ($r = -0.737$, $p <0.05$). Other parameters exhibited non-correlation at both 5% and 1% level of significance. The research done by Vikram *et al*. (2018) also reported that tomato fruit borer population was positively correlated with maximum and minimum

temperature, similar result were also observed by Singh and Gupta (2017). The present study presents

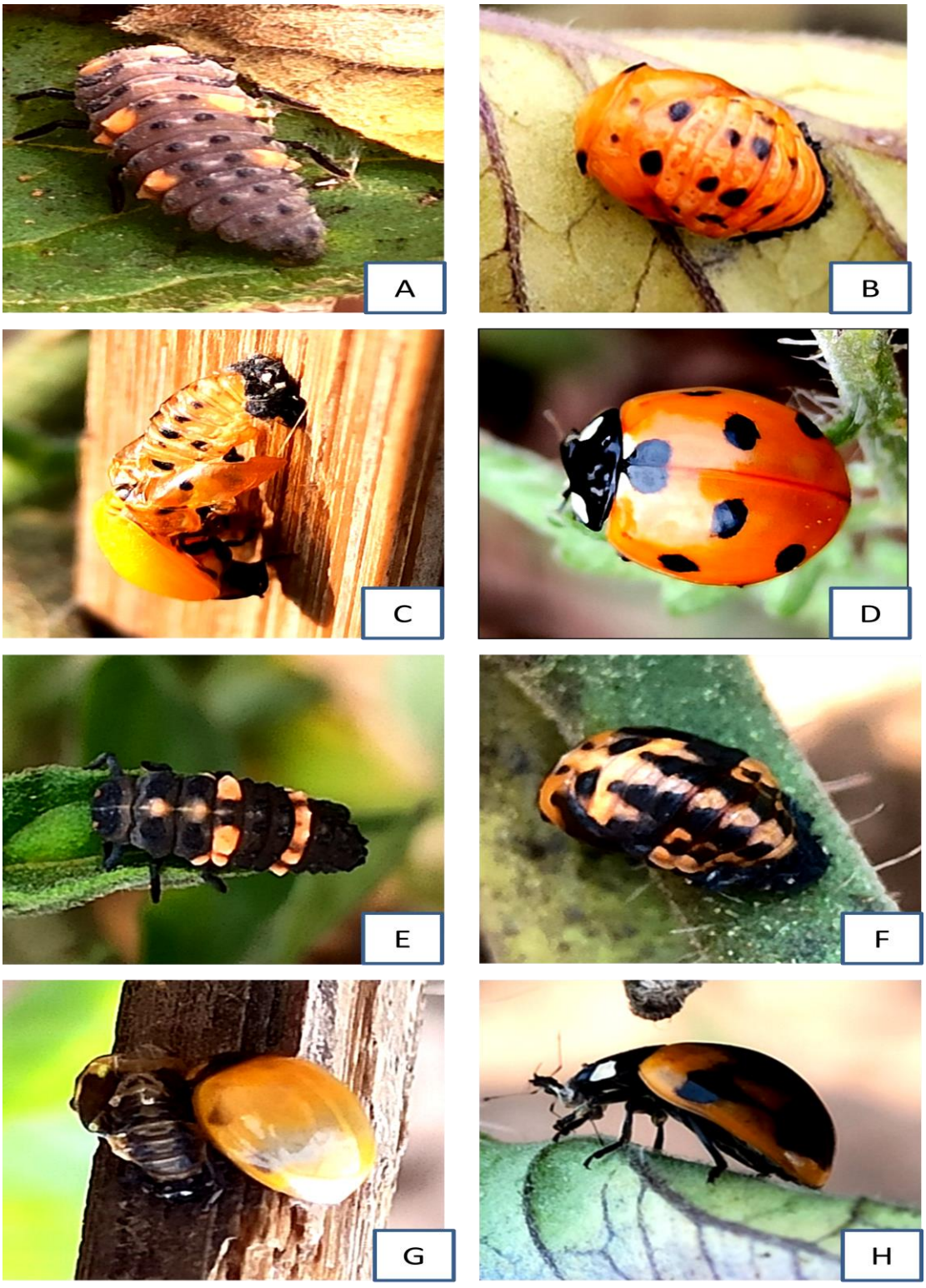


Plate 6. A-D. *Coccinella septempunctata*
E-H. *Coccinalla transversalis*

a significant negative correlation with relative humidity (maximum and minimum) in both years, the result of which is in line with the observations of Rishikesh *et al*. (2015) and Harshita *et al*. (2018).

4.1.4. Influence of date of planting and varieties on abundance of coccinellid population in tomato ecosystem

The data on the incidence of coccinellids populationare tabulated in Table 4.15 – 4.18 and illustrated in Figure 4.7 and 4.8. The present study has aimed to investigate the best management technique to encourage conservation of beneficial organisms by applying integrated pest management to advance pest control while minimizing cost and environmental impacts. Two species of coccinellids viz., *Coccinella septempuctata* and *Coccinella transversalis*were observed during the study period.

Analysis of data revealed from the first experimental trial (2019-2020) show that all the dates of observation had significant influence on coccinellid population except on 45, 90 and 105 DAT whereas, for the second research period 45, 75, 90 and 105 DAT revealed non sifnificant results. In both the years of experimental trial, the coccinellids were recorded right from the beginning of data observation *i.e.* 45 DAT feeding on aphids. The coccinellid population was recorded highest in D_3 (120 DAT) in both the research period with 0.81 and 0.74 number of coccinellid per plant whereas the lowest population was recorded during the initial period *i.e.* 45 DAT in D_1 with mean population of 0.20 coccinellid/plant (2019-2020) and 0.21 coccinellid/plant (2020-2021). In addition the total mean population for all the planting dates (D_1, D_2 and D_3) were at par viz., 0.47, 0.49 and 0.56 coccinellid/plant respectively was observed during the first research period and for the second research period the total mean population of 0.48, 0.51 and 0.56 coccinellid/plant respectively were recorded. The pooled data (Table 4.17) also revealed all the different planting dates had significant influence on the incidence of coccinellids except on 45 and 105 DAT. The maximum number of

Table 4.15: Effect of date of planting and varieties on abundance of coccinellids population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of coccinellids / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D_1	0.20 (0.84)	0.29 (0.89)	0.37 (0.93)	0.55 (1.02)	0.64 (1.06)	0.69 (1.08)	0.56 (1.02)	0.47	0.21 (0.84)	0.32 (0.90)	0.45 (0.97)	0.60 (1.04)	0.71 (1.08)	0.59 (1.04)	0.51 (0.99)	0.48
D_2	0.24 (0.86)	0.44 (0.96)	0.49 (1.00)	0.51 (1.00)	0.63 (1.06)	0.71 (1.10)	0.44 (0.96)	0.49	0.24 (0.86)	0.51 (1.00)	0.45 (0.97)	0.54 (1.02)	0.61 (1.04)	0.64 (1.06)	0.59 (1.04)	0.51
D_3	0.29 (0.89)	0.41 (0.96)	0.57 (1.03)	0.59 (1.04)	0.67 (1.07)	0.81 (1.14)	0.59 (1.04)	0.56	0.33 (0.91)	0.51 (1.00)	0.43 (0.96)	0.62 (1.06)	0.67 (1.07)	0.74 (1.11)	0.59 (1.04)	0.56
SEm±	*0.02*	*0.01*	*0.01*	*0.01*	*0.02*	*0.01*	*0.02*		*0.02*	*0.01*	*0.01*	*0.01*	*0.04*	*0.01*	*0.01*	
CD (P= 0.05)	*NS*	*0.05*	*0.02*	*NS*	*NS*	*0.02*	*0.06*		*NS*	*0.02*	*NS*	*NS*	*NS*	*0.03*	*0.04*	
Varieties																
V_1	0.29 (0.89)	0.38 (0.93)	0.49 (0.99)	0.58 (1.04)	0.82 (1.15)	0.86 (1.16)	0.73 (1.11)	0.59	0.33 (0.91)	0.56 (1.03)	0.53 (1.01)	0.71 (1.10)	0.87 (1.16)	0.82 (1.15)	0.60 (1.05)	0.63
V_2	0.20 (0.83)	0.33 (0.91)	0.44 (0.97)	0.51 (1.00)	0.60 (1.05)	0.64 (1.07)	0.40 (0.94)	0.45	0.22 (0.85)	0.36 (0.92)	0.41 (0.95)	0.56 (1.03)	0.62 (1.06)	0.58 (1.04)	0.52 (1.01)	0.47
V_3	0.24 (0.86)	0.51 (1.00)	0.57 (1.03)	0.69 (1.09)	0.80 (1.14)	0.84 (1.16)	0.67 (1.08)	0.62	0.27 (0.87)	0.47 (0.98)	0.54 (1.02)	0.69 (1.09)	0.78 (1.12)	0.71 (1.10)	0.71 (1.10)	0.60
V_4	0.31 (0.90)	0.42 (0.96)	0.56 (1.03)	0.71 (1.10)	0.80 (1.14)	0.78 (1.13)	0.60 (1.04)	0.60	0.31 (0.90)	0.53 (1.01)	0.41 (0.95)	0.69 (1.09)	0.78 (1.12)	0.76 (1.12)	0.58 (1.04)	0.58
V_5	0.18 (0.82)	0.27 (0.87)	0.33 (0.91)	0.27 (0.87)	0.20 (0.84)	0.56 (1.02)	0.26 (0.86)	0.30	0.18 (0.82)	0.31 (0.90)	0.31 (0.90)	0.29 (0.89)	0.27 (0.87)	0.42 (0.95)	0.40 (0.93)	0.31
SEm±	*0.02*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*	*0.02*		*0.02*	*0.02*	*0.02*	*0.01*	*0.04*	*0.01*	*0.02*	
CD (P= 0.05)	*0.05*	*0.05*	*0.02*	*0.03*	*0.04*	*0.03*	*0.05*		*0.05*	*0.05*	*0.05*	*0.02*	*0.11*	*0.04*	*0.05*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Table 4.16: Interaction effect of date of planting and varieties on abundance of coccinellids population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of coccinellids / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.27 (0.88)	0.27 (0.87)	0.40 (0.95)	0.47 (0.98)	0.87 (1.16)	0.77 (1.13)	0.73 (1.11)	0.54	0.33 (0.91)	0.53 (1.02)	0.67 (1.08)	0.60 (1.05)	0.93 (1.19)	0.77 (1.13)	0.80 (1.14)	0.66
D_1V_2	0.13 (0.79)	0.20 (0.84)	0.27 (0.88)	0.53 (1.02)	0.53 (1.02)	0.73 (1.11)	0.67 (1.08)	0.44	0.27 (0.87)	0.20 (0.84)	0.40 (0.95)	0.57 (1.03)	0.73 (1.11)	0.60 (1.05)	0.40 (0.94)	0.45
D_1V_3	0.20 (0.84)	0.47 (0.98)	0.50 (1.00)	0.70 (1.10)	0.80 (1.14)	0.80 (1.14)	0.87 (1.17)	0.62	0.20 (0.84)	0.33 (0.91)	0.53 (1.02)	0.73 (1.11)	0.87 (1.16)	0.67 (1.08)	0.80 (1.14)	0.59
D_1V_4	0.20 (0.84)	0.27 (0.87)	0.40 (0.95)	0.87 (1.17)	0.80 (1.14)	0.87 (1.17)	0.53 (1.02)	0.56	0.13 (0.79)	0.27 (0.87)	0.40 (0.95)	0.83 (1.15)	0.87 (1.17)	0.80 (1.14)	0.53 (1.02)	0.55
D_1V_5	0.20 (0.84)	0.27 (0.87)	0.27 (0.88)	0.20 (0.84)	0.20 (0.84)	0.27 (0.87)	0.00 (0.71)	0.20	0.13 (0.79)	0.27 (0.87)	0.27 (0.87)	0.27 (0.88)	0.13 (0.79)	0.13 (0.79)	0.00 (0.71)	0.17
D_2V_1	0.20 (0.84)	0.47 (0.98)	0.47 (0.98)	0.60 (1.05)	0.80 (1.14)	0.80 (1.14)	0.87 (1.16)	0.60	0.20 (0.84)	0.53 (1.02)	0.67 (1.08)	0.80 (1.14)	0.67 (1.08)	0.87 (1.17)	0.60 (1.05)	0.62
D_2V_2	0.13 (0.79)	0.40 (0.95)	0.47 (0.98)	0.40 (0.95)	0.60 (1.05)	0.53 (1.02)	0.20 (0.84)	0.39	0.13 (0.79)	0.40 (0.95)	0.40 (0.95)	0.50 (1.00)	0.67 (1.08)	0.53 (1.02)	0.57 (1.03)	0.46
D_2V_3	0.33 (0.91)	0.60 (1.05)	0.60 (1.05)	0.67 (1.08)	0.73 (1.11)	0.87 (1.17)	0.47 (0.98)	0.61	0.27 (0.87)	0.60 (1.05)	0.43 (0.97)	0.53 (1.02)	0.80 (1.13)	0.73 (1.11)	0.73 (1.11)	0.58
D_2V_4	0.40 (0.95)	0.60 (1.05)	0.60 (1.05)	0.60 (1.05)	0.80 (1.14)	0.67 (1.08)	0.47 (0.98)	0.59	0.40 (0.95)	0.73 (1.11)	0.40 (0.95)	0.60 (1.05)	0.67 (1.05)	0.67 (1.08)	0.60 (1.05)	0.58
D_2V_5	0.13 (0.79)	0.13 (0.79)	0.33 (0.91)	0.27 (0.88)	0.20 (0.84)	0.67 (1.08)	0.20 (0.84)	0.28	0.20 (0.84)	0.27 (0.87)	0.33 (0.91)	0.27 (0.88)	0.27 (0.86)	0.40 (0.95)	0.47 (0.98)	0.32
D_3V_1	0.40 (0.95)	0.40 (0.95)	0.60 (1.05)	0.67 (1.08)	0.80 (1.14)	1.00 (1.22)	0.60 (1.05)	0.64	0.47 (0.98)	0.60 (1.05)	0.27 (0.87)	0.73 (1.11)	1.00 (1.22)	0.83 (1.15)	0.40 (0.95)	0.61
D_3V_2	0.33 (0.91)	0.40 (0.95)	0.60 (1.05)	0.60 (1.05)	0.67 (1.08)	0.67 (1.08)	0.33 (0.91)	0.51	0.27 (0.87)	0.47 (0.98)	0.43 (0.97)	0.60 (1.05)	0.47 (0.98)	0.60 (1.05)	0.60 (1.05)	0.49
D_3V_3	0.20 (0.84)	0.47 (0.98)	0.60 (1.05)	0.70 (1.09)	0.87 (1.17)	0.87 (1.17)	0.67 (1.08)	0.63	0.33 (0.91)	0.47 (0.98)	0.67 (1.08)	0.80 (1.14)	0.67 (1.08)	0.73 (1.11)	0.60 (1.05)	0.61
D_3V_4	0.33 (0.91)	0.40 (0.95)	0.67 (1.08)	0.67 (1.08)	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.64	0.40 (0.95)	0.60 (1.05)	0.43 (0.97)	0.63 (1.06)	0.80 (1.14)	0.80 (1.14)	0.60 (1.05)	0.61
D_3V_5	0.20 (0.84)	0.40 (0.95)	0.40 (0.95)	0.33 (0.91)	0.20 (0.84)	0.73 (1.11)	0.57 (1.03)	0.40	0.20 (0.84)	0.40 (0.95)	0.33 (0.91)	0.33 (0.91)	0.40 (0.95)	0.73 (1.11)	0.73 (1.11)	0.45
SEm±	*0.03*	*0.03*	*0.01*	*0.02*	*0.02*	*0.02*	*0.03*		*0.03*	*0.03*	*0.03*	*0.01*	*0.06*	*0.03*	*0.03*	
CD (P= 0.05)	*0.08*	*0.08*	*0.04*	*0.06*	*0.07*	*0.05*	*0.09*		*0.08*	*0.09*	*0.08*	*0.04*	*0.19*	*0.08*	*0.08*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values NS:Non-significant at 5% level of significance

population was seen at 120 DAT in D_3 (0.78 coccinellid/plant) and the minimum was recorded at 45 DAT in D_1 (0.21` coccinellid/plant), likewise the highest overall mean of 0.56 coccinellid/plant was recorded in D_3 which was closely followed by D_2 (0.50 coccinellid/plant) and D_1 (0.48 coccinellid/plant). The findings of Harshita *et al*. (2019) reported that the peak population was observed during the month of February and March. A similar observation was also made by Mondal *et al*. (2019); the authors reported the highest lady bird population during the 13th standard week (*i.e.* fourth week of March) which is in line with the present finding.

The findings of the present study revealed that coccinellid beetles had significant effect on all tomato varieties under study throughout the study period (Table 4.15). The variety Pusa Rohini(V_1) recorded the highest mean population in both the research period *i.e.* 0.86 coccinellid/plant on 120 DAT (2019-2020) and 0.87 coccinellid/plant at 105 DAT (2020-2021) whereas accounting the lowest population of 0.18 coccinellid/plant at 45 DAT was recorded in Local cultivar (V_5) for both research trials. The pooled analysis (Table 4.17) for different varieties under study reveals significant effect on predator population. Analysis on the pooled data reveals the highest predator population of 0.84 coccinellid/plant on the variety Pusa Rohini(V_1) at 105 and 120 DAT while the lowest recorded on Local cultivar (V_5) at 45 DAT with 0.18 coccinellid/plant.

The interaction (Table 4.16) of planting date and varieties on the population abundance of coccinellid beetles reveals that it is significant for all the date of observation in both years of research trial. The interaction combination of Sakata-914 planted on 23rd October (D_3V_4) recorded the highest total mean population of 0.64 coccinellid/plant in the year 2019-2020 on the other hand for the year 2020-2021 the treatment combination Pusa Rohini planted on 23rd September (D_1V_1) recorded the highest mean of 0.66 coccinellid per plant. The pooled data analysis (Table 4.18) also showed a

Table 4.17: Effect of date of planting and varieties on abundance of coccinellids population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of coccinellids / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	0.21 (0.84)	0.31 (0.90)	0.41 (0.95)	0.58 (1.03)	0.67 (1.07)	0.64 (1.06)	0.53 (1.00)	0.48
D_2: 8th October 2019	0.24 (0.86)	0.47 (0.98)	0.47 (0.98)	0.52 (1.01)	0.62 (1.05)	0.67 (1.08)	0.52 (1.00)	0.50
D_3: 23rd October 2019	0.31 (0.90)	0.46 (0.98)	0.50 (1.00)	0.61 (1.05)	0.67 (1.07)	0.78 (1.13)	0.59 (1.04)	0.56
SEm±	*0.01*	*0.01*	*0.00*	*0.01*	*0.02*	*0.00*	*0.01*	
CD (P= 0.05)	*NS*	*0.02*	*0.01*	*0.02*	*NS*	*0.02*	*0.03*	
Varieties								
V_1	0.31 (0.90)	0.47 (0.98)	0.51 (1.00)	0.64 (1.07)	0.84 (1.16)	0.84 (1.16)	0.67 (1.08)	0.61
V_2	0.21 (0.84)	0.34 (0.92)	0.43 (0.96)	0.53 (1.02)	0.61 (1.05)	0.61 (1.05)	0.46 (0.98)	0.46
V_3	0.26 (0.87)	0.49 (0.99)	0.56 (1.03)	0.69 (1.09)	0.79 (1.13)	0.78 (1.13)	0.69 (1.09)	0.61
V_4	0.31 (0.90)	0.48 (0.98)	0.48 (0.98)	0.70 (1.09)	0.79 (1.13)	0.77 (1.12)	0.59 (1.04)	0.59
V_5	0.18 (0.82)	0.29 (0.89)	0.32 (0.91)	0.28 (0.88)	0.23 (0.85)	0.49 (0.99)	0.33 (0.90)	0.30
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*	
CD (P= 0.05)	*0.03*	*0.03*	*0.02*	*0.02*	*0.06*	*0.03*	*0.03*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values.

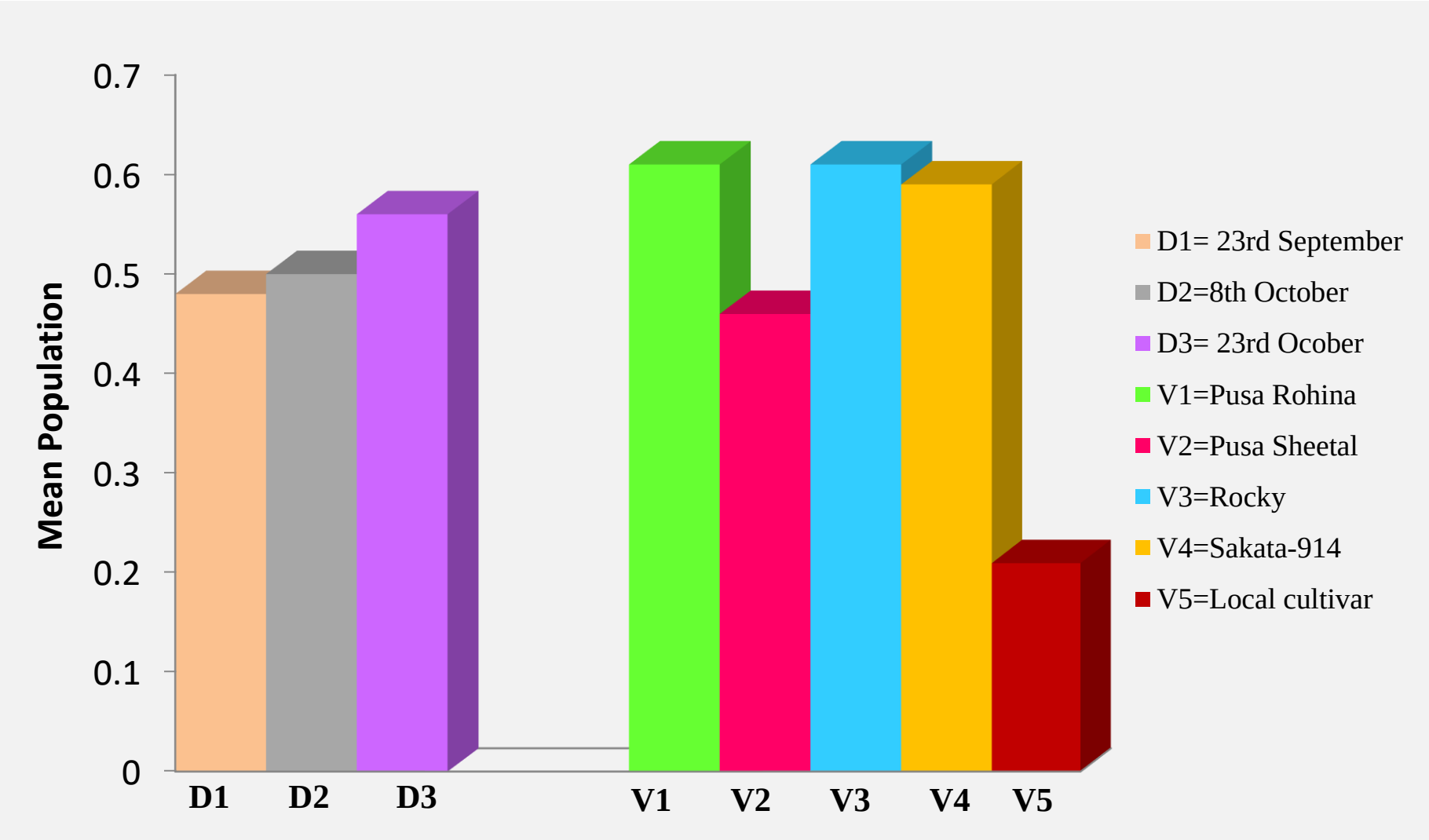


Fig **4.7: Pooled data on the effect of planting and varieties on abundance of coccinellids population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.18: Interaction effect of date of planting and varieties on abundance of coccinellids population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of coccinellids / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.30 (0.89)	0.40 (0.94)	0.53 (1.01)	0.53 (1.02)	0.90 (1.18)	0.77 (1.13)	0.77 (1.12)	0.60
D_1V_2	0.20 (0.83)	0.20 (0.84)	0.33 (0.91)	0.55 (1.02)	0.63 (1.06)	0.67 (1.08)	0.53 (1.01)	0.44
D_1V_3	0.20 (0.84)	0.40 (0.95)	0.52 (1.01)	0.72 (1.10)	0.83 (1.15)	0.73 (1.11)	0.83 (1.15)	0.60
D_1V_4	0.17 (0.82)	0.27 (0.87)	0.40 (0.95)	0.85 (1.16)	0.83 (1.15)	0.83 (1.15)	0.53 (1.02)	0.55
D_1V_5	0.17 (0.82)	0.27 (0.87)	0.27 (0.87)	0.23 (0.86)	0.17 (0.82)	0.20 (0.83)	0.00 (0.71)	0.19
D_2V_1	0.20 (0.84)	0.50 (1.00)	0.57 (1.03)	0.70 (1.09)	0.73 (1.11)	0.83 (1.15)	0.73 (1.11)	0.61
D_2V_2	0.13 (0.79)	0.40 (0.95)	0.43 (0.97)	0.45 (0.97)	0.63 (1.06)	0.53 (1.02)	0.38 (0.93)	0.42
D_2V_3	0.30 (0.89)	0.60 (1.05)	0.52 (1.01)	0.60 (1.05)	0.77 (1.12)	0.80 (1.14)	0.60 (1.05)	0.60
D_2V_4	0.40 (0.95)	0.67 (1.08)	0.50 (1.00)	0.60 (1.05)	0.73 (1.10)	0.67 (1.08)	0.53 (1.01)	0.59
D_2V_5	0.17 (0.82)	0.20 (0.83)	0.33 (0.91)	0.27 (0.88)	0.23 (0.85)	0.53 (1.01)	0.33 (0.91)	0.29
D_3V_1	0.43 (0.97)	0.50 (1.00)	0.43 (0.96)	0.70 (1.09)	0.90 (1.18)	0.92 (1.19)	0.50 (1.00)	0.63
D_3V_2	0.30 (0.89)	0.43 (0.97)	0.52 (1.01)	0.60 (1.05)	0.57 (1.03)	0.63 (1.06)	0.47 (0.98)	0.50
D_3V_3	0.27 (0.87)	0.47 (0.98)	0.63 (1.06)	0.75 (1.12)	0.77 (1.12)	0.80 (1.14)	0.63 (1.06)	0.62
D_3V_4	0.37 (0.93)	0.50 (1.00)	0.55 (1.02)	0.65 (1.07)	0.80 (1.14)	0.80 (1.14)	0.70 (1.09)	0.62
D_3V_5	0.20 (0.84)	0.40 (0.95)	0.37 (0.93)	0.33 (0.91)	0.30 (0.89)	0.73 (1.11)	0.65 (1.07)	0.43
SEm±	*0.02*	*0.02*	*0.02*	*0.01*	*0.03*	*0.02*	*0.02*	
CD (P= 0.05)	*0.06*	*0.06*	*0.04*	*0.03*	*0.10*	*0.05*	*0.06*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values;NS: Non-significant at 5% level of significance

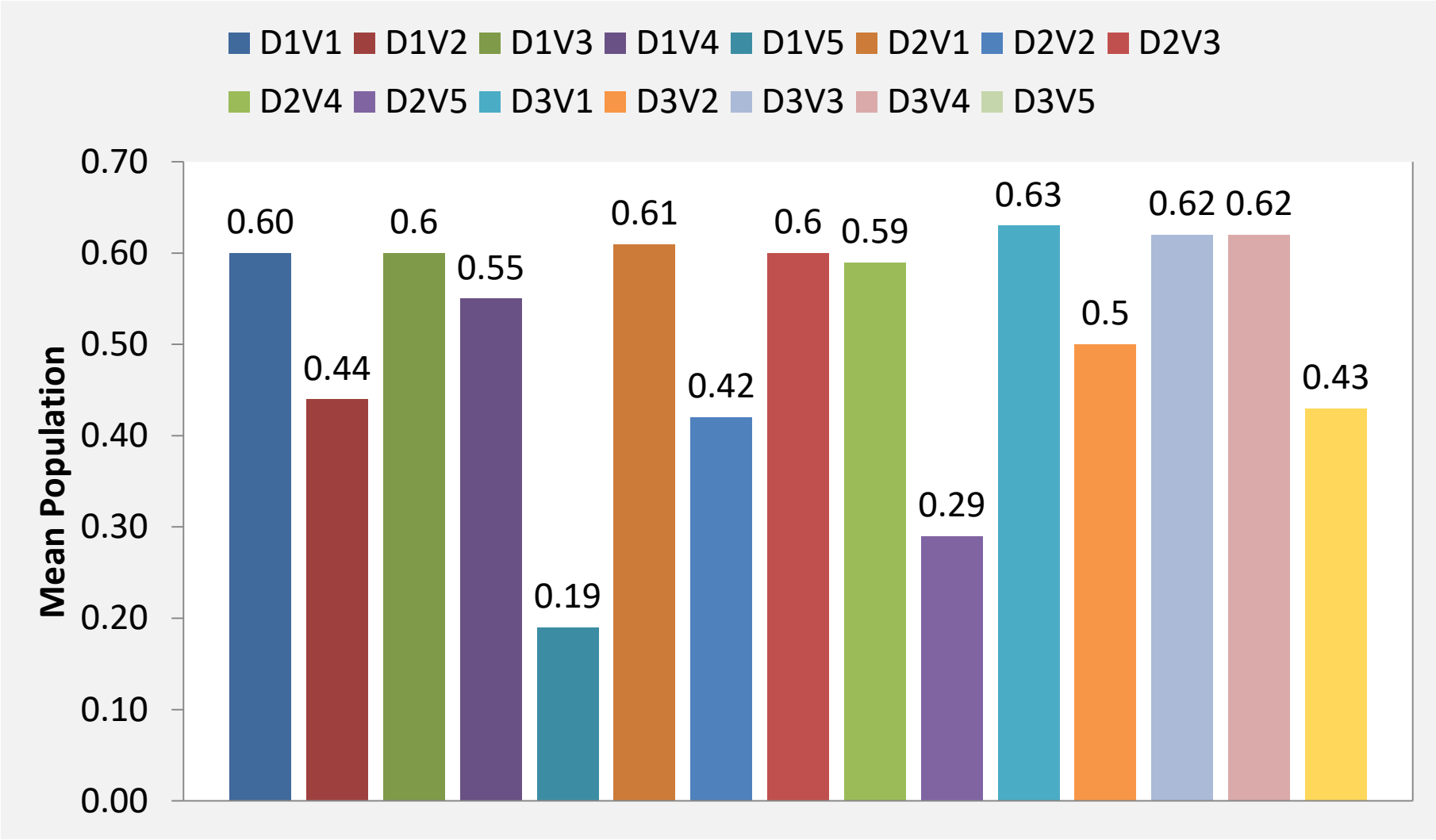


Fig 4.8: Pooled data on the interaction effect of date of planting and varieties on abundance of coccinellid population in tomato ecosystem during 2019-2020 and 2020-2021

Similar result with the maximum total mean of 0.63 coccinellid/plant was observed on D_3V_1 (Pusa Rohini planted on 23rd October) and the minimum of 0.19 coccinellid/plant on D_1V_5 (Local cultivar planted on 23rd September).

Correlation analysis (Table 4.27) for coccinellids with abiotic factors indicated negatively significant with minimum relative humidity on D_1 ($r = -0.686$, $p< 0.05$) and D_3 ($r = -0.716$, $p< 0.05$) for the first research trial (2019-2020) whereas no significant correlation was observed on all dates of planting for the second research period (2020-2021). For the different varieties (Table 4.28), the correlation analysis proved Local cultivar (V_5) to be negatively significant with maximum temperature ($r = -0.929$, $p< 0.01$) and minimum temperature ($r = -0.673$, $p< 0.05$); and Pusa Rohini (V_1) had significant negative correlation with maximum relative humidity ($r = -0.670$, $p< 0.05$) during the first research period whereas during the second research period (2020-2021), Local cultivar (V_5) showed significant and negative correlation with maximum temperature ($r = -0.744$, $p< 0.05$) and minimum temperature ($r = -0.720$, $p< 0.05$) while Sakata-914 (V_4) showed negative correlation with minimum temperature ($r = -0.720$, $p< 0.05$). Other parameters exhibited non-correlation at both 5% and 1% level of significance. According to Meena and Kanwat (2010) and Venkateshwarlu *et al*. (2011), the population buildup of coccinellid were negatively influenced by relative humidity. Singh *et al*. (2013) also reported that coccinellids showed negative correlation with minimum and maximum temperature, rainfall and relative humidity.

4.1.5. Influence of date of planting and varieties on abundance of parasitoid population in tomato ecosystem

The data on the incidence of rate of parasitism by larval parasitoid, *Glyptapantele*ssp are tabulated in Table 4.19 – 4.22 and illustrated in Figure 4.9 and 4.10; the data reveals a significant observation in all planting dates.

High rate of parasitism *i.e.* 86.78% in D_1 which was closely followed by 81.11% in

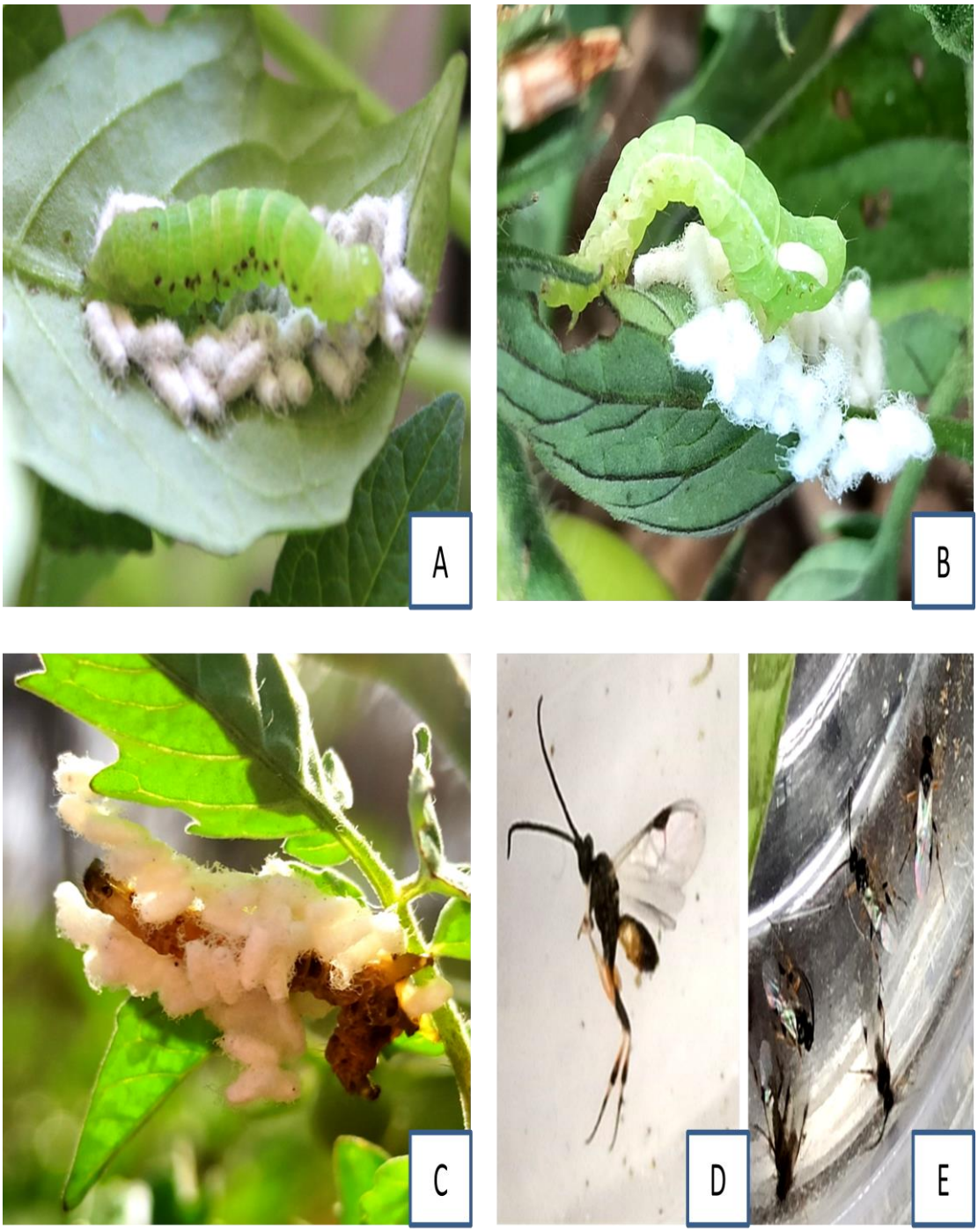


Plate 7. A-C. Larval parasitism of tomato green looper

E-D.Adult of larval parasitoid, *Glyptapanteles sp.*

D_2 was observed on 60 DAT during the first year of experimental period likewise parasitism rate of 65.56% was recorded the highest on 75 DAT in D_2 for the second research period whereas, the lowest was observed on D_2 at 120 DAT (4.44%) in D_2 and parasitism rate of 3.56% on 45 DAT in D_1 during 2019-2020 and 2020-2021 respectively. In both experimental years, *Glyptapanteles* sp. (Hymenoptera: Braconidae) was observed in field conditions actively parasitizing on larva of*C.eriosoma* (Lepidoptera: Noctuidae) and thus effectively managing the pest (*C.eriosoma*) population in tomato ecosystem resulting in zero rate of parasitism in some dates of observation due to absence of host (*C.eriosoma*). Penna (2014) in an extensive study reported *Glyptapanteles* attack mainly members of the family noctuidae followed by erebidae and geometridae. The pooled data (Table 4.21) also reveals a significant relation on the abundance of the parasitoid population, the highest of which was observed on 60 DAT (53.56%) at D_1 which was closely followed by 53.33% parasitism rate on 75 DAT at D_2. The overall total mean rate of parasitism observed for the three different date of planting are as follows: 27.05% (D_1), 24.67% (D_2) and 19.64 % (D_3).

The findings of the present study revealed that all tomato varieties under study had significant effect on the larval parasitoid, *Glyptapanteles* sp. throughout the study period (Table 4.19). Price *et al*. (1980) and Lill *et al*. (2002) also studied on the influence of host plants on natural enemies and reported herbivore-infested plants influence the foraging efficiency of parasitoids. In the field observation, larval parasitism of *C.eriosoma* by *Glyptapantele* sp. was recorded highest on Pusa Rohini (V_1) with parasitism rate of 88.89% at 60 DAT during the first year (2019-2020) and at 75 DAT for the second year trial period (2020-2021). On the contrary, the lowest rate of parasitism of 7.14% (Rocky) and 3.17 (Pusa Rohini) at 45 DAT was observed during the research period 2019-2020 and 2020-2021 respectively. It was observed that varieties infested with high density of host larvae attracted more

Table 4.19: Effect of date of planting and varieties on abundance of parasitoid (*Glyptapanteles sp*.) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**No. of parasitoid (*Glyptapanteles sp.*) / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D_1	13.33 (2.73)	86.78 (9.31)	33.33 (4.28)	0.00 (0.71)	0.00 (0.71)	40.00 (4.90)	33.33 (3.81)	29.54	3.56 (1.58)	18.33 (3.47)	40.00 (5.07)	33.33 (4.58)	20.00 (2.57)	36.67 (4.24)	20.00 (2.80)	24.56
D_2	18.89 (3.15)	81.11 (8.95)	41.11 (4.97)	13.33 (2.20)	13.33 (2.20)	4.44 (1.21)	6.67 (1.33)	25.55	6.35 (2.16)	19.00 (3.25)	65.56 (7.31)	10.00 (1.99)	40.00 (4.68)	6.67 (1.33)	18.89 (2.72)	23.78
D_3	0.00 (0.71)	62.78 (6.96)	11.11 (2.01)	28.89 (3.76)	40.00 (4.43)	33.33 (3.81)	0.00 (0.71)	25.16	8.89 (2.27)	10.00 (2.14)	46.67 (6.22)	20.00 (3.20)	13.33 (2.20)	0.00 (0.71)	0.00 (0.71)	14.13
SEm±	*0.41*	*0.47*	*0.40*	*0.06*	*0.06*	*0.36*	*0.44*		*0.13*	*0.25*	*0.39*	*0.15*	*0.39*	*0.43*	*0.34*	
CD (P= 0.05)	*1.62*	*1.84*	*1.57*	*0.23*	*0.25*	*1.43*	*1.72*		*0.52*	*0.96*	*1.52*	*0.59*	*1.52*	*1.67*	*1.32*	
Varieties																
V_1	0.00 (0.71)	88.89 (9.40)	11.11 (2.13)	14.81 (2.70)	33.33 (3.81)	57.41 (6.39)	44.44 (4.85)	35.71	3.17 (1.40)	6.67 (1.98)	88.89 (9.40)	11.11 (2.38)	33.33 (3.81)	33.33 (3.81)	0.00 (0.71)	25.21
V_2	9.26 (2.24)	85.19 (8.79)	44.44 (5.24)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	19.84	14.81 (3.31)	3.70 (1.60)	55.56 (6.96)	11.11 (2.38)	22.22 (3.19)	0.00 (0.71)	0.00 (0.71)	15.34
V_3	7.41 (1.84)	87.04 (9.32)	42.59 (5.46)	55.56 (6.30)	55.56 (6.30)	33.33 (3.81)	22.22 (2.78)	43.39	3.70 (1.60)	21.30 (3.71)	48.15 (5.80)	50.00 (5.95)	44.44 (4.85)	0.00 (0.71)	27.78 (3.88)	27.91
V_4	25.93 (3.79)	78.89 (8.82)	44.44 (5.24)	0.00 (0.71)	0.00 (0.71)	38.89 (4.91)	0.00 (0.71)	26.88	4.07 (1.85)	13.89 (2.87)	50.00 (6.45)	22.22 (3.19)	22.22 (3.19)	27.78 (3.49)	37.04 (4.38)	25.32
V_5	11.11 (2.41)	44.44 (5.70)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	7.94	5.56 (1.85)	33.33 (4.61)	11.11 (2.38)	11.11 (2.38)	0.00 (0.71)	11.11 (1.74)	0.00 (0.71)	10.32
SEm±	*0.38*	*0.47*	*0.54*	*0.10*	*0.08*	*0.72*	*0.65*		*0.21*	*0.51*	*0.33*	*0.18*	*0.46*	*0.49*	*0.66*	
CD (P= 0.05)	*1.12*	*1.38*	*1.59*	*0.30*	*0.24*	*2.11*	*1.91*		*0.62*	*1.48*	*0.97*	*0.52*	*1.35*	*1.42*	*1.91*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Table 4.20: Interaction effect of date of planting and varieties on abundance of parasitoid (*Glyptapanteles sp.*)population in tomato ecosystem during 2019-2020 and 2020-2021

Treatments	**No. of parasitoid (*Glyptapanteles sp.*) / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.00 (0.71)	91.67 (9.58)	33.33 (4.97)	0.00 (0.71)	0.00 (0.71)	50.00 (5.95)	100.00 (10.02)	39.29	0.00 (0.71)	0.00 (0.71)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	100.00 (10.02)	0.00 (0.71)	28.57
D_1V_2	27.78 (5.31)	88.89 (9.42)	33.33 (4.97)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	21.43	11.11 (3.40)	11.11 (3.40)	66.67 (8.16)	33.33 (5.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	17.46
D_1V_3	22.22 (4.11)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	100.00 (10.02)	66.67 (6.92)	41.27	0.00 (0.71)	47.22 (6.82)	0.00 (0.71)	100.00 (10.02)	100.00 (10.02)	0.00 (0.71)	66.67 (8.08)	44.84
D_1V_4	16.67 (2.84)	86.67 (9.32)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	50.00 (7.11)	0.00 (0.71)	36.19	6.67 (2.40)	33.33 (5.74)	33.33 (5.74)	0.00 (0.71)	0.00 (0.71)	83.33 (9.05)	33.33 (3.81)	27.14
D_1V_5	0.00 (0.71)	66.67 (8.19)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	9.52	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	33.33 (5.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	4.76
D_2V_1	0.00 (0.71)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	22.22 (3.20)	33.33 (3.81)	22.22	9.52 (2.77)	20.00 (4.53)	100.00 (10.02)	0.00 (0.71)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	32.79
D_2V_2	0.00 (0.71)	100.00 (10.02)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	28.57	0.00 (0.71)	0.00 (0.71)	83.33 (9.13)	0.00 (0.71)	66.67 (8.16)	0.00 (0.71)	0.00 (0.71)	21.43
D_2V_3	0.00 (0.71)	88.89 (9.42)	72.22 (8.44)	66.67 (8.16)	66.67 (8.16)	0.00 (0.71)	0.00 (0.71)	42.06	0.00 (0.71)	0.00 (0.71)	44.44 (6.68)	50.00 (7.11)	33.33 (3.81)	0.00 (0.71)	16.67 (2.84)	20.63
D_2V_4	61.11 (7.83)	50.00 (7.11)	33.33 (4.97)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	20.63	5.56 (2.46)	8.33 (2.15)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	77.78 (8.62)	27.38
D_2V_5	33.33 (5.82)	66.67 (8.19)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	14.29	16.67 (4.13)	66.67 (8.16)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	33.33 (3.81)	0.00 (0.71)	16.67
D_3V_1	0.00 (0.71)	75.00 (8.61)	0.00 (0.71)	44.44 (6.68)	100.00 (10.02)	100.00 (10.02)	0.00 (0.71)	45.63	0.00 (0.71)	0.00 (0.71)	66.67 (8.16)	33.33 (5.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	14.29
D_3V_2	0.00 (0.71)	66.67 (6.92)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	9.52	33.33 (5.82)	0.00 (0.71)	16.67 (3.60)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	7.14
D_3V_3	0.00 (0.71)	72.22 (8.52)	55.55 (7.22)	100.00 (10.02)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	46.82	11.11 (3.40)	16.67 (3.60)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	18.25
D_3V_4	0.00 (0.71)	100.00 (10.02)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	66.67 (6.92)	0.00 (0.71)	23.81	0.00 (0.71)	0.00 (0.71)	16.67 (3.60)	66.67 (8.16)	66.67 (8.16)	0.00 (0.71)	0.00 (0.71)	21.43
D_3V_5	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00	0.00 (0.71)	33.33 (4.97)	33.33 (5.74)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	9.52
SEm±	*0.67*	*0.82*	*0.94*	*0.18*	*0.14*	*1.25*	*1.13*		*0.37*	*0.88*	*0.57*	*0.31*	*0.80*	*0.84*	*1.14*	
CD (P= 0.05)	*1.94*	*2.39*	*2.75*	*0.53*	*0.42*	*3.65*	*3.31*		*1.07*	*2.56*	*1.67*	*0.90*	*2.34*	*2.45*	*3.32*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

parasitoids in the field of which similar observation was also made by Girling *et al*. (2011). The female parasitoid wasp oviposits during the early instar of *C. eriosoma* (host), the larvae matures inside the host caterpillar and later pupates outside of the host, ultimately killing the host during the later instar stage after the emergence of the parasitoid, this nature of the parasitoid was also observed by Nussbaumer and Schopf, 2000, Nussbaumer *et al*. 2002. The pooled data analysis (Table 4.21) also reveals that all varieties have significant effect on the parasitism rate of the larval parasitoid with the highest observation of 54.17% at 60 DAT in the tomato variety Rocky and the lowest in Pusa Rohini (1.59%) at 45 DAT. The total mean population recorded for all the varieties ranged from 35.65% (Rocky), 30.46% (Pusa Rohini), 26.10% (Sakata-914), 17.59% (Pusa Sheetal) and 9.13% (Local cultivar). The present finding is in accordance with the research conducted by Yi Feng *et al*. (2014), the authors indicated that plants play a role in the habitat preferences of parasitoid species by influencing their foraging behaviour, and are likely to contribute to their distributions among habitats.

It is evident from the data collected (Table 4.20) that both date of planting and varieties had significant influence on the rate of parasitism by *Glyptapanteles* sp. It was observed that both factors (planting date and varieties) on separate data analysis gave moderate rate of parasitism but on combination treatment had synergistic result *i.e.* 100% rate of parasitism was recorded on different dates of observation. The maximum total mean of 46.82% (D_3V_3) and 44.84% (D_1V_3) parasitism rate was observed on the two year period 2019-2020 and 20202-2021 respectively whereas the minimum was observed on D_1V_5 with parasitism rate of 9.52% (2019-2020) and 4.76% (2020-2021). The pooled data analysis (Table 4.22) also revealed a similar result with the maximum total mean of 43.06% was observed on D_1V_3 (Rocky

Table 4.21: Pooled data on theeffect of date of planting and varieties on abundance of parasitoid (*Glyptapanteles sp.*) population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**No. of parasitoid*(Glyptapanteles sp.)* / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	8.44 (2.16)	53.56 (6.39)	36.67 (4.67)	16.67 (2.64)	10.00 (1.64)	38.33 (4.57)	26.67 (3.31)	27.05
D_2: 8th October 2019	12.62 (2.65)	50.06 (6.10)	53.33 (6.14)	11.67 (2.09)	26.67 (3.44)	5.56 (1.27)	12.78 (2.02)	24.67
D_3: 23rd October 2019	4.44 (1.49)	36.39 (4.55)	28.89 (4.12)	24.44 (3.48)	26.67 (3.32)	16.67 (2.26)	0.00 (0.71)	19.64
SEm±	*0.22*	*0.26*	*0.28*	*0.08*	*0.20*	*0.28*	*0.28*	
CD (P= 0.05)	*0.71*	*0.86*	*0.91*	*0.26*	*0.64*	*0.91*	*0.90*	
Varieties								
V_1: Pusa Rohini	1.59 (1.05)	47.78 (5.69)	50.00 (5.77)	12.96 (2.54)	33.33 (3.81)	45.37 (5.10)	22.22 (2.78)	30.46
V_2: Pusa Sheetal	12.04 (2.77)	44.44 (5.20)	50.00 (6.10)	5.56 (1.55)	11.11 (1.95)	0.00 (0.71)	0.00 (0.71)	17.59
V_3: Rocky	5.56 (1.72)	54.17 (6.52)	45.37 (5.63)	52.78 (6.12)	50.00 (5.57)	16.67 (2.26)	25.00 (3.33)	35.65
V_4: Sakata-914	15.00 (2.82)	46.39 (5.84)	47.22 (5.84)	11.11 (1.95)	11.11 (1.95)	33.33 (4.20)	18.52 (2.54)	26.10
V_5: Local Cultivar	8.33 (2.13)	38.89 (5.15)	5.56 (1.55)	5.56 (1.55)	0.00 (0.71)	5.56 (1.22)	0.00 (0.71)	9.13
SEm±	*0.22*	*0.35*	*0.32*	*0.10*	*0.23*	*0.43*	*0.46*	
CD (P= 0.05)	*0.62*	*0.98*	*0.91*	*0.29*	*0.67*	*1.24*	*1.32*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

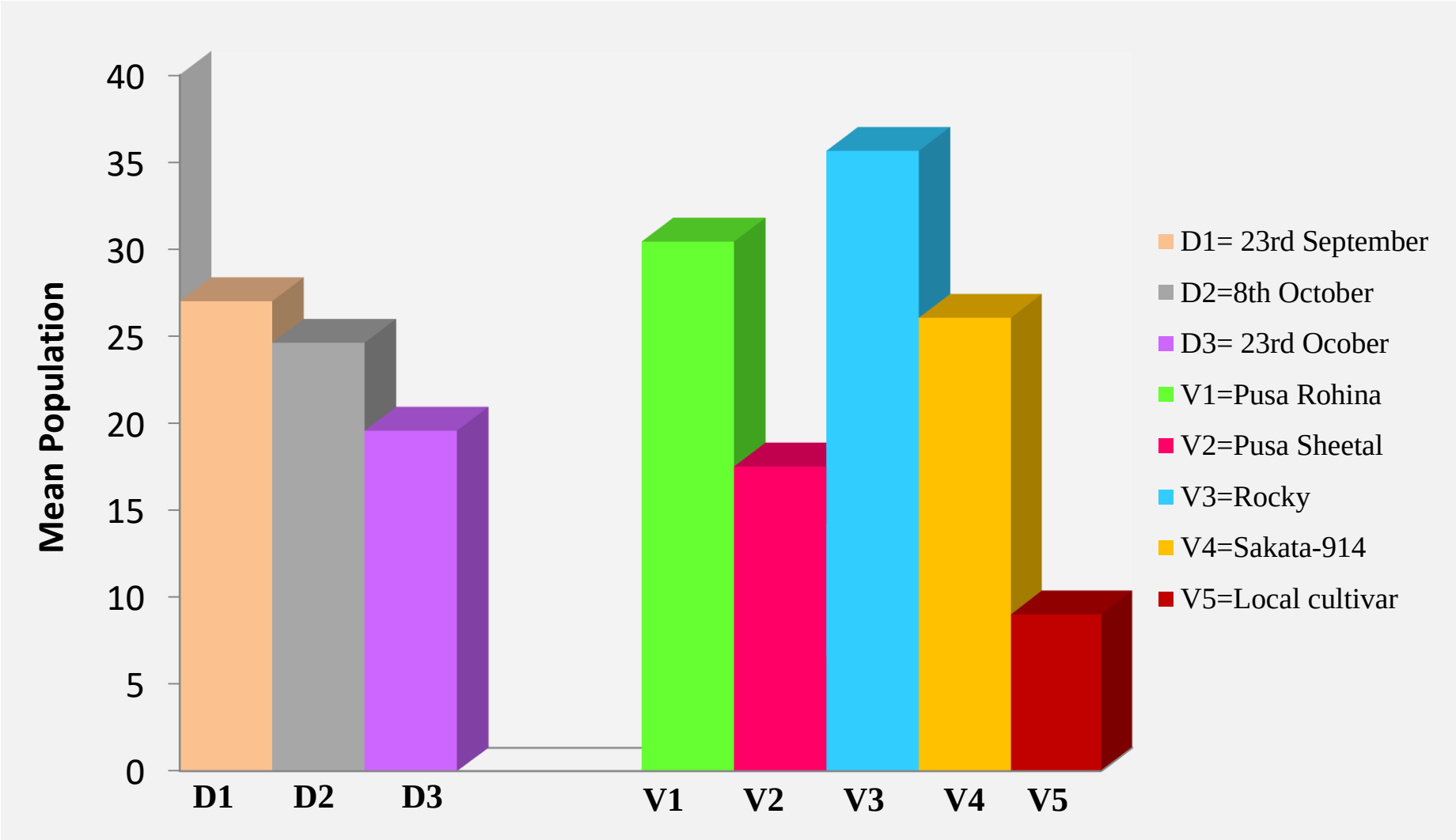


Fig **4.9: Pooled data on the effect of planting and varieties on abundance of parasitoid (*Glyptapanteles sp.*) population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.22: Pooled data on theinteraction effect of date of planting and varieties on abundance of parasitoid (*Glyptapanteles sp.*)population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**No. of parasitoid (*Glyptapanteles sp.*) / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.00 (0.71)	45.83 (5.14)	66.67 (7.50)	0.00 (0.71)	0.00 (0.71)	75.00 (7.99)	50.00 (5.37)	33.93
D_1V_2	19.44 (4.35)	50.00 (6.41)	50.00 (6.57)	16.67 (3.22)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	19.44
D_1V_3	11.11 (2.41)	73.61 (8.42)	0.00 (0.71)	50.00 (5.37)	50.00 (5.37)	50.00 (5.37)	66.67 (7.50)	43.06
D_1V_4	11.67 (2.62)	60.00 (7.53)	66.67 (7.88)	0.00 (0.71)	0.00 (0.71)	66.67 (8.08)	16.67 (2.26)	31.67
D_1V_5	0.00 (0.71)	33.33 (4.45)	0.00 (0.71)	16.67 (3.22)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	7.14
D_2V_1	4.76 (1.74)	60.00 (7.28)	50.00 (5.37)	0.00 (0.71)	50.00 (5.37)	11.11 (1.96)	16.67 (2.26)	27.51
D_2V_2	0.00 (0.71)	50.00 (5.37)	91.67 (9.58)	0.00 (0.71)	33.33 (4.43)	0.00 (0.71)	0.00 (0.71)	25.00
D_2V_3	0.00 (0.71)	44.45 (5.06)	58.33 (7.56)	58.33 (7.63)	50.00 (5.99)	0.00 (0.71)	8.33 (1.77)	31.35
D_2V_4	33.34 (5.15)	29.17 (4.63)	66.67 (7.50)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	38.89 (4.66)	24.01
D_2V_5	25.00 (4.98)	66.67 (8.17)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	16.67 (2.26)	0.00 (0.71)	15.48
D_3V_1	0.00 (0.71)	37.50 (4.66)	33.33 (4.43)	38.89 (6.21)	50.00 (5.37)	50.00 (5.37)	0.00 (0.71)	29.96
D_3V_2	16.67 (3.26)	33.33 (3.81)	8.33 (2.15)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	8.33
D_3V_3	5.56 (2.05)	44.45 (6.06)	77.78 (8.62)	50.00 (5.37)	50.00 (5.37)	0.00 (0.71)	0.00 (0.71)	32.54
D_3V_4	0.00 (0.71)	50.00 (5.37)	8.33 (2.15)	33.33 (4.43)	33.33 (4.43)	33.33 (3.81)	0.00 (0.71)	22.62
D_3V_5	0.00 (0.71)	16.67 (2.84)	16.67 (3.22)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	4.76
SEm±	*0.38*	*0.60*	*0.55*	*0.18*	*0.41*	*0.75*	*0.80*	
CD (P= 0.05)	*1.08*	*1.71*	*1.57*	*0.51*	*1.16*	*2.14*	*2.28*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

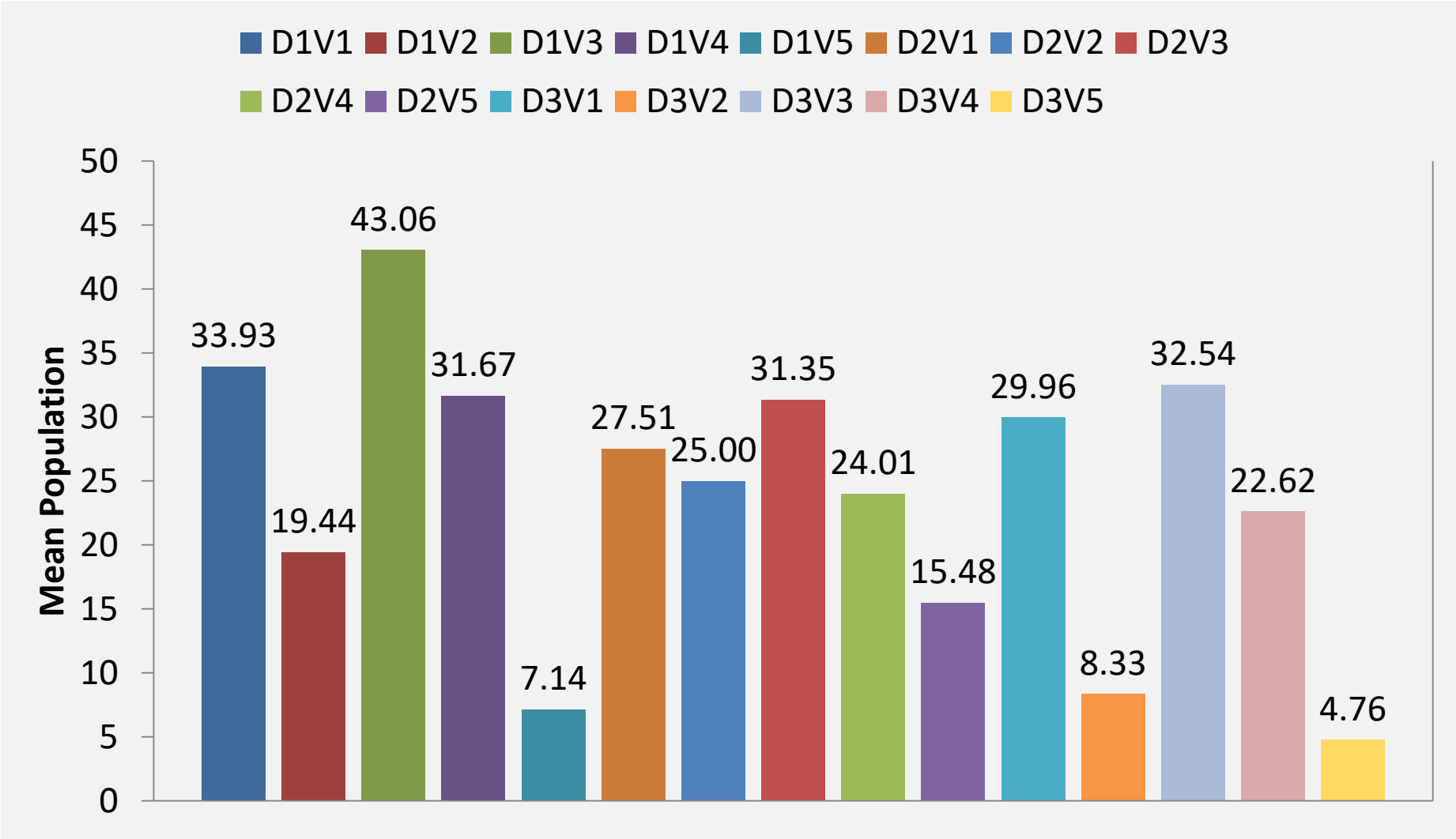


Fig **4.10: Pooled data on the interaction effect of date of planting and varieties on abundance of parasitoid (*Glyptapanteles sp.*) population in tomato ecosystem during 2019-2020 and 2020-2021**

planted on 23rd September) and the minimum of 4.76% on D_3V_5 (Local cultivar planted on 23rd October).

The results obtained (Table 4.27) during the first experimental period (2019-2020) revealed that larval parasitoid, *Glyptapanteles* sp. had significant negative correlation with maximum temperature ($r = -0.761$, $p<0.05$) in D_2 and significant positive correlation with minimum relative humidity ($r = 0.701$, $p<0.05$) in D_2. On the other hand, *Glyptapanteles* sp. exhibited non-significant correlation with all abiotic factors during the second research period. For the different varieties (Table 4.28), the correlation analysis proved Pusa sheetal (V2) and Sakata-914 (V4) to be positively significant with minimum relative humidity *i.e.* $r = 0.797$, $p<0.05$ and $r= 0.779$, $p<0.05$ respectively for the first experimental year whereas, for the second year Pusa Sheetal (V2) had negative and significant correlation ($r = -0.689$, $p<0.05$) with minimum temperature. Other parameters exhibited non-correlation at both 5% and 1% level of significance. There is very limited literature on *Glyptapanteles* sp. and the only literature available which is slightly in line with the present study is the work reported by Jarzembowska (2016), the author worked on three species of *Gyptapanteles* species viz., *G. liparidis* and *G. fulvipes* than for *G. porthetriae,* and reported highest successful wasp emergence at 20°C, regardless of the wasp species.However comparable study on the relationship of abiotic factors and larval parasitoid, *Campoletis chlorideae* on pod borer, *Helicoverpa armigera* under sole and chickpea-coriander ecosystem was reported by Jagdish and Agnihotri, (2018).

4.1.6. Influence of date of planting and varieties on abundance of spider populatrion in tomato ecosystem

The data on the incidence of spider population in tomato ecosystem are tabulated in Table 4.23 - 4.26 and illustrated in Figure 4.11 and 4.12, the data reveals a significant observation in all planting dates except in 105 DAT and 120 DAT in the year 2019-2020 whereas 105 DAT, 120DAT and 135 DAT in

the year 2020-2021. The spider population for both years of research was observed from 45 DAT in all dates of observation (*i.e.* D_1, D_2 and D_3) and was present all through the planting season feeding on small insects especially aphids. For the first research period, the highest incidence of 0.73 number of spider per plant was observed on 60 DAT in D_3 (23^{rd} October planting date) which falls in the 3^{rd} week of January with the maximum mean of 0.63 spider/plant in D_3, whereas the lowest population of 0.37 spider/plant was recorded on 45 DAT in D_1 which falls in the first week of December with the minimum mean of 0.49 spider/plant also observed in D_1. In the second research period, the highest spider population was recorded on 105 DAT in D_3 (first week of March) with the maximum mean of 0.58 number of spider per plant observed on D_3. On the contrary, lowest number of spider was recorded on 45 DAT in D_1 with 0.31 number of spider per plant and the minimum mean of 0.55 spider/plant was observed on D_1. The pooled data representation (Table 4.25) also had significant effect on the population incidence on all dates of observation except on 120 DAT and 135 DAT. The spider population was actively seen in all dates of observation with the highest number of 0.67 spider/plant observed on 60 DAT in D_3 (*i.e.* the third week of January) and the lowest number of 0.34 spider/plant observed on 45 DAT in D_1 (*i.e.* first week of December). The overall total mean population observed for the three different date of planting (*i.e.* D_1, D_2 and D_3) are, 0.51, 0.54 and 0.60 number of spider per plant respectively. The present finding is in compliance with that of Hirur*et al*. (2020); the authors reported peak spider population in tomato ecosystem in the month of January and also recorded spider population from the first week after transplantation to the end of the harvest. Similarly Khokhar and Rolania (2021) conducted an extensive study on spider population in tomato and reported predatory spiders were present throughout the crop period from 9^{th} standard meteorological week (SMW) to 22^{nd} SMW.

Plate 8. Predatory spiders recorded

Table 4.23: Effect of date of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021

Treatments	**Number of spider / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting																
D	0.37 (0.93)	0.49 (0.99)	0.47 (0.98)	0.51 (1.00)	0.53 (1.01)	0.55 (1.02)	0.49 (0.99)	0.49	0.31 (0.90)	0.51 (1.00)	0.53 (1.01)	0.60 (1.05)	0.67 (1.08)	0.60 (1.05)	0.55 (1.02)	0.54
D_2	0.45 (0.97)	0.51 (1.00)	0.55 (1.02)	0.55 (1.02)	0.61 (1.05)	0.57 (1.03)	0.48 (0.98)	0.53	0.41 (0.95)	0.49 (1.00)	0.55 (1.02)	0.57 (1.03)	0.64 (1.06)	0.57 (1.03)	0.52 (1.00)	0.54
D_3	0.73 (1.11)	0.72 (1.10)	0.69 (1.09)	0.67 (1.08)	0.63 (1.05)	0.52 (1.00)	0.47 (0.98)	0.63	0.53 (1.01)	0.60 (1.05)	0.63 (1.06)	0.64 (1.07)	0.65 (1.07)	0.51 (1.00)	0.53 (1.01)	0.58
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.02*		*0.01*	*0.01*	*0.005*	*0.01*	*0.02*	*0.01*	*0.02*	
CD (P= 0.05)	*0.04*	*0.04*	*0.04*	*0.03*	*0.04*	*NS*	*NS*		*0.04*	*0.04*	*0.02*	*0.02*	*NS*	*NS*	*NS*	
Varieties																
V_1	0.64 (1.07)	0.71 (1.10)	0.64 (1.07)	0.69 (1.09)	0.76 (1.12)	0.76 (1.12)	0.71 (1.10)	0.70	0.51 (1.00)	0.60 (1.05)	0.71 (1.10)	0.69 (1.09)	0.78 (1.13)	0.69 (1.09)	0.64 (1.07)	0.66
V_2	0.47 (0.98)	0.51 (1.00)	0.53 (1.01)	0.49 (0.99)	0.51 (1.00)	0.53 (1.01)	0.36 (0.92)	0.49	0.31 (0.90)	0.51 (1.00)	0.53 (1.02)	0.64 (1.07)	0.73 (1.11)	0.58 (1.04)	0.60 (1.05)	0.56
V_3	0.53 (1.01)	0.60 (1.05)	0.62 (1.06)	0.60 (1.05)	0.67 (1.08)	0.53 (1.02)	0.51 (1.00)	0.58	0.49 (0.99)	0.62 (1.06)	0.64 (1.07)	0.56 (1.03)	0.69 (1.09)	0.64 (1.07)	0.51 (1.00)	0.59
V_4	0.60 (1.04)	0.69 (1.09)	0.73 (1.11)	0.76 (1.12)	0.76 (1.12)	0.71 (1.10)	0.62 (1.06)	0.70	0.47 (0.98)	0.56 (1.03)	0.58 (1.04)	0.71 (1.10)	0.71 (1.10)	0.62 (1.06)	0.62 (1.06)	0.61
V_5	0.36 (0.92)	0.36 (0.92)	0.31 (0.90)	0.33 (0.91)	0.27 (0.87)	0.20 (0.83)	0.20 (0.83)	0.29	0.31 (0.90)	0.38 (0.94)	0.38 (0.94)	0.42 (0.96)	0.36 (0.92)	0.27 (0.87)	0.29 (0.89)	0.34
SEm±	*0.02*	*0.01*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*		*0.02*	*0.01*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*	
CD (P= 0.05)	*0.06*	*0.04*	*0.04*	*0.03*	*0.05*	*0.03*	*0.04*		*0.04*	*0.04*	*0.02*	*0.03*	*0.06*	*0.04*	*0.04*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

Table 4.24: Interaction effect of date of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021

Treatments	**Number of spider / plant**															
	2019-2020								***2020-2021***							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***	***45 DAT***	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.53 (1.02)	0.67 (1.08)	0.53 (1.02)	0.67 (1.08)	0.67 (1.08)	0.73 (1.11)	0.73 (1.11)	0.65	0.47 (0.98)	0.60 (1.05)	0.73 (1.11)	0.80 (1.14)	0.80 (1.14)	0.73 (1.11)	0.60 (1.05)	0.68
D_1V_2	0.33 (0.91)	0.40 (0.95)	0.47 (0.98)	0.47 (0.98)	0.47 (0.98)	0.53 (1.02)	0.40 (0.95)	0.44	0.20 (0.84)	0.40 (0.95)	0.47 (0.98)	0.60 (1.05)	0.60 (1.05)	0.67 (1.08)	0.67 (1.08)	0.52
D_1V_3	0.47 (0.98)	0.60 (1.05)	0.60 (1.05)	0.60 (1.05)	0.67 (1.08)	0.60 (1.05)	0.60 (1.05)	0.59	0.40 (0.95)	0.67 (1.08)	0.60 (1.05)	0.60 (1.05)	0.73 (1.11)	0.53 (1.02)	0.53 (1.02)	0.58
D_1V_4	0.27 (0.87)	0.53 (1.02)	0.53 (1.02)	0.60 (1.05)	0.73 (1.11)	0.73 (1.11)	0.60 (1.05)	0.57	0.27 (0.88)	0.53 (1.02)	0.53 (1.02)	0.60 (1.05)	0.67 (1.08)	0.60 (1.05)	0.53 (1.02)	0.53
D_1V_5	0.27 (0.87)	0.27 (0.87)	0.20 (0.84)	0.20 (0.84)	0.13 (0.79)	0.13 (0.79)	0.13 (0.79)	0.19	0.20 (0.84)	0.33 (0.91)	0.33 (0.91)	0.40 (0.95)	0.53 (1.01)	0.47 (0.98)	0.40 (0.95)	0.38
D_2V_1	0.53 (1.02)	0.60 (1.05)	0.60 (1.05)	0.60 (1.05)	0.80 (1.14)	0.80 (1.14)	0.73 (1.11)	0.67	0.40 (0.95)	0.53 (1.02)	0.67 (1.08)	0.67 (1.08)	0.80 (1.14)	0.73 (1.11)	0.73 (1.11)	0.65
D_2V_2	0.40 (0.95)	0.47 (0.98)	0.47 (0.98)	0.40 (0.95)	0.40 (0.95)	0.40 (0.95)	0.27 (0.87)	0.40	0.33 (0.91)	0.47 (0.98)	0.53 (1.02)	0.60 (1.05)	0.80 (1.14)	0.53 (1.02)	0.40 (0.95)	0.52
D_2V_3	0.33 (0.91)	0.40 (0.95)	0.47 (0.98)	0.47 (0.98)	0.60 (1.05)	0.60 (1.05)	0.47 (0.98)	0.48	0.47 (0.98)	0.47 (0.98)	0.60 (1.05)	0.47 (0.98)	0.60 (1.05)	0.67 (1.08)	0.53 (1.02)	0.54
D_2V_4	0.67 (1.08)	0.67 (1.08)	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.67 (1.08)	0.74	0.47 (0.98)	0.60 (1.05)	0.60 (1.05)	0.73 (1.11)	0.67 (1.08)	0.73 (1.11)	0.73 (1.11)	0.65
D_2V_5	0.33 (0.91)	0.40 (0.95)	0.40 (0.95)	0.47 (0.98)	0.47 (0.98)	0.27 (0.87)	0.27 (0.87)	0.37	0.40 (0.95)	0.40 (0.95)	0.33 (0.91)	0.40 (0.95)	0.33 (0.91)	0.20 (0.84)	0.20 (0.84)	0.32
D_3V_1	0.87 (1.17)	0.87 (1.17)	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.73 (1.11)	0.67 (1.08)	0.79	0.67 (1.08)	0.67 (1.08)	0.73 (1.11)	0.60 (1.05)	0.73 (1.11)	0.60 (1.05)	0.60 (1.05)	0.66
D_3V_2	0.67 (1.08)	0.67 (1.08)	0.67 (1.08)	0.60 (1.05)	0.67 (1.08)	0.67 (1.08)	0.40 (0.95)	0.62	0.40 (0.95)	0.67 (1.08)	0.60 (1.05)	0.73 (1.11)	0.80 (1.14)	0.53 (1.02)	0.73 (1.11)	0.64
D_3V_3	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.73 (1.11)	0.73 (1.11)	0.40 (0.95)	0.47 (0.98)	0.68	0.60 (1.05)	0.73 (1.11)	0.73 (1.11)	0.60 (1.05)	0.73 (1.11)	0.73 (1.11)	0.47 (0.98)	0.66
D_3V_4	0.87 (1.17)	0.87 (1.17)	0.87 (1.17)	0.87 (1.17)	0.73 (1.11)	0.60 (1.05)	0.60 (1.05)	0.77	0.67 (1.08)	0.53 (1.02)	0.60 (1.05)	0.80 (1.14)	0.80 (1.14)	0.53 (1.02)	0.60 (1.05)	0.65
D_3V_5	0.47 (0.98)	0.40 (0.95)	0.33 (0.91)	0.33 (0.91)	0.20 (0.83)	0.20 (0.84)	0.20 (0.84)	0.30	0.33 (0.91)	0.40 (0.95)	0.47 (0.98)	0.47 (0.98)	0.20 (0.83)	0.13 (0.79)	0.27 (0.87)	0.32
SEm±	*0.03*	*0.02*	*0.02*	*0.02*	*0.03*	*0.02*	*0.02*		*0.03*	*0.03*	*0.01*	*0.02*	*0.04*	*0.02*	*0.02*	
CD (P= 0.05)	*0.10*	*0.07*	*0.07*	*0.05*	*0.09*	*0.05*	*0.07*		*0.08*	*0.07*	*0.03*	*0.05*	*0.11*	*0.07*	*0.07*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values; NS: Non-significant at 5% level of significance

All the varieties under study had significant influence on the incidence of spider population in all dates of observation in both the years of research trial (Table 4.23). According to the data analysis, the variety Pusa Rohini (V_1) and Sakata-914 (V_4) had the highest incidence of spider recorded while Local cultivar recorded the lowest incidence of spider in both experimental years. The highest number of incidence was recorded in Pusa Rohini (V_1) on 105 DAT in D_1 with 0.78 spider/plant in both years as well as the maximum mean incidence of 0.70 spider/plant was recorded in Pusa Rohini and Sataka-914 in the first research period and a record of 0.66 spider/plant in Pusa Rohini in the second year. On the other hand, the Local variety recorded the lowest number of 0.20 and 0.27 spider/plant on 120 DAT in D_3 during the year 2019-2020 and 2020-2021 respectively with the minimum mean also observed on the Local variety with 0.29 and 0.34 number of spider population in both years respectively. The pooled analysis (Table 4.25) observed a similar result, the highest number of 0.77 spider/plant was recorded on 105 DAT in Pusa Rohini and the lowest of 0.23 spider/plant recorded on the Local cultivar on 120 DAT. The maximum mean of 0.68 spider population was observed on Pusa Rohini while the minimum of 0.31 was recorded on Local cultivar. There is very limited study done on influence of tomato varieties in spider population however Arthur *et al*. (1972), in their study on spider reported architectural structure and plant canopy as components for habitat selection while others, Harwood *et al*. (2003), Thevenard *et al*. (2004) and Gesraha *et al*. (2019), concluded that the abundance of spider is associated with their preferable insect pest (prey) availability and did not relate to a certain plant.

The treatment combination of different planting date and varieties under study revealed significant interaction in all date of observation for both the experimental years (Table 4.24). The interaction combination of D_3V_1 (Pusa Rohini planted on 23rd October) had the maximum mean population of 0.79 spider/plant and the minimum mean of 0.19spider/plant on the combination

Table 4.25: Pooled data on the effect of date of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of spider / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
Date of Planting								
D_1: 23rd September 2019	0.34 (0.91)	0.50 (1.00)	0.50 (1.00)	0.55 (1.02)	0.60 (1.04)	0.57 (1.03)	0.52 (1.01)	0.51
D_2: 8th October 2019	0.43 (0.96)	0.50 (1.00)	0.55 (1.02)	0.56 (1.03)	0.63 (1.06)	0.57 (1.03)	0.50 (0.99)	0.53
D_3: 23rd October 2019	0.63 (1.06)	0.67 (1.07)	0.66 (1.07)	0.65 (1.07)	0.64 (1.06)	0.51 (1.00)	0.50 (1.00)	0.60
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	
CD (P= 0.05)	*0.02*	*0.02*	*0.02*	*0.02*	*0.03*	*NS*	*NS*	
Varieties								
V_1: Pusa Rohini	0.58 (1.04)	0.66 (1.07)	0.68 (1.08)	0.69 (1.09)	0.77 (1.12)	0.72 (1.10)	0.68 (1.08)	0.68
V_2: Pusa Sheetal	0.39 (0.94)	0.51 (1.00)	0.53 (1.02)	0.57 (1.03)	0.62 (1.06)	0.56 (1.03)	0.48 (0.98)	0.52
V_3: Rocky	0.51 (1.00)	0.61 (1.05)	0.63 (1.06)	0.58 (1.04)	0.68 (1.08)	0.59 (1.04)	0.51 (1.00)	0.59
V_4: Sakata-914	0.53 (1.01)	0.62 (1.06)	0.66 (1.07)	0.73 (1.11)	0.73 (1.11)	0.67 (1.08)	0.62 (1.06)	0.65
V_5: Local Cultivar	0.33 (0.91)	0.37 (0.93)	0.34 (0.92)	0.38 (0.93)	0.31 (0.89)	0.23 (0.85)	0.24 (0.86)	0.31
SEm±	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	
CD (P= 0.05)	*0.04*	*0.03*	*0.02*	*0.02*	*0.04*	*0.02*	*0.03*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

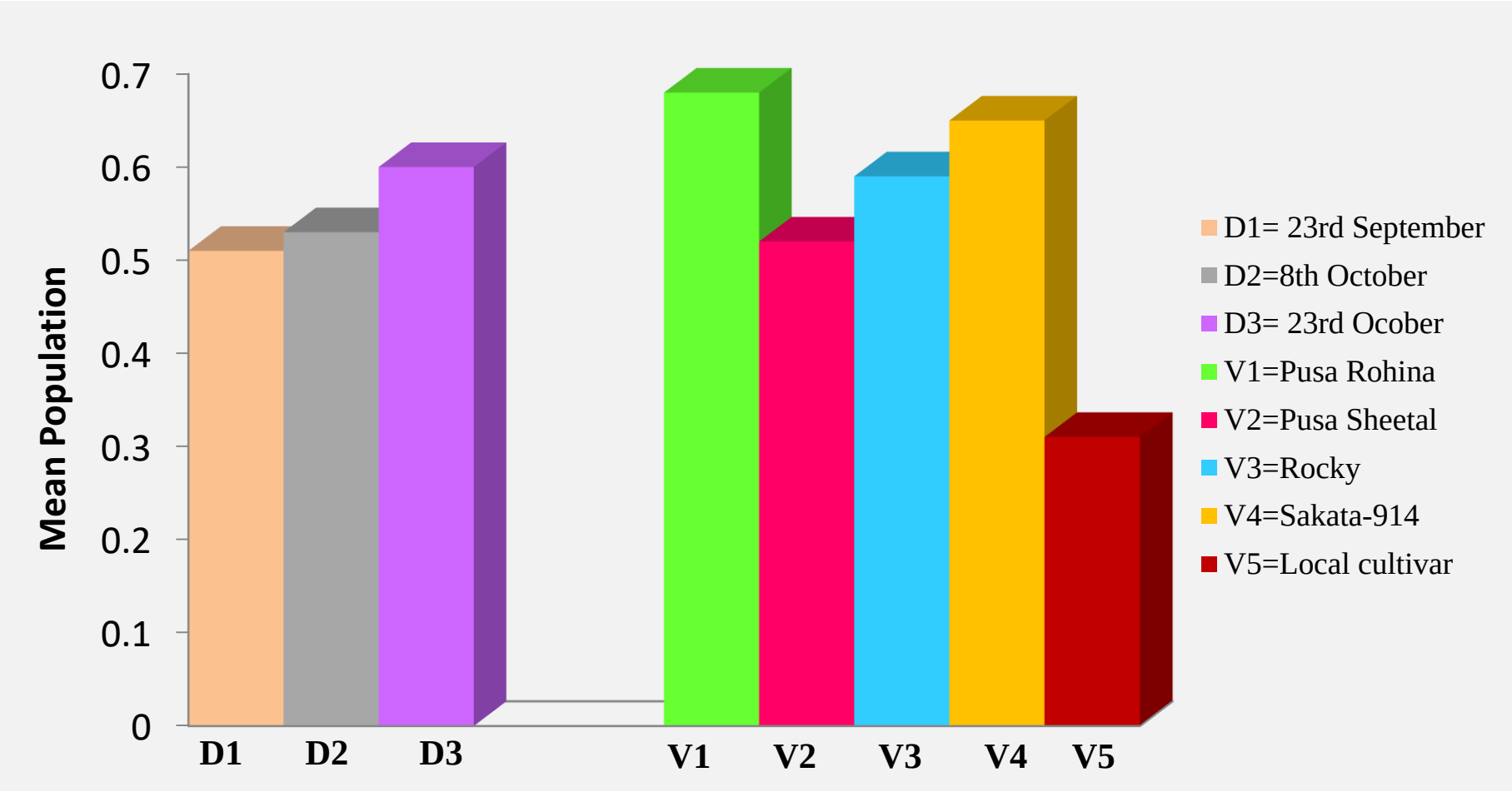


Fig **4.11: Pooled data on the effect of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.26: Pooled data on the interaction effect of date of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021

Treatment	**Number of spider / plant**							
	Pooled data 2019-2020 and 2020-2021							
	45 DAT	***60 DAT***	***75 DAT***	***90 DAT***	***105 DAT***	***120 DAT***	***135 DAT***	***Mean***
D_1V_1	0.50 (1.00)	0.63 (1.06)	0.63 (1.06)	0.73 (1.11)	0.73 (1.11)	0.73 (1.11)	0.67 (1.08)	0.66
D_1V_2	0.27 (0.87)	0.40 (0.95)	0.47 (0.98)	0.53 (1.02)	0.53 (1.02)	0.60 (1.05)	0.53 (1.01)	0.48
D_1V_3	0.43 (0.97)	0.63 (1.06)	0.60 (1.05)	0.60 (1.05)	0.70 (1.09)	0.57 (1.03)	0.57 (1.03)	0.59
D_1V_4	0.27 (0.87)	0.53 (1.02)	0.53 (1.02)	0.60 (1.05)	0.70 (1.09)	0.67 (1.08)	0.57 (1.03)	0.55
D_1V_5	0.23 (0.86)	0.30 (0.89)	0.27 (0.87)	0.30 (0.89)	0.33 (0.90)	0.30 (0.89)	0.27 (0.87)	0.29
D_2V_1	0.47 (0.98)	0.57 (1.03)	0.63 (1.06)	0.63 (1.06)	0.80 (1.14)	0.77 (1.12)	0.73 (1.11)	0.66
D_2V_2	0.37 (0.93)	0.47 (0.98)	0.50 (1.00)	0.50 (1.00)	0.60 (1.04)	0.47 (0.98)	0.33 (0.91)	0.46
D_2V_3	0.40 (0.95)	0.43 (0.97)	0.53 (1.02)	0.47 (0.98)	0.60 (1.05)	0.63 (1.06)	0.50 (1.00)	0.51
D_2V_4	0.57 (1.03)	0.63 (1.06)	0.70 (1.09)	0.77 (1.12)	0.73 (1.11)	0.77 (1.12)	0.70 (1.09)	0.70
D_2V_5	0.37 (0.93)	0.40 (0.95)	0.37 (0.93)	0.43 (0.97)	0.40 (0.94)	0.23 (0.86)	0.23 (0.86)	0.35
D_3V_1	0.77 (1.12)	0.77 (1.12)	0.77 (1.13)	0.70 (1.09)	0.77 (1.12)	0.67 (1.08)	0.63 (1.06)	0.73
D_3V_2	0.53 (1.01)	0.67 (1.08)	0.63 (1.06)	0.67 (1.08)	0.73 (1.11)	0.60 (1.05)	0.57 (1.03)	0.63
D_3V_3	0.70 (1.09)	0.77 (1.12)	0.77 (1.13)	0.67 (1.08)	0.73 (1.11)	0.57 (1.03)	0.47 (0.98)	0.67
D_3V_4	0.77 (1.12)	0.70 (1.09)	0.73 (1.11)	0.83 (1.15)	0.77 (1.12)	0.57 (1.03)	0.60 (1.05)	0.71
D_3V_5	0.40 (0.94)	0.40 (0.95)	0.40 (0.95)	0.40 (0.95)	0.20 (0.83)	0.17 (0.82)	0.23 (0.86)	0.31
SEm±	*0.02*	*0.02*	*0.01*	*0.01*	*0.02*	*0.02*	*0.02*	
CD (P= 0.05)	*0.06*	*0.05*	*0.04*	*0.04*	*0.07*	*0.04*	*0.05*	

Note: Figures in the table are mean values and those in parenthesis are square root transformed values; NS: Non-significant at 5% level of significance

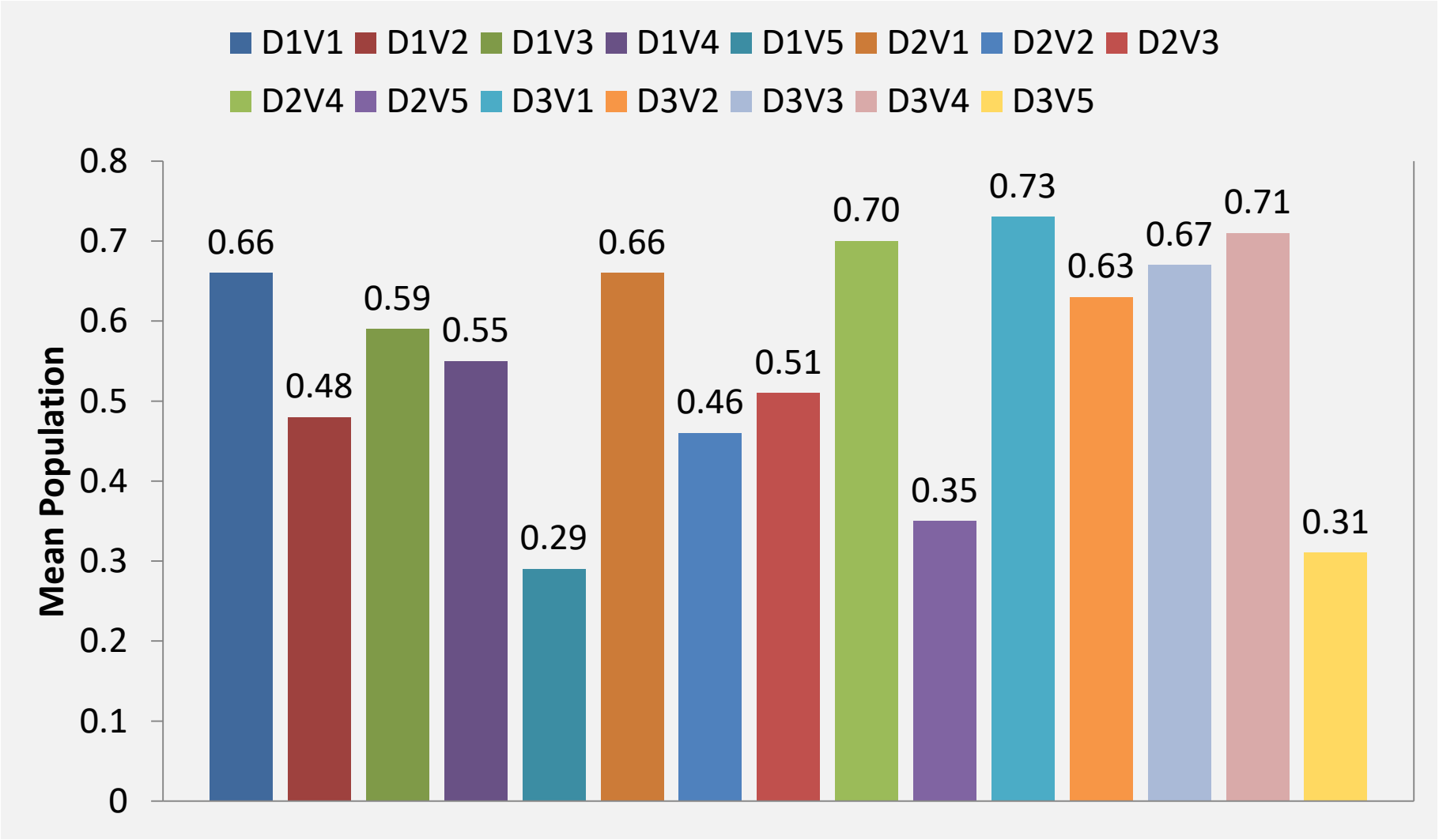


Fig **4.12: Pooled data on the interaction effect of date of planting and varieties on abundance of spider population in tomato ecosystem during 2019-2020 and 2020-2021**

Table 4.27: Correlation coefficient (r) of natural enemies on dates of sowing of tomato with abiotic factors during 2019-2020 and 2020-2021

Pearson correlation coefficient	Year 2019-2020								
	Coccinellid			Parasitoid			Spider		
	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)
Maximum temperature (ºC)	0.274	0.198	0.324	0.020	-0.761*	0.144	0.089	0.144	-0.671*
Minimum temperature (ºC)	-0.084	0.000	-0.118	0.404	-0.470	-0.193	-0.111	0.049	-0.526
Maximum relative humidity (%)	-0.550	-0.308	-0.260	0.272	0.467	-0.109	-0.371	-0.075	0.200
Minimum relative humidity (%)	-0.686*	-0.390	-0.716*	0.582	0.701*	-0.516	-0.414	-0.201	0.344
Rainfall (mm)	-0.089	-0.111	-0.608	0.083	0.540	-0.234	-0.125	-0.144	0.220
Pearson correlation coefficient	Year 2020-2021								
	Coccinellid			Parasitoid			Spider		
	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)	23rdSeptember: (D_1)	8th October: (D_2)	23rd October: (D_3)
Maximum temperature (ºC)	0.153	0.070	-0.515	0.042	-0.151	-0.515	-0.045	0.373	-0.446
Minimum temperature (ºC)	-0.133	-0.034	-0.480	-0.377	-0.103	-0.599	-0.302	0.254	-0.264
Maximum relative humidity (%)	-0.450	-0.050	0.640	-0.433	0.080	0.601	-0.332	-0.353	0.505
Minimum relative humidity (%)	-0.269	0.002	0.364	-0.399	0.215	0.230	-0.254	-0.181	0.594
Rainfall (mm)	0.136	0.150	-0.444	-0.104	-0.196	-0.306	0.082	0.237	0.207

Note: df = (9-2) = 7 $r_{0.05}$ = 0.666; $r_{0.01}$ = 0.798

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

Those values in the table without assign any symbols are non-correlated at 5% and 1% level of significance respectively

Table 4.28: Correlation coefficient (r) of natural enemies on varieties of tomato with abiotic factors during 2019-2020 and 2020-2021

Pearson correlation coefficient	Year 2019-2020														
	Coccinellid					Parasitoid					Spider				
	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)	Pusa Rohini: (V_1)	Pusa Sheetal: (V_2)	Rocky: (V_3)	Sakata-914: (V_4)	Local Cultivar: (V_5)
Maximum temperature (ºC)	0.210	-0.108	-0.410	-0.157	-0.929**	0.253	-0.493	-0.541	-0.216	-0.158	0.494	-0.458	-0.705*	-0.568	-0.680*
Minimum temperature (ºC)	-0.011	-0.353	-0.557	-0.424	-0.673*	0.295	-0.015	-0.486	0.145	0.007	0.111	-0.504	-0.660	-0.690*	-0.594
Maximum relative humidity (%)	-0.670*	-0.113	-0.204	-0.230	0.602	-0.002	0.489	0.307	0.580	0.558	-0.425	0.521	0.053	0.048	0.793*
Minimum relative humidity (%)	-0.612	-0.294	-0.265	-0.437	0.641	0.035	0.797*	0.190	0.779*	0.451	-0.637	0.351	0.097	-0.079	0.489
Rainfall (mm)	-0.020	-0.123	0.001	-0.092	0.168	-0.255	0.153	-0.216	0.015	-0.314	-0.454	-0.211	-0.011	-0.043	-0.194
Pearson correlation coefficient	**Year 2020-2021**														
	Coccinellid					**Parasitoid**					**Spider**				
	Pusa Rohini: (V_1)	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**	**Pusa Rohini: (V_1)**	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**	**Pusa Rohini: (V_1)**	**Pusa Sheetal: (V_2)**	**Rocky: (V_3)**	**Sakata-914: (V_4)**	**Local Cultivar: (V_5)**
Maximum temperature (ºC)	-0.006	-0.167	-0.229	-0.479	-0.744*	-0.013	-0.314	-0.652	0.208	-0.437	-0.065	-0.119	-0.115	-0.176	-0.959**
Minimum temperature (ºC)	-0.450	-0.479	-0.445	-0.720*	-0.720*	-0.659	-0.689*	-0.555	-0.138	-0.346	-0.482	-0.247	-0.729*	-0.215	-0.708*
Maximum relative humidity (%)	-0.356	-0.192	-0.200	0.127	0.585	-0.118	0.286	0.338	-0.532	0.318	-0.248	-0.237	-0.064	-0.165	0.738*
Minimum relative humidity (%)	-0.444	-0.255	-0.138	-0.141	0.129	-0.661	-0.309	0.270	-0.341	0.058	-0.401	-0.095	-0.701*	0.041	0.438
Rainfall (mm)	-0.080	-0.179	0.025	-0.331	-0.536	-0.398	-0.369	0.083	0.332	-0.402	-0.056	0.193	-0.529	0.160	-0.318

Note: df = (9-2) = 7 $r_{0.05}$ = 0.666; $r_{0.01}$ = 0.798

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

D_1V_5 (Local cultivar planted on 23rd September) for the first trial whereas for the second trial period D_1V_1 (Pusa Rohini planted on 23rd September) recorded the maximum spider mean population and the lowest of 0.32 spider/plant observed on D_2V_5 (Local variety planted on 8th October) and D_3V_5 (Local variety planted on 23rd October). The pooled data analysis (Table 4.26) also reveals significant incidence on all dates of observation. The highest population of 0.83 spider/plant was observed in D_3V_4 (Sakata-914 planted on 23rd October) on 90 DAT and the maximum mean of 0.73 spider/plant recorded in the treatment combination, D_3V_1 (Pusa Rohini planted on 23rd October) whereas, the lowest population was observed on D_1V_5 (Local variety planted on 23rd September) with 0.23 spider/plant on 45 DAT with minimum mean recorded in D_1V_5 with 0.29 spider/population.

Correlation analysis (Table 4.27) for spider with abiotic factors indicated negatively significant with maximum temperature ($r = -0.671$, $p < 0.05$) in D_3 for the first research trial (2019-2020) whereas no significant correlation was observed on all dates of planting for the second research period (2020-2021). For the different varieties (Table 4.28), the correlation analysis proved Rocky (V_3) and Local variety (V_5) to be negatively significant with maximum temperature *i.e.* $r = -0.705$, $p<0.05$ and $r= -0.680$, $p<0.05$ respectively; significant but negative impact ($r = -0.690$, $p<0.05$) with minimum temperature on Sakata-914 (V_4); and positively significant with maximum relative humidity for Local variety ($r = 0.793$, $p<0.05$). For the second research trial, Local variety (V_5) was negatively significant with maximum temperature ($r= -0.959$, $p=<0.01$), minimum temperature ($r = -0.708$, $p<0.05$) and positively significant with maximum relative temperature ($r = 0.738$, $p<0.05$) while the variety Rocky (V_3) indicated negative correlation with minimum temperature ($r = -0.729$, $p<0.01$) and minimum relative humidity ($r = -0.701$, $p<0.05$). Other parameters exhibited non-correlation at both 5% and 1% level of significance. The results are in line with observations

of earlier workers *i.e.* significant negative correlation with maximum temperature (Madhu *et al*. 2020); significant negative correlation with minimum temperature (Khokhar and Rolania, 2021; Madhu *et al*. 2020); significant negative correlation with minimum relative humidity (Patel *et al*. 2005).

4.2. To evaluate the efficacy of some biopesticides and trap crop against major insect pests and its impact on natural enemies of tomato

Six biopesticides viz. Marigold *Pusa Narangi* (T_1), multineem 0.03% (T_2), emamectin benzoate 5% SG (T_3), spinosad 45% SC (T_4), *Beauveria bassiana* (T_5)and *Pongamia pinnata* (T_6) were evaluated against major insect pests and their impact on natural enemy of tomato during the experimental trial (2019-2020 and 2020-2021). As previously mentioned in section 4.1.5 of results and discussion chapter, the parasitoid *Glyptapanteles* sp. is a major natural enemy found in tomato ecosystem but maybe due to lack of preferred prey (*C. eriosoma*) the population of *Gyptapanteles* sp. almost disappeared from the field before any treatment was initiated, and hence data could not be obtained for this natural enemy. The results thus obtained are presented and discussed under the following headings.

4.2.1. Efficacy of biopesticides against aphid, *Aphis spiraecola*

The data on the mean population of aphid, *A. spiraecola* recordedone day before spraying and the percent reduction at 3, 5 and 7 days after spraying for two different spray schedules are presented in Table 4.29 – 4.31 and illustrated in Figure 4.13. A significant influence on all the planting dates at 3rd, 5th and 7th days after spray (DAS) was observed in both experimental years (2019-2020 and 2020-2021). The effect of different treatments was worked out in terms of percent (%) reduction over the pre-treatment count. From the first experimental year 2019-2020 (Table 4.29), it is evident from the data observed that the percent reduction of *A. spiraecola* after the 1st and 2nd spray recorded

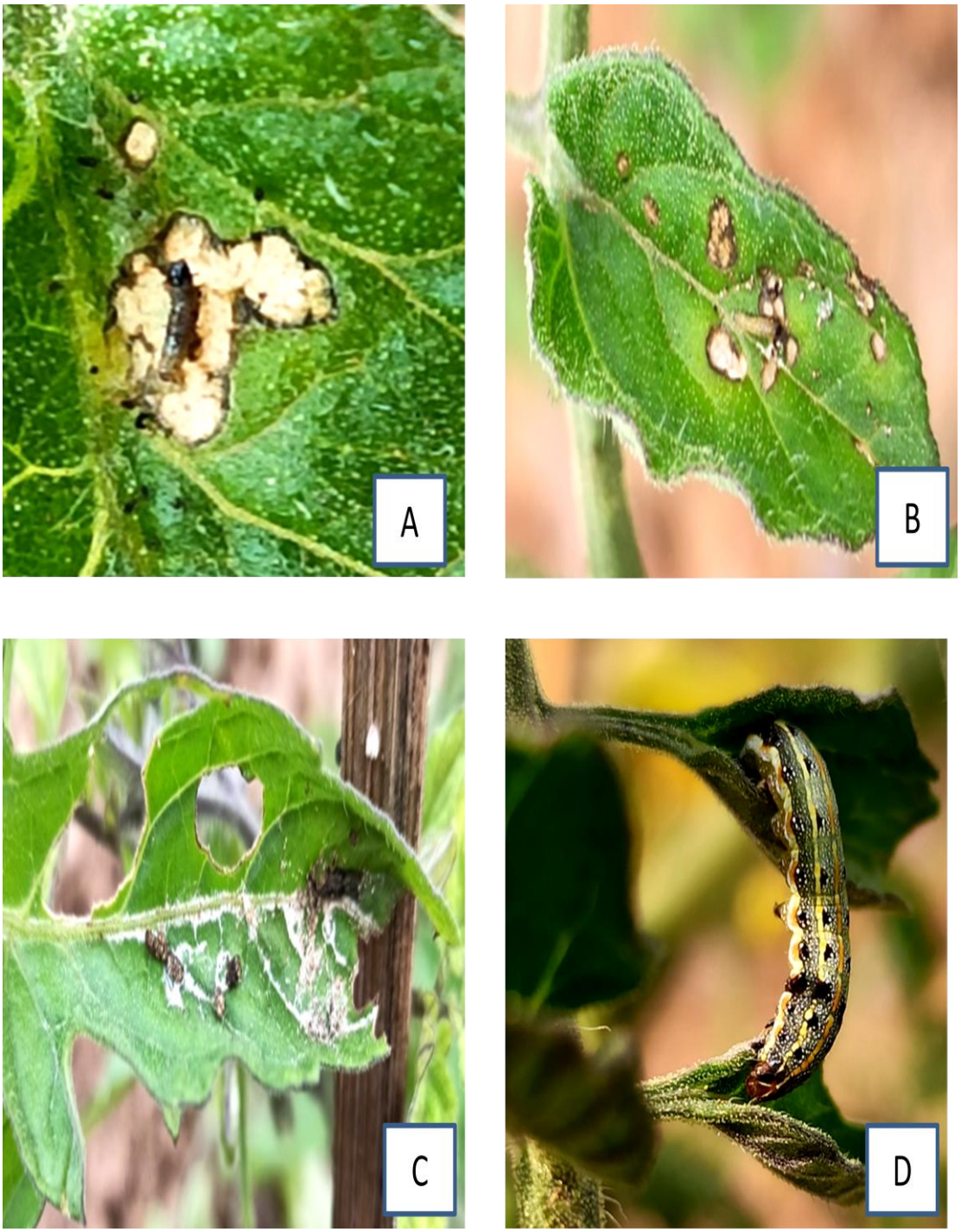


Plate 9. A-D) Effect of biopesticides on insect pest of tomato

Plate 10. A-B. Marigold (trap crop) cultivation on the bunds around the main crop (tomato)
C-D. Marigold as effective trap crop

Table 4.29: Effect of different trap crop and biopesticides against aphids on tomato variety Sakata-914 during 2019-2020

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Percent reduction*			*Pre-treatment count*	*Percent reduction*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	8.73	6.79 (13.94)	12.36 (20.27)	6.79 (13.94)	7.93	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*4.32*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	9.73	24.17 (29.44)	29.27 (32.73)	32.49 (34.74)	9.27	26.38 (30.90)	36.18 (36.96)	42.79 (40.85)	*31.88*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	9.87	34.44 (35.93)	42.47 (40.67)	39.72 (39.05)	9.53	35.42 (36.51)	52.30 (46.32)	47.35 (43.48)	*41.95*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	8.80	15.87 (23.46)	17.43 (24.66)	20.42 (26.86)	7.87	32.38 (34.65)	40.47 (39.48)	45.43 (42.37)	*28.67*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	8.27	18.52 (25.48)	22.58 (28.35)	25.02 (29.99)	8.27	20.06 (26.60)	25.66 (30.42)	28.27 (32.12)	*23.35*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	9.67	15.12 (22.88)	17.21 (24.51)	20.42 (26.86)	9.53	17.23 (24.26)	20.74 (27.03)	23.49 (28.93)	*19.04*
Untreated control: (T_0)	7.53	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	8.27	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*0.59*	*1.70*	*1.70*	*2.11*	*0.99*	*1.81*	*2.13*	*1.61*	-
CD (P=0.05)	*NS*	*5.23*	*5.24*	*6.49*	*NS*	*5.59*	*6.57*	*4.95*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values; NS: Non-significant at 5% level of significance

Table 4.30: Effect of different trap crop and biopesticides against aphids on tomato variety Sakata-914 during 2020-2021

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Percent reduction***			***Pre-treatment count***	***Percent reduction***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	7.07	9.43 (17.88)	12.57 (20.74)	9.43 (17.88)	8.00	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	*5.24*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	7.60	26.88 (31.16)	32.12 (34.49)	35.55 (36.57)	7.20	24.58 (29.54)	35.81 (36.72)	42.32 (40.56)	*32.88*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	8.13	32.66 (34.85)	39.17 (38.74)	38.37 (38.27)	8.13	37.32 (37.63)	53.44 (46.99)	50.21 (45.12)	*41.86*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	8.33	18.86 (25.70)	20.14 (26.60)	22.51 (28.30)	8.27	34.65 (36.06)	42.00 (40.39)	46.68 (43.09)	*30.81*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	7.27	21.94 (27.91)	25.53 (30.32)	27.25 (31.44)	7.60	22.90 (28.45)	27.23 (31.35)	30.83 (33.67)	*25.95*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	8.07	17.62 (24.77)	19.35 (26.06)	22.82 (28.47)	7.80	20.81 (27.07)	22.80 (28.50)	25.18 (30.08)	*21.43*
Untreated control: (T_0)	7.27	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	8.80	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*0.56*	*1.58*	*1.76*	*2.04*	*0.71*	*2.70*	*2.56*	*2.46*	-
CD (P=0.05)	*NS*	*4.86*	*5.41*	*6.29*	*NS*	*8.33*	*7.88*	*7.59*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values;

NS: Non-significant at 5% level of significance

highest in emamectin benzoate 5% SG (T_3) on 5 DAS with 44.47 and 52.30 percent reduction respectively. The biopesticidal action of multineem (T_2) followed closely after emamectin benzoate 5% SG with percent reduction of 32.49 and 42.79 on 7 DAS after the 1st and 2nd spray respectively; on the contrary the lowest reduction of aphid was recorded in marigold (T_1) with 6.79% (1st spray) at 7 DAS and no reduction after the 2nd spray. A similar trend was observed during the second experimental year 2020-2021 (Table 4.30), the data revealed that the highest percent reduction of 39.17 and 53.44 was observed in emamectin benzoate 5% SG (T_3) in 5 DAS after the 1st and 2nd spray respectively, while the lowest was observed in marigold (T_1) with 9.43% (1st spray) at 7 DAS and no reduction was observed after the second spray. The pooled data analysis (Table 4.31) at 3 DAS reveals aphid population reduction varied from 8.11-33.55% and 0.00-36.67 % respectively during first and second application. All the treatments under study showed superior and significant reduction over control. The treatments, T_3 (emamectin benzoate 5% SG) and T_2 (multineem) were most effective followed by T_4 (spinosad 45% SC) and T_5 (*Beauveria bassiana*) and the least was observed in T_1 (marigold) and T_6 (*Pongamia pinnata*). At 5th DAS of first and second spray the highest percent reduction (40.82% and 53.44% respectively) was recorded in emamectin benzoate 5% SG (T_3) while the lowest (12.46% and 0.00% respectively) reduction was found in marigold (T_1) treatment in both spray schedules. Percent reduction at 7th DAS, also observed emamectin benzoate 5% SG (T_3) to be the most effective biopesticide giving a reduction of 39.04%and 48.78% respectively, while the least effective was exhibited by marigold (T_1) with 8.11% and 0.00% respectively during first and second spray. The overall mean data was observed highest in emamectin benzoate 5% SG (42.00%) followed by multineem (32.35%), spinosad 45% SC (28.87%), *Beauveria bassiana* (24.78%), *Pongamia pinnata* (20.40%) and lastly marigold

Table 4.31: Effect of different trap crop and biopesticides against aphids on tomato variety Sakata-914 during 2019-2020 and 2020-2021 (Pooled)

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Percent reduction*			*Pre-treatment count*	*Percent reduction*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	7.90	8.11 (15.91)	12.46 (20.50)	8.11 (15.91)	7.97	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	*4.78*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	8.67	25.53 (30.30)	30.70 (33.61)	34.02 (35.65)	8.23	25.48 (30.22)	35.81 (36.72)	42.56 (40.71)	*32.35*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	9.00	33.55 (35.39)	40.82 (39.70)	39.04 (38.66)	8.83	36.37 (37.07)	53.44 (46.99)	48.78 (44.30)	*42.00*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	8.57	17.37 (24.58)	18.78 (25.63)	21.47 (27.58)	8.07	33.52 (35.36)	42.00 (40.39)	46.05 (42.73)	*29.87*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	7.77	20.23 (26.70)	24.06 (29.33)	26.14 (30.72)	7.93	21.48 (27.53)	27.23 (31.35)	29.55 (32.89)	*24.78*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	8.87	16.37 (23.83)	18.28 (25.29)	21.62 (27.66)	8.67	19.02 (25.67)	22.80 (28.50)	24.33 (29.51)	*20.40*
Untreated control: (T_0)	7.40	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	8.53	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*0.40*	*1.16*	*1.22*	*1.47*	*0.61*	*1.63*	*2.56*	*1.47*	-
CD (P=0.05)	*NS*	*3.38*	*3.57*	*4.28*	*NS*	*4.75*	*7.88*	*4.29*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values
NS: Non-significant at 5% level of significance

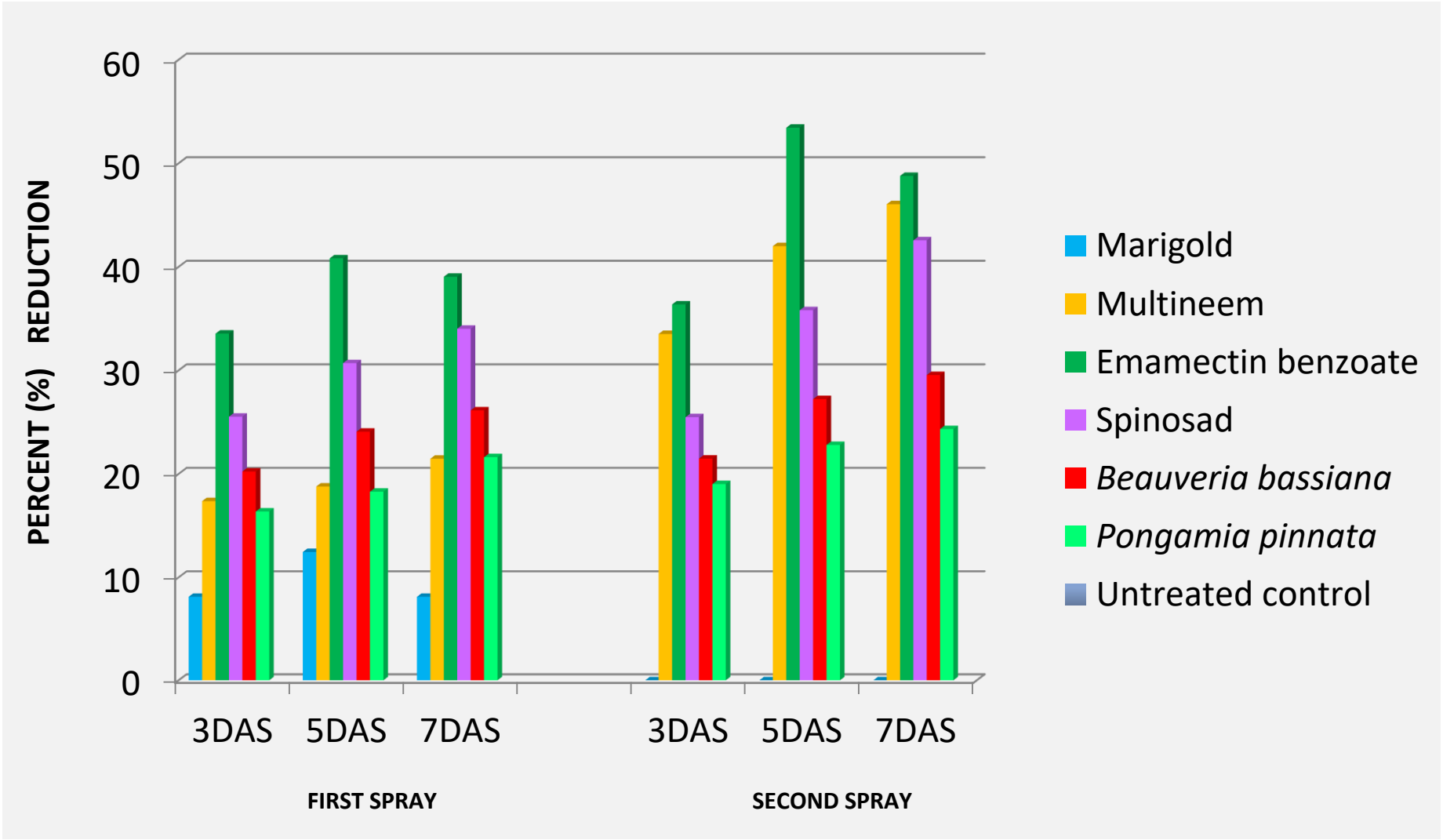


Fig 4 13. Pooled data on the efficacy of biopesticides against aphid, *Aphis spiraecola* population

Table 4.32: Effect of different trap crop and biopesticides against *Helicoverpa armigera* on tomato variety Sakata-914 during 2019-2020

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Percent reduction***			***Pre-treatment count***	***Percent reduction***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	9.33	32.26 (34.54)	42.52 (40.70)	55.37 (48.08)	9.33	30.74 (33.66)	39.26 (38.77)	47.78 (43.71)	*41.32*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	11.94	22.50 (27.23)	37.75 (37.90)	49.32 (44.61)	11.80	26.46 (30.86)	40.38 (39.44)	50.46 (45.26)	*37.81*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	10.36	49.98 (44.99)	54.66 (47.68)	72.48 (58.43)	11.67	50.53 (45.31)	55.17 (47.98)	72.14 (58.14)	*59.16*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	12.71	43.53 (41.08)	52.38 (46.38)	67.10 (55.00)	11.34	46.32 (42.89)	56.42 (48.69)	68.08 (55.61)	*55.64*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	11.06	32.86 (34.54)	40.57 (39.51)	46.90 (43.22)	7.65	34.45 (35.94)	43.48 (41.25)	48.78 (44.30)	*41.17*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	10.66	16.48 (23.95)	20.74 (26.98)	28.48 (32.24)	9.79	18.51 (25.44)	22.29 (28.12)	30.60 (33.58)	*22.85*
Untreated control: (T_0)	10.28	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	11.71	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*0.97*	*6.21*	*2.74*	*1.68*	*2.03*	*2.59*	*2.15*	*2.25*	-
CD (P=0.05)	*NS*	*19.15*	*8.43*	*5.16*	*NS*	*7.98*	*6.61*	*6.93*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values

NS: Non-significant at 5% level of significance

Table 4.33: Effect of different trap crop and biopesticides against *Helicoverpa armigera* on tomato variety Sakata-914 during 2020-2021

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Percent reduction***			***Pre-treatment count***	***Percent reduction***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	9.00	34.22 (34.88)	45.33 (42.32)	57.78 (49.48)	9.67	34.19 (35.76)	41.22 (39.92)	50.52 (45.29)	*43.88*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	10.97	23.72 (29.12)	38.58 (38.36)	50.16 (45.09)	9.56	25.81 (30.41)	38.41 (38.28)	50.57 (45.33)	*37.88*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	12.17	50.82 (45.48)	55.66 (48.26)	74.17 (59.51)	9.61	52.06 (46.21)	57.33 (49.23)	72.58 (58.44)	*60.44*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	13.08	45.79 (42.58)	56.11 (48.51)	68.33 (55.77)	11.34	45.03 (41.94)	55.32 (48.21)	67.17 (55.13)	*56.29*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	9.00	33.25 (35.21)	42.85 (40.86)	48.18 (43.96)	8.14	32.59 (34.79)	40.75 (39.63)	46.48 (42.98)	*40.68*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	10.27	18.64 (25.36)	23.53 (28.98)	30.37 (33.40)	13.52	18.38 (25.36)	24.32 (29.51)	32.00 (34.45)	*24.54*
Untreated control: (T_0)	10.48	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	10.55	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*1.44*	*5.12*	*2.27*	*1.95*	*1.67*	*4.96*	*5.56*	*2.48*	-
CD (P=0.05)	*NS*	*15.78*	*6.99*	*6.02*	*NS*	*15.29*	*17.15*	*7.63*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values

NS: Non-significant at 5% level of significance

(4.78%). Throughout the entire investigation periods, it was found that the plots treated with emamectin benzoate 5% SG (T_3) and multineem (T_2) were found to give the highest reduction whereas, marigold as trap crop (T_1) showed little to no reduction in most of the plots. A comparable study was conducted by Patel *et al*. (2015) and Gaikwad *et al*. (2020); the authors reported emamectin benzoate to be among the most effective biopesticide as it recorded the lowest aphid infestation in field condition. Wagh *et al*. (2017) also in a similar study reported that emamectin benzoate 5% SG, cypermetrin 25 EC and abamectin 1.9 EC emerged as most effective treatment to reduce aphid population in tomato ecosystem. The present finding is also supported by the findings of Khalequzzaman and Nahar (2008) that azadirachtin was more toxic than imidacloprid, malathion, carbosulfan and cymbush to control *A. craccivora*.

4.2.2. Efficacy of biopesticides against tomato fruit borer, *Helicoverpa armigera*

The data on the mean fruit infested by *H. armigera* recordedone day before spraying and the percent reduction at 3, 5 and 7 days after spraying for two different spray schedules are presented in Table 4.32 – 4.34 and illustrated in Figure 4.14. A significant influence on all the planting dates at 3rd, 5th and 7th days after spray was observed in both experimental year (2019-2020 and 2020-2021). The effect of different treatments was worked out in terms of percent (%) reduction over the pre-treatment count. From the first experimental year 2019-2020 (Table 4.32), it is evident from the data observed that the percent reduction of *H. armigera* after the 1st and 2nd spray recorded highest in emamectin benzoate 5% SG (T_3) on 7 DAS with 72.48 and 72.14 percent reduction respectively. The biopesticidal action of spinosad 45% SC (T_4) followed closely after with percent reduction of 67.10% and 68.08% on 7 DAS after the 1st and 2nd spray respectively whereas; *Pongamia pinnata* (T_6)

recorded the lowest reduction of *H. armigera* with 16.48% (1st spray) and 8.51% (2nd spray) at 3 DAS. The second experimental year 2020-2021 (Table 4.33) also recorded similar results, the highest percent reduction of 74.17and 72.58 was observed in emamectin benzoate 5% SG (T_3) at 7 DAS after the 1st and 2nd spray respectively, while the lowest was observed in *Pongamia pinnata* (T_6) with 18.64 (1st spray) and 18.38%(2nd spray) at 7 DAS. The pooled data analysis (Table 4.34) at 3 DAS reveals *H. armigera* population reduction varied from 17.56-50.40% and 18.44-51.30% after first and second application respectively. The treatments, T_3 (emamectin benzoate 5% SG) and T_4 (spinosad 45% SC) were most effective followed by T_5 (*Beauveria bassiana*) and T_1 (trap crop marigold) and the least was observed in T_2 (multineem) and T_6 (*Pongamia pinnata*). On 5th DAS of first and second spray the highest percent reduction (5516% and 56.25% respectively) was recorded in emamectin benzoate 5% SG (T_2) while the lowest (22.14% and 23.31% respectively) reduction was found in *Pongamia pinnata* (T_6) treatment in both spray schedules. Percent reduction at 7th DAS, also observed emamectin benzoate 5% SG (T_3) to be the most effective biopesticide giving a reduction of 73.32% and 72.36% respectively, while the least effective was exhibited by *Pongamia pinnata* (T_6) with 29.43% and 31.30% during first and second spray respectively. The overall mean data was observed highest in emamectin benzoate 5% SG (59.80%) followed by spinosad 45% SC (55.97%), Trap crop marigold (42.60%), *Beauveria bassiana* (40.93%), multineem (37.84%) and lastly *Pongamia pinnata* (23.70%). Throughout the entire investigation periods, the percent reduction of spinosad 45% SC (T_4) was recorded to be at par with emamectin benzoate (T_3) and also all treatments under study showed superior and significant reduction over control. These results are consistent with previous observations made by Murugaraj *et al*. (2006) and Wade *et al*. (2020), reported that emamectin benzoate was highly effective in percent reduction in fruit infestation by fruit borer, *H. armigera*. The present results

Table 4.34: Effect of different trap crop and biopesticides against *Helicoverpa armigera* on tomato variety Sakata-914 during 2019-2020 and 2020-2021 (Pooled)

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Percent reduction***			***Pre-treatment count***	***Percent reduction***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	9.17	33.24 (34.71)	43.93 (41.51)	56.57 (48.78)	9.50	32.46 (34.71)	40.24 (39.35)	49.15 (44.50)	*42.60*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	11.45	23.11 (28.18)	38.16 (38.13)	49.74 (44.85)	10.68	26.13 (30.64)	39.39 (38.86)	50.51 (45.29)	*37.84*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	11.26	50.40 (45.23)	55.16 (47.97)	73.32 (58.97)	10.64	51.30 (45.76)	56.25 (48.61)	72.36 (58.29)	*59.80*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	12.89	44.66 (41.83)	54.25 (47.45)	67.72 (55.38)	11.34	45.67 (42.41)	55.87 (48.45)	67.63 (55.37)	*55.97*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	10.03	33.06 (34.88)	41.71 (40.19)	47.54 (43.59)	7.90	33.52 (35.36)	42.11 (40.44)	47.63 (43.64)	*40.93*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	10.46	17.56 (24.65)	22.14 (27.98)	29.43 (32.82)	11.66	18.44 (25.40)	23.31 (28.81)	31.30 (34.01)	*23.70*
Untreated control: (T_0)	10.38	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	11.13	0.00 (0.25)	0.00 (0.25)	0.00 (0.25)	*0.00*
SEm±	*0.87*	*4.03*	*1.78*	*1.29*	*1.31*	*2.80*	*2.98*	*1.67*	-
CD (P=0.05)	*NS*	*11.75*	*5.19*	*3.76*	*NS*	*8.17*	*8.70*	*4.88*	-

Note: Figures in the table are mean values and those in parenthesis are arc sine transformed values

NS: Non-significant at 5% level of significance

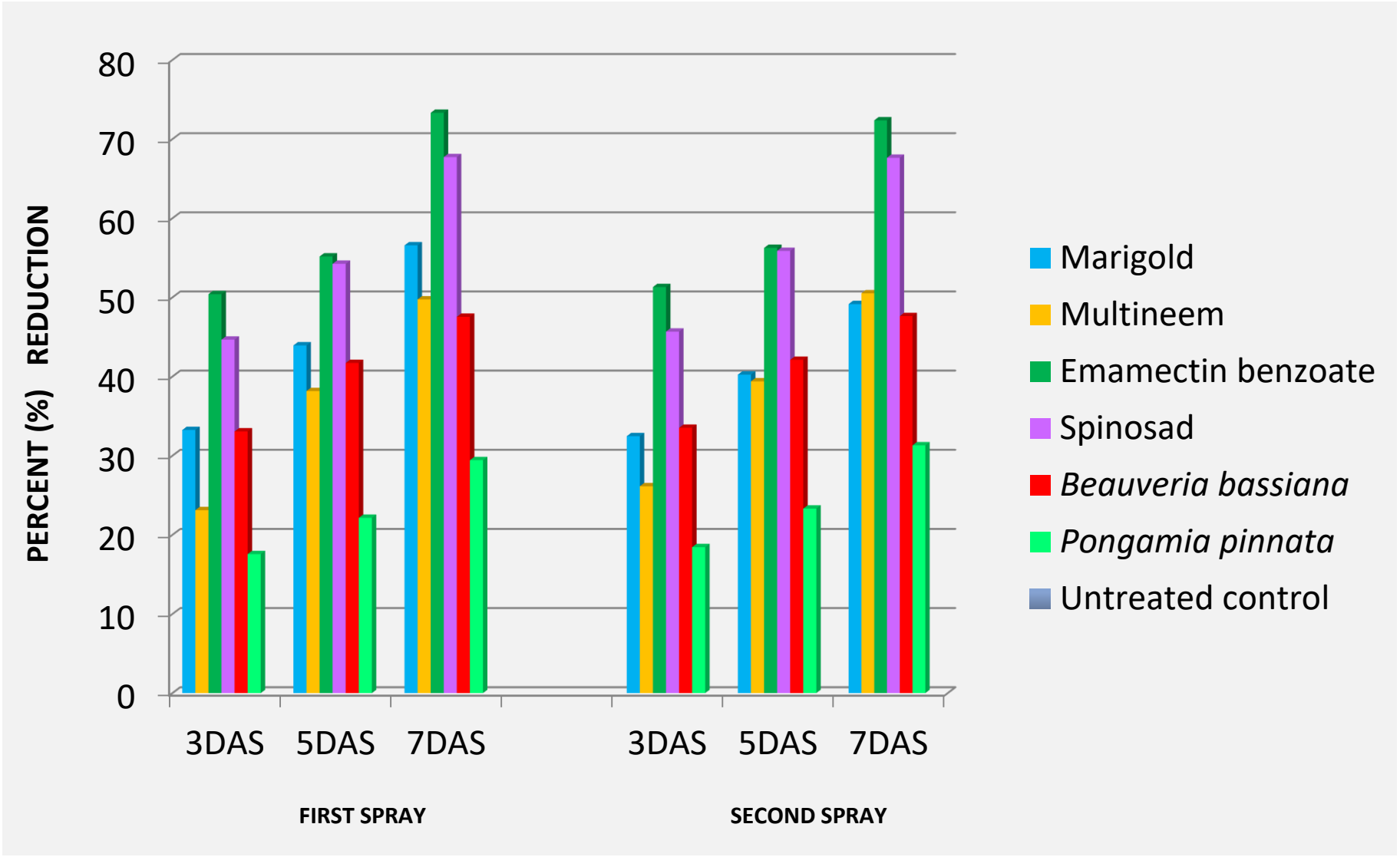


Fig **4 14. Pooled data on the effficacy of biopesticides against *H. armigera* population**

Table 4.35: Effect of different trap crop and biopesticides against coccinellids on tomato variety Sakata-914 during 2019-2020

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Mean population of coccinellids over control/ 15 plants*			*Pre-treatment count*	*Mean population of coccinellids over control/ 15 plants*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	0.67	0.67 (1.08)	0.60 (1.05)	0.73 (1.11)	0.67	0.67 (1.07)	0.67 (1.07)	0.73 (1.11)	*0.68*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.73	0.80 (1.14)	0.80 (1.14)	0.73 (1.11)	0.73	0.73 (1.11)	0.73 (1.11)	0.73 (1.11)	*0.75*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.67	0.73 (1.11)	0.67 (1.08)	0.67 (1.08)	0.60	0.53 (1.02)	0.60 (1.05)	0.60 (1.05)	*0.63*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.67	0.53 (1.02)	0.47 (0.98)	0.40 (0.95)	0.60	0.67 (1.08)	0.67 (1.08)	0.47 (0.98)	*0.54*
Beauveria bassiana @ 1.5 ml/lt of water: (T_5)	0.73	0.73 (1.11)	0.80 (1.14)	0.80 (1.14)	0.67	0.67 (1.07)	0.73 (1.11)	0.80 (1.14)	*0.76*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.73	0.53 (1.02)	0.67 (1.08)	0.60 (1.05)	0.60	0.73 (1.11)	0.73 (1.11)	0.60 (1.05)	*0.64*
Untreated control: (T_0)	0.73	0.80 (1.14)	0.67 (1.08)	0.73 (1.11)	0.67	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	*0.77*
SEm±	*0.06*	*0.07*	*0.07*	*0.07*	*0.12*	*0.10*	*0.07*	*0.04*	-
CD (P=0.05)	*NS*	*NS*	*NS*	*0.22*	*NS*	*NS*	*NS*	*0.12*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

NS: Non-significant at 5% level of significance

Table 4.36: Effect of different trap crop and biopesticides against coccinellids on tomato variety Sakata-914 during 2020-2021

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Mean population of coccinellids over control/ 15 plants***			***Pre-treatment count***	***Mean population of coccinellids over control/ 15 plants***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	0.73	0.73 (1.11)	0.67 (1.08)	0.50 (1.00)	0.67	0.67 (1.08)	0.67 (1.08)	0.67 (1.08)	*0.65*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.73	0.73 (1.11)	0.80 (1.14)	0.53 (1.02)	0.67	0.67 (1.08)	0.67 (1.08)	0.67 (1.08)	*0.68*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.67	0.67 (1.08)	0.67 (1.08)	0.20 (0.84)	0.67	0.67 (1.07)	0.67 (1.07)	0.67 (1.07)	*0.59*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.80	0.80 (1.14)	0.67 (1.08)	0.37 (0.93)	0.60	0.60 (1.05)	0.60 (1.05)	0.60 (1.05)	*0.61*
Beauveria bassiana($1x10^7$ conidia/ml) @ 1.5 ml/lt of water: (T_5)	0.67	0.67 (1.08)	0.80 (1.14)	0.43 (0.96)	0.73	0.73 (1.10)	0.73 (1.10)	0.73 (1.10)	*0.68*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.67	0.67 (1.08)	0.67 (1.08)	0.32 (0.90)	0.60	0.60 (1.05)	0.60 (1.05)	0.60 (1.05)	*0.58*
Untreated control: (T_0)	0.80	0.80 (1.14)	0.60 (1.05)	0.80 (1.14)	0.73	0.73 (1.11)	0.73 (1.11)	0.73 (1.11)	*0.73*
SEm±	*0.07*	*0.07*	*0.08*	*0.07*	*0.09*	*0.07*	*0.08*	*0.09*	-
CD (P=0.05)	*NS*	*NS*	*NS*	*0.21*	*NS*	*NS*	*NS*	*NS*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values;

NS: Non-significant at 5% level of significance

also corroborates with the findings of Patil *et al*. (2007), who evaluated bio efficacy and economics of insecticides for management of *H.armigera* and found emamectin benzoate 5% SG to be more effective followed by spinosad 45% SC. From the analysed data, it was also observed that marigold acted as an efficient treatment *i.e.* trap crop against tomato fruit borer, *H.armigera*. Successful use of marigold as a trap crop for management of tomato fruit borer on tomato was also reported by Hussain and Bilal (2007) and Srinivasan *et al*. (2008).

4.2.3. Abundance of coccinellid beetle in biopesticides treated tomato field

The safety of six biopesticides evaluated against coccinellid predators based on two sprays are presented in Table 4.35 – 4.37 and illustrated in Figure 4.15. In the first research trial (2019-2020), treatment of multineem (T_2) and *Beauveria bassiana* (T_5) recorded more number of coccinellid population compared to rest of treatments *i.e.* a total mean of 0.75/15 plants and 0.76/15 plants respectively. Similar trend was observed in the second research trial (2020-2021), the treatment multineem (T_2) and *Beauveria bassiana* (T_3) resulted in maximum mean population of cocinellid beetles of 0.68/15 plants in each respectively. On the contrary, the least mean population of 0.54/plant was recorded in spinosad 45% SC (T_4) during the first year (2019-2020) while emamectin benzoate 5% SG (T_3) recorded the least population of coccinellid beetles (0.59/plant) in the second year (2020-2021). The pooled data (Table 4.37) during the both the year 2019-2020 and 2020-2021 on coccinellid beetle population after 1st and 2nd sprays at different days of observation revealed that there was very little difference among all treatments and also no treatment under study showed significant effect on the natural enemies population. The pre treatment population of coccinellids ranged from 0.67 to 0.77 per fifteen plants. After the first round of spraying, At 3 DAS, the plots treated with multineem (T_2) recorded 0.77/15 plants which was on par with *Beauveria bassiana* (T_5) (0.73/ 15 plants) whereas, the lowest population was observed in

Pongamia pinnata (T_6) (0.60/15 plants) and spinosad 45% SC (T_4) (0.67/15 plants). A similar observation was made on the 5 DAS, biopesticide multineem (0.80/15 plants) had the highest population and the lowest was observed in spinosad 45% SC (0.57/15 plants). At 7 DAT, the highest population of predatory coccinellids per fifteen plants was recorded in plots treated with multineem (0.63) and the lowest in spinosad 45% SC (0.38) and emamectin benzoate 5% SG (0.43). The results of the second season field experiment (2020-2021) carried out on the impact of biopesticides on coccinellids in tomato ecosystem revealed that the pre treatment population of coccinellids ranged from 0.60-0.70 per fifteen plants. After the first round of spraying, at 3 DAT, the plots treated with *Beauveria bassiana* (T_5) recorded the maximum population (0.77/15 plants) and the minimum observed in emamectin benzoate 5% SG (T_3) (0.60/15 plants). Similar trend of coccinellids population was observed at 5 DAT with 0.63 in spinosad 45% SC (T_4) and emamectin benzoate 5% SG (T_3) to 0.77 / 15 plants in *Beauveria bassiana*. At 7 DAT, the population ranged from 0.53/15 plants in T_4 (spinosad 45% SC) to 0.77/15 plants in T_5 (*Beauveria bassiana*). The overall mean data of coccinellid population per fifteen plants was observed highest in multineem (0.72) and *Beauveria bassiana* (0.72) followed by Trap crop marigold (0.67), *Pongamia pinnata* (0.61) and emamectin benzoate 5% SG (0.61) and the least population was recorded in spinosad 45% SC (0.53). Our present study recorded spinosad 45% SC with the lowest population after both sprays compared to the other biopesticides under study, this finding are in close agreement with the finding of Das *et al*. (2021), reported that spinosad 45% SC (Libsen 45 SC) showed moderate toxicity to all predators with 30-40% of the predator population were reduced over control in tomato plants. In addition, mortality of 35% and 45% of lynx spiders and ladybird beetles respectively were reported when sprayed with spinosad 45% SC in rice field (Galven *et al*. 2005; Ahmed *et al*. 2015). Although the result revealed that all the selected bio-pesticides treatments were

Table 4.37: Effect of different trap crop and biopesticides against coccinellids on tomato variety Sakata-914 during 2019-2020 and 2020-2021 (Pooled)

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Mean population of coccinellids over control/ 15 plants*			*Pre-treatment count*	*Mean population of coccinellids over control/ 15 plants*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	0.70	0.70 (1.09)	0.63 (1.06)	0.62 (1.05)	0.67	0.67 (1.08)	0.67 (1.08)	0.70 (1.09)	*0.67*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.73	0.77 (1.12)	0.80 (1.14)	0.63 (1.06)	0.70	0.70 (1.09)	0.70 (1.09)	0.70 (1.09)	*0.72*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.67	0.70 (1.09)	0.67 (1.08)	0.43 (0.96)	0.63	0.60 (1.04)	0.63 (1.06)	0.63 (1.06)	*0.61*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.73	0.67 (1.08)	0.57 (1.03)	0.38 (0.94)	0.60	0.63 (1.06)	0.63 (1.06)	0.53 (1.02)	*0.53*
Beauveria bassiana @ 1.5 ml/lt of water: (T_5)	0.70	0.73 (1.11)	0.73 (1.11)	0.58 (1.04)	0.70	0.77 (1.12)	0.77 (1.12)	0.77 (1.12)	*0.72*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.70	0.60 (1.05)	0.67 (1.08)	0.46 (0.97)	0.60	0.67 (1.08)	0.67 (1.08)	0.60 (1.05)	*0.61*
Untreated control: (T_0)	0.77	0.77 (1.12)	0.70 (1.09)	0.80 (1.14)	0.70	0.70 (1.09)	0.73 (1.11)	0.77 (1.12)	*0.75*
SEm±	*0.05*	*0.05*	*0.05*	*0.05*	*0.08*	*0.07*	*0.06*	*0.05*	-
CD (P=0.05)	*NS*	*NS*	*NS*	*0.15*	*NS*	*NS*	*NS*	*NS*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

NS: Non-significant at 5% level of significance

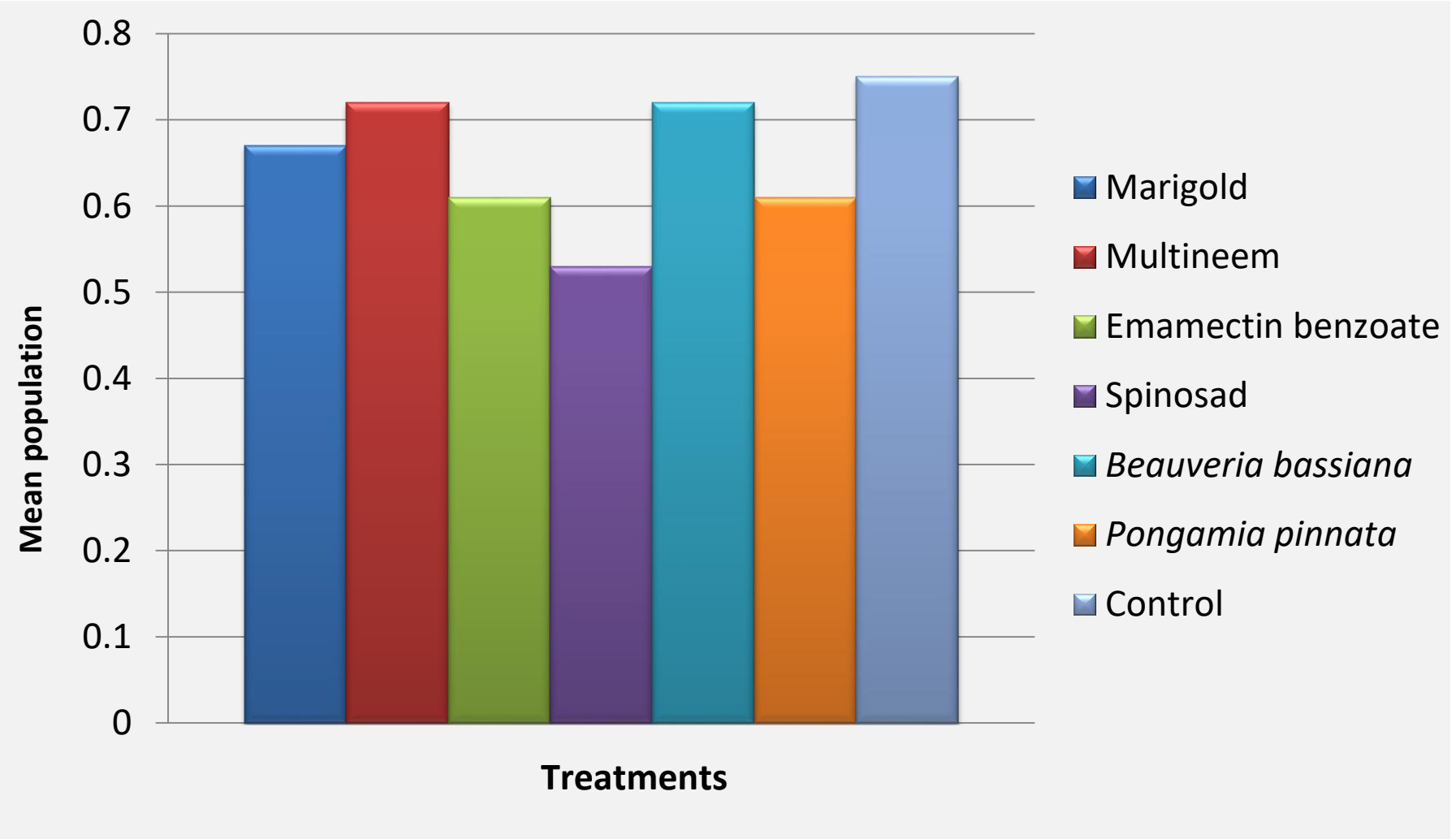


Fig **4.15. Pooled data on the effect of biopesticides and trap crop against coccinellids (natural enemy) on tomato variety Sakata-914**

Table 4.38: Effect of different trap crop and biopesticides against spiders on tomato variety Sakata-914 during 2019-2020

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Mean population of spiders over control/ 15 plants*			*Pre-treatment count*	*Mean population of spiders over control/ 15 plants*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	0.80	0.93 (1.20)	0.73 (1.11)	0.87 (1.17)	0.73	0.80 (1.14)	0.73 (1.11)	0.87 (1.17)	*0.82*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.67	0.60 (1.05)	0.73 (1.11)	0.73 (1.11)	0.80	0.87 (1.17)	0.60 (1.05)	0.73 (1.11)	*0.71*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.67	0.53 (1.02)	0.47 (0.98)	0.47 (0.98)	0.80	0.67 (1.08)	0.67 (1.08)	0.53 (1.02)	*0.56*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.80	0.60 (1.05)	0.47 (0.98)	0.47 (0.98)	0.80	0.60 (1.05)	0.53 (1.02)	0.53 (1.02)	*0.53*
Beauveria bassiana @ 1.5 ml/lt of water: (T_5)	0.73	0.80 (1.14)	0.80 (1.14)	0.80 (1.14)	0.73	0.73 (1.11)	0.67 (1.08)	0.80 (1.14)	*0.77*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.67	0.67 (1.08)	0.73 (1.11)	0.80 (1.14)	0.73	0.80 (1.14)	0.67 (1.08)	0.67 (1.08)	*0.72*
Untreated control: (T_0)	0.80	0.87 (1.17)	0.73 (1.11)	0.80 (1.14)	0.80	0.67 (1.08)	0.67 (1.08)	0.73 (1.11)	*0.75*
SEm±	*0.13*	*0.08*	*0.08*	*0.13*	*0.16*	*0.20*	*0.14*	*0.15*	-
CD (P=0.05)	*NS*	*0.25*	*0.25*	*NS*	*NS*	*NS*	*NS*	*NS*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

NS: Non-significant at 5% level of significance

Table 4.39: Effect of different trap crop and biopesticides against spiders on tomato variety Sakata-914 during 2020-2021

Treatments	***First spray***				***Second spray***				***Mean***
	Pre-treatment count	***Mean population of spiders over control/ 15 plants***			***Pre-treatment count***	***Mean population of spiders over control/ 15 plants***			
		3 DAS	***5 DAS***	***7 DAS***		***3 DAS***	***5 DAS***	***7 DAS***	
Marigold (trap crop): (T_1)	0.80	0.73 (1.11)	0.80 (1.14)	0.80 (1.14)	0.67	0.53 (1.02)	0.73 (1.11)	0.73 (1.11)	*0.72*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.67	0.73 (1.11)	0.60 (1.05)	0.60 (1.05)	0.67	0.67 (1.08)	0.73 (1.11)	0.67 (1.08)	*0.67*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.73	0.60 (1.05)	0.53 (1.02)	0.53 (1.02)	0.67	0.53 (1.02)	0.47 (0.98)	0.53 (1.02)	*0.53*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.80	0.67 (1.08)	0.53 (1.02)	0.47 (0.98)	0.73	0.53 (1.02)	0.53 (1.02)	0.60 (1.05)	*0.56*
Beauveria bassiana @ 1.5 ml/lt of water: (T_5)	0.80	0.80 (1.14)	0.87 (1.17)	0.73 (1.11)	0.67	0.67 (1.08)	0.73 (1.11)	0.67 (1.08)	*0.75*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.73	0.60 (1.05)	0.80 (1.14)	0.67 (1.08)	0.80	0.80 (1.14)	0.87 (1.17)	0.73 (1.11)	*0.75*
Untreated control: (T_0)	0.80	0.80 (1.14)	0.67 (1.08)	0.80 (1.14)	0.67	0.67 (1.08)	0.73 (1.11)	0.80 (1.14)	*0.75*
SEm±	*0.25*	*0.15*	*0.17*	*0.14*	*0.98*	*0.15*	*0.12*	*0.15*	-
CD (P=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values

NS: Non-significant at 5% level of significance

found safer to coccinellid beetles but mutineem a by product of neem proved as the safest of all and this result is in consistent with the findings of Gosalwad and Tikotkar (2016) and Agale *et al*. (2019). In addition, the entomopathogenic fungi, *Beauveria bassiana* which proved to be non toxic to coccinellids in the present investigation gets the support from Thungrabeab and Tongma (2007) and Sayed *et al.* (2021)

4.2.4. Abundance of spider in biopesticide treated tomato field

Six biopesticides were evaluated against spiders based on two sprays which are presented in Table 4.38 – 4.40 and illustrated in Figure 4.16. In the first experimental year (2019-2020), the total mean ranged from 0.53/15 plants to 0.75/15 plants, the lowest population was seen in emamectin benzoate 5% SG (T_3) (0.53/15 plants) and spinosad 45% SC (T_4) (0.56/15 plants) while the other treatments were almost at par with each other. For the second experimental year (2020-2021), the treatment marigold as trap crop (T_1) recorded the maximum mean population of 0.77 /15plant whereas, the least mean population of 0.55/15 plant each was recorded in emamectin benzoate 5% SG (T_3) and spinosad 45% SC (T_4). The pooled data (Table 4.40) during the both the year 2019-2020 and 2020-2021 on 1st and 2nd sprays at different days of spider population revealed that all treatments showed non-significant effect on the population of spider except on 7 DAS. For the first spray, the pre treatment population of spider ranged from 0.67 to 0.80 per fifteen plants. The data recorded at 3 DAS presents that the plots with marigold as trap crop (T_1) recorded the highest population of 0.83/15 plants whereas, the lowest population was observed in emamectin benzoate 5% SG (T_3) with 0.57/15 plants. The observation made at 5 DAS recorded, *Beauveria bassiana* (T_5) (0.83/15 plants) with the highest population and the lowest was observed in spinosad 45% SC (T_4) and emamectin benzoate 5% SG (T_2) (0.50/15 plants). At 7 DAS, the highest population of spider per fifteen plants was recorded in plots treated with marigold (0.83) and the lowest in spinosad 45% SC (0.47).

Table 4.40: Effect of different trap crop and biopesticides against spiders on tomato variety Sakata-914 during 2019-2020 and 2020-2021 (Pooled)

Treatments	*First spray*				*Second spray*				*Mean*
	Pre-treatment count	*Mean population of spiders over control/ 15 plants*			*Pre-treatment count*	*Mean population of spiders over control/ 15 plants*			
		3 DAS	*5 DAS*	*7 DAS*		*3 DAS*	*5 DAS*	*7 DAS*	
Marigold (trap crop): (T_1)	0.80	0.83 (1.15)	0.77 (1.12)	0.83 (1.15)	0.70	0.67 (1.07)	0.73 (1.10)	0.80 (1.14)	*0.77*
Multineem (0.03%) @ 3 ml/lt of water: (T_2)	0.67	0.67 (1.08)	0.67 (1.07)	0.67 (1.07)	0.73	0.77 (1.12)	0.67 (1.07)	0.70 (1.09)	*0.69*
Emamectin benzoate (5% SG) @ 0.3 g/lt of water: (T_3)	0.70	0.57 (1.03)	0.50 (1.00)	0.50 (0.99)	1.93	0.60 (1.04)	0.57 (1.03)	0.53 (1.01)	*0.55*
Spinosad 45% SC @ 0.5 ml/lt of water: (T_4)	0.80	0.63 (1.06)	0.50 (1.00)	0.47 (0.98)	0.77	0.57 (1.03)	0.53 (1.01)	0.57 (1.03)	*0.55*
Beauveria bassiana @ 1.5 ml/lt of water: (T_5)	0.77	0.80 (1.14)	0.83 (1.15)	0.77 (1.11)	0.70	0.70 (1.08)	0.70 (1.09)	0.73 (1.11)	*0.76*
Pongamia pinnata @ 3 ml/lt of water: (T_6)	0.70	0.63 (1.06)	0.77 (1.12)	0.73 (1.10)	0.77	0.80 (1.13)	0.77 (1.12)	0.70 (1.09)	*0.73*
Untreated control: (T_0)	0.80	0.83 (1.15)	0.80 (1.14)	0.80 (1.14)	0.73	0.73 (1.11)	0.67 (1.08)	0.73 (1.11)	*0.76*
SEm±	*0.41*	*0.10*	*0.09*	*0.10*	*0.49*	*0.13*	*0.09*	*0.11*	-
CD (P=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	-

Note: Figures in the table are mean values and those in parenthesis are square root transformed values
NS: Non-significant at 5% level of significance

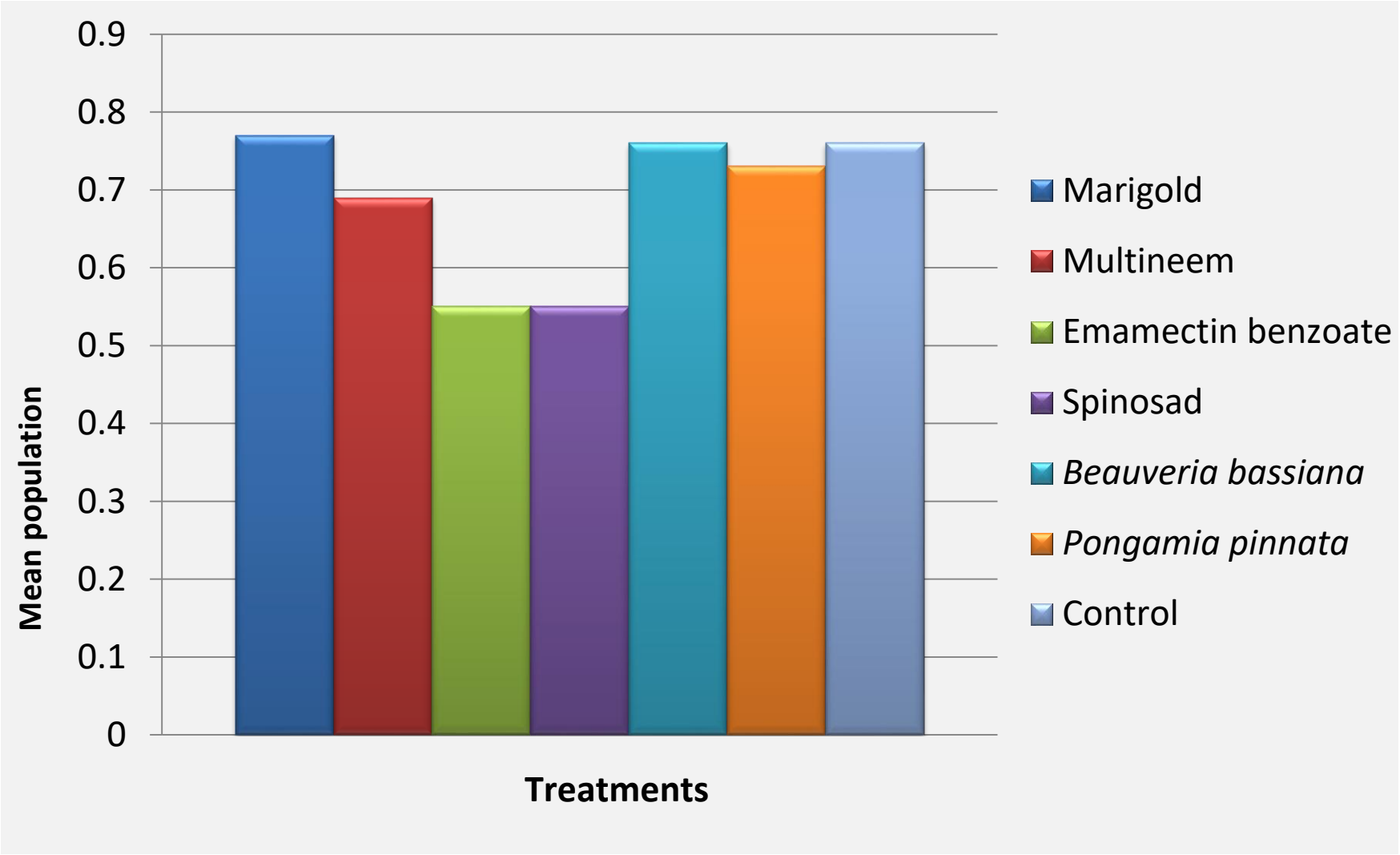


Fig **416 . Pooled data on the effect of biopesticides and trap crop against predatory spiders (natural enemy)on tomato variety Sakata-914**

The data from the second spray reveals that at 3 DAS, the plots treated with *Pongamia pinnata* (T_6) recorded the maximum population (0.80/15 plants) and the minimum observed in spinosad 45% SC (T_4) (0.57/15 plants). On the 5 DAS, data recorded highest in *Pongamia pinnata* (0.77/15 plants) while the lowest in spinosad 45% SC (0.53/15 plants). The spider population ranged from 0.57/15 plants (spinosad 45% SC) to 0.80/15 plants (marigold) at 7DAS. An added advantage of trap crop is that it can attract and conserve natural enemies of insect pests. These results are consistent with previous observations documented by Parolin *et al*. (2012), Parker *et al*. (2013) and Naranjo *et al*. (2015). The overall mean data of spider population per fifteen plants was observed maximum in marigold (T_1) (0.77) followed by *Beauveria bassiana* (T_5) (0.76), *Pongamia pinnata* (T_6) (0.73), multineem (T_2) (0.69) and the minimum population was recorded in spinosad 45% SC (T_4) (0.55) and emamectin benzoate 5% SG (T_3) (0.55). Biopesticides when compared with insecticides offer a better alternative and are least damaging to spider population, however mortality of spinosad 45% SC treated plots was significantly the highest among other biopesticides (Ahmad *et al*. 2015). In a similar research conducted by Gaikwad *et al*. (2020) on the efficacy of different biopesticides against spider concluded that emamectin benzoate 5 SG and thiamethoxam 25 WG recorded the lowest spider population which is in line with our findings. In another finding by Kumar (2021), documented the effect of insecticides spray on the field population of predators and observed emamectin benzoate 5% SG caused 55.74 to 65.99% reduction in predators population over pre-treatment spray.

4.3. Molecular characterization of major insect pests and their natural enemies in tomato

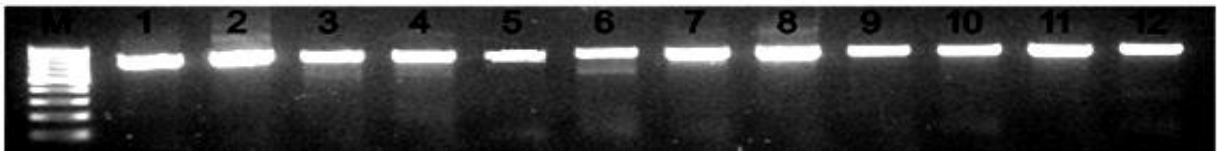
In the present investigation attempts were made to develop DNA barcodes using partial COI gene of mtDNA for a total of seven insect species involving pest species and natural enemies in tomato ecosystem.

4.3.1 Extraction of DNA (Deoxyribonucleic acid) from insect

DNA was successfully extracted from either single leg or antennae (in case of large insect) and whole insect (in case of small insects) following phenol:chloroform protocol which generated sufficient quality and quantity of DNA for all the specimens. DNA was extracted from multiple specimens of collected insect species and to avoid cross contamination, a blank control was kept for all the batches of DNA extraction.

4.3.2. PCR amplification of COI gene

By employing standard DNA barcoding primers LCO & HCO and LepF1 &LepR1 multiple specimens of all seven species were successfully amplified. The barcoding primers were designed to amplify partial COI gene which targeted 709bp DNA fragment. The targeted 709bp PCR fragment was successfully amplified for all the collected specimens. Irrespective of the insect order, no variation at band size was detected. Amplified PCR fragments were detected by gel electrophoresis on 1.5% agarose gel. The representative gel picture of amplification of the seven different insect species is presented in (Plate 11). DNA extraction and PCR amplification was carried out in different batches on different dates. To eliminate the chances of contamination during PCR amplification, for every batch of PCR amplification, one negative control was used. There was no contamination observed in all the batches of PCR amplification.



NB: M=100bp ladder; Lane 1 to 12:

1-2) *Chrysodeisix eriosoma;* 3-4) *Coccinellid transversalis;* 5-6) *Glyptapanteles*sp.; 7-8) *Coccinella septempunctata*; 9-10) *Aphis spiraecola*; 11-12) *Helicoverpa armigera*

Plate 11. PCR amplification of insect species using LCO and HCO primers on 1.5% agarose gel

4.3.3. Sequencing of partial PCR fragment of COI gene

Two specimens were sequenced for each species using the standard barcoding primers (i.e. LCO & HCO and LepF1 & LepR1). The Sanger sequencing of all the samples was done commercially by sending 40µl of post PCR product in frozen condition to M/S Eurofins Genomics India Pvt. Ltd, Bangalore. For accuracy purpose, sequencing was carried out bi-directionally (from both the ends 5' and 3') for all the samples. The samples which gave poor quality sequence due to degradation of post PCR product or excess quantity of DNA, the re-sequencing of such samples were carried out. From the total seven species, good quality sequence were obtained from six species but one1 species *viz*., *Oxyopes* sp. resulted in poor quality sequence. Re-sequencing attempts were made for obtaining good quality sequences but all the times attempts were unsuccessful, it might be due the degradation of PCR products during transportation or mutations at primer binding sites or technical errors by service providers (m/s Eurofins Genomics India Pvt. Ltd, Bangalore).

4.3.4. Sequencing analysis

After the DNA samples were successfully sequenced, sequence analysis was carried out utilizing the Pregap and Gap program within the software Staden Package (Staden *et al*., 2000). The sequencing analysis was carried out individually for each species and to obtain error free result, sequences were checked manually within the software. The messy/ambiguous 5' and 3' end of the sequences were trimmed to obtain good quality sequence. The longest good quality partial COI sequence length was obtained in *Helicoverpa armigera* (675bp) and the shortest sequence length was obtained in *Coccinella septempunctata*(621bp) (Table 4.42).

4.3.5. Blast analysis

The analysed sequences were subjected to BLASTN search on online portal of National Centre for Biotechnology Information (NCBI: http://www.ncbi .nlm.nih.gov/). The correct identity and homologous species were establishedby comparing with a library or database of sequences that resembles

the sequence. All the sequences were analysed individually by nucleotide blast search at NCBI portal and the first three hits were recorded (Table 4.41). The blast results with 99-100% homology to NCBI database were considered as similar species and molecular identity of the test species was confirmed without any ambiguities as there were sequences which shown more than 99% similarities with our sequences at NCBI.

4.3.6. Submission of sequences to NCBI

The final analysed sequences were submitted to National Centre for Biotechnology Information (NCBI) for accession numbers. The accession numbers were obtained for the representative partial COI gene sequence of six identified species *viz*., ON460288, ON460289, ON461368, ON461370, ON489304 and ON496461. The nucleotide length, protein length along with NCBI accession numbers are presented in (Table 4.42).

4.3.7. Development of DNA barcodes

The DNA barcode images for all nucleotide sequences submitted to NCBI were developed using web based software or App http://biorad-ads.com/DNABarcodeWeb/ of *BIO-RAD* (Plate 13). The DNA barcode generator allows creating a barcode in color — each line of the barcode represents a particular base pair: green = adenine, blue = cytosine, black = guanine, red = thymine.

Table 4.41. Top three NCBI BLASTN search results for insect pest and natural enemy of tomato as on 3.05.2022

Sl. no	Insect name	Insect	Max score	Total score	Query cover	E value	Ident.	Accession no
1	Green garden looper	*C. eriosoma*	1216	100%	0.0	100.00%	658	HQ991180.1
		C. eriosoma	1210	100%	0.0	99.85%	658	HQ990831.1
		C.eriosoma	1210	100%	0.0	99.85%	658	HQ990830.1
2	Transverse ladybird	*C.transversalis*	1210	100%	0.0	99.85%	658	KY838208.1
		C. transversalis	1205	99%	0.0	99.85%	659	KT693133.1
		C.transversalis	1199	100%	0.0	99.54%	658	MH187251.1
3	Seven spot ladybird	*C.septempunctata*	1147	100%	0.0	100.00%	621	MH020505.1
		C.septempunctata	1142	99%	0.0	100.00%	650	KM845410.1
		Coccinella sp.	1142	99%	0.0	100.00%	655	MZ630085.1
4	Green peach aphid	*A. spiraecola*	1160	100%	0.0	99.53%	709	MT445577.1
		A. spiraecola	1160	100%	0.0	99.53%	709	MT445576.1
		A.spiraecola	1160	100%	0.0	99.53%	709	MT445575.1
5	Parasitic wasps	*Microgastrinae sp.*	1210	100%	0.0	99.85%	658	HM430512.1
		Microgastrinae sp.	1157	95%	0.0	99.84%	629	HQ941809.1
		Glyptapanteles sp	1127	100%	0.0	97.57%	658	MH138746.1
6.	Tomato fruit borer	*H. armigera*	1247	100%	0.0	100.00%	680	KX351388.1
		H.armigera	1247	100%	0.0	100.00%	680	OK524002.1
		H. armigera	1247	100%	0.0	100.00%	675	JX532104.1

Table 4.42. List of identified species along with nucleotide length, protein length and NCBI accession number

Common Name	Scientific name	Nucleotide sequence length (bp)	Protein Sequence	NCBI Accession number
Green garden looper	*Chrysodeixis eriosoma*	658	219	ON460288
Transverse ladybird	*Coccinella transversalis*	658	219	ON460289
Seven spot ladybird	*Coccinella septempunctata*	621	207	ON461368
Green citrus aphid	*Aphis spiraecola*	637	212	ON461370
Parasitic wasps	Glyptapanteles sp.	658	219	ON489304
Tomato fruit borer	*Helicoverpa armigera*	675	225	ON496461

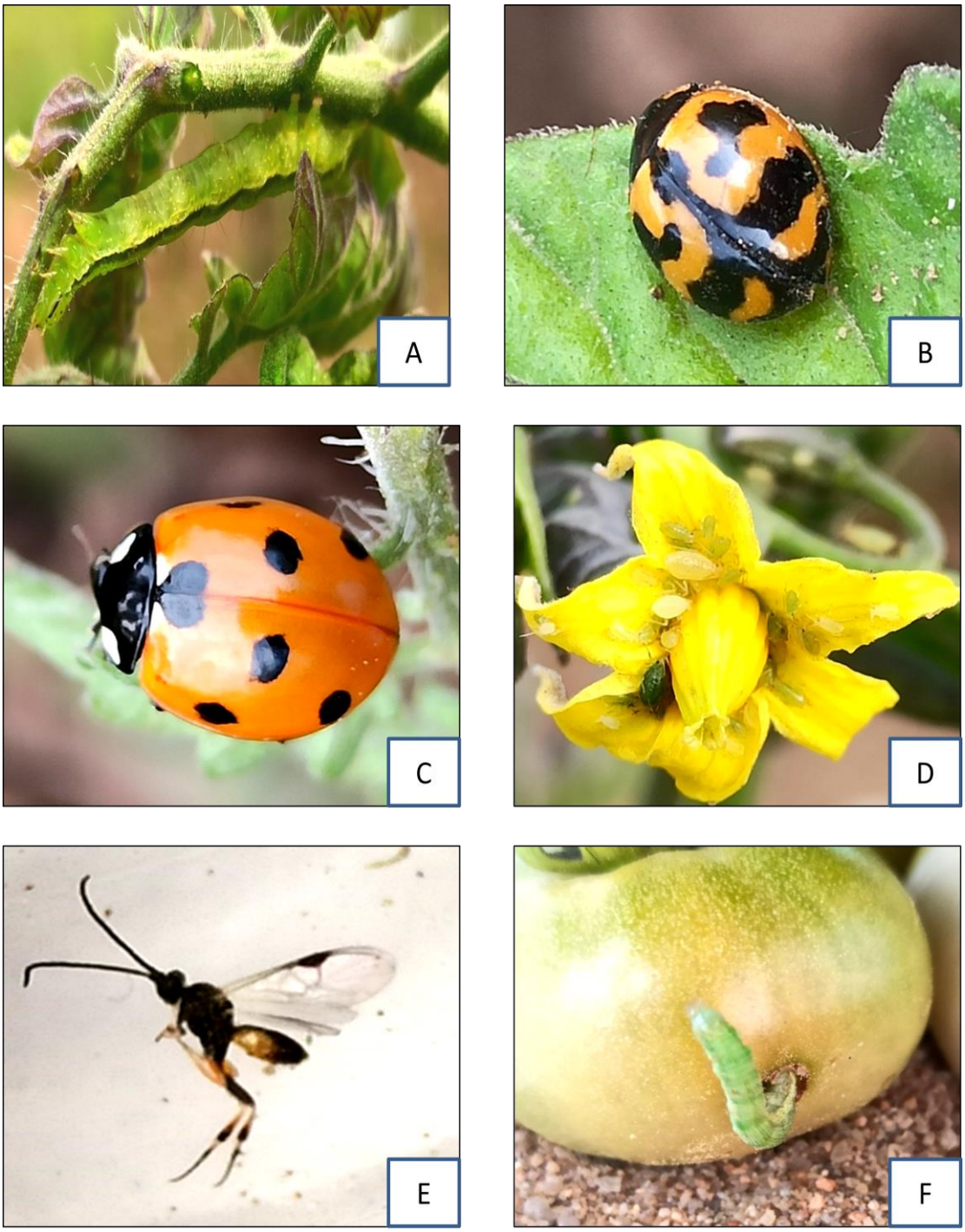
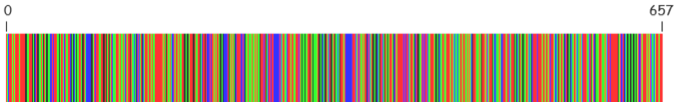
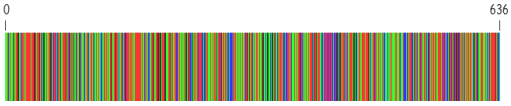


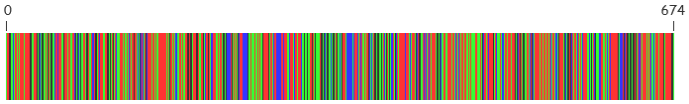
Plate 12. A) ***Chrysodeixis eriosoma;*** **B)** ***Coccinellid transversalis;*** **C)** ***Coccinella septempunctata;***
D) ***Aphis spiraecola;*** **E)*Glyptapanteles sp.;***
F)*Helicoverpa armigera.*



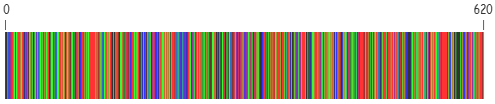
1. *Chrysodeixis eriosoma*



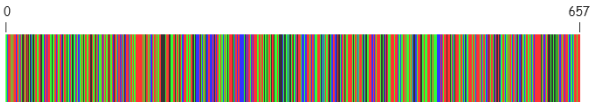
2. *Aphis spiraecola*



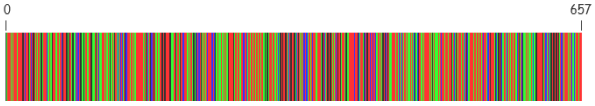
3. *Helicoverpa armigera*



4. *Coccinella septempunctata*



5. *Coccinella transversalis*



6. *Glyptapanteles* sp

Plate 13. Translated image of nucleotide sequences of some insect pests and natural enemies recorded in tomato ecosystem

Establishment of correct identity of target insect pest is a prerequisite for undertaking any control measures in integrated management because, misidentifications could lead to ineffective control and may potentially increase the impact caused by a particular pest species (Rivera and Currie, 2009). Morphological data are usually time consuming and with the dwindling number of taxonomists and other identification experts (Jinbo *et al*. 2011), cytochrome oxidase I (COI) based technique has provided an alternative practical method of species identification of insects and can be used for the identification of all developmental stages of insects, their food webs and biotypes which may not be possible with morphology-based taxonomy (Srinivasan *et al.* 2013, Jalali *et al*., 2015). This holds true as the insect pest *Aphis crassivora* and *C. eriosoma* identified in this research through COI based barcodingwere performed with the nymphal and larval stage of the insect, respectively. Extraction and PCR amplification of DNA and subsequent sequencing presented no challenge. With the advanacement of science, it is now possible to carry out the DNA work evry quickly and reliably with minimum technical skill.

DNA barcodingon insect pests of agricultural importance has lead to identifying cryptic and potentially new species (Seifert *et al*., 2007; Vaglia *et al*., 2008; Burns *et al*., 2008). In current investigation, the insect species *A. crassivora, C. eriosoma* and *Glyptapanteles* sp. observed in tomato ecosystem has not been reported previously from Nagaland.Likewisemany new invasive insect pest species have been reported from India as well as from northeast India and has facilitated in establishing the correct identity of insect pest species. South American tomato pinworm (*Tuta absoluta*) has successfully invaded into India and was reported for the first time in 2014 in Maharashtra and the pest was detected and identified using DNA barcoding in Meghalaya in 2017 (Sankarganesh *et al*., 2017). Simlarly, invasive tomato leaf miner *Liriomyza sativae* was also detected and identified by DNA barcoding from

North East India in 2017 (Firake *et al*., 2017). Furthermore past experiences of DNA barcoding was found to be very successful in identifying invasive and other taxonomically difficult insect species. For example Behere *et al.* (2007) used DNA barcoding for studying the global genetic diversity of *H. armigera*, diversity of fruit flies (Manger, 2015), pest of cereal crops (Kuotsu, 2016), pest of solanaceous crops (Sankarganesh, 2017) and pest of cucurbitaceous crops (Pongen, 2018). Comprehensive molecular information on insect species is still very limited in India as it has generated a total of only 3,694 barcodes of known species with its contrast to an approximate of 59,000 described insect species. On the other hand the corresponding global scenario global scenario is about 1, 63,617 barcodes of described species, therefore a lot of emphasis is required to catch up with the world scenario (IBIn, 2022). DNA barcoding technique used in the present investigation has appeared very useful in correct identification of insect pests and natural enemies in tomato ecosystem. Over the last decade this technique has proven to be an authentic and efficient tool achieving species level resolution in 95 % to 97% of cases (Hebert et al., 2004; Ward et al., 2005). The comprehensive data on DNA barcodes generated in this study would certainly help as a diagnostic guide for identification and designing of better management strategies for the management of insect pests of tomato.

CHAPTER V
SUMMARY AND CONCLUSION

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The present research investigation entitled "Integrated Pest Management and Molecular Characterization of Major Insect Pests of Tomato (*Solanumlycopersicum*L.)" was carried out at the experimental cum research farm of School of Agricultural Sciences and Rural Development, Nagaland, University, Medziphema campus, while the laboratory work was conducted in the Molecular Entomology Laboratory, Division of Crop Protection of ICAR Research Complex for North Eastern Hills (NEH) Region, Umiam, Meghalaya. The research was commenced under three objectives with the aim to bring about genuine results; the salient findings of which are summarized below:

- Three major insect pests of tomato was collected, identified and documented during the year 2019-2020 and 2020-2021and these were *Aphis spiraecola, Chrysodeixis eriosoma* and *Helicoverpa armigera.*
- The highest incidence of *A. spiraecola* recorded for both years of experiment (2019-20 and 2020-21) was at 120 DAT D_3 while the lowest population at 45 DAT in D_1. The finding also reveals that the aphid population persisted throughout the season in an increasing trend.
- In both the years of experimental trials (2019-2020 and 2020-2021), local cultivar registered the lowest mean population while the highest was recorded in the variety Pusa Rohini.
- The highest incidence of *C.eriosoma* recorded during the year 2019-20 was at 45 DAT in D1, while the lowest pest incidence was recorded at 135 DAT (D2). Whereas for the year 2020-2021, the highest incidence was observed at 45 DAT in D1 and D2 respectively while the lowest pest incidence was recorded on 135 DAT in D2

- Presence of an endoparasitoid wasp, *Glyptapanteles* sp. was present in the field actively parasitizing the larva of *C.eriosoma*.
- The influence of variety Sakata-914 (V4) was found to be more susceptible to *C. eriosoma* during the first experimental year while Pusa Rohini (V1) had maximum pest incidence during the second year. Throughout the crop growth in both experimental years, significantly low population of this pest was recorded on Pusa Sheetal (V2), while the least number of *C.eriosoma* populations was found on the Local cultivar.
- Limited literature is found for *C. eriosoma* infesting tomato crop in India and North east India. Hence this research will be the first of its kind and also the first time report of *C.eriosoma* from Nagaland.
- The data on the incidence of tomato fruit borer, *H. armigera*reveals that planting date had significant effect on the incidence of *H.armigera* in both years. The collected data from the year 2019-2020 reveals that the incidence of tomato fruit borer, *H. armigera*was recorded from 75 DAT in D1, 75 DAT in D2 and 90 DAT in D3 planting date.
- The present findings reveal that the insect pest was found to be higher at fruit maturing stage till the final harvest of the crop fruit.
- In both years of experimental trial (2019-20 and 2020-21) the maximum fruit infestation was recorded at 120 DAT in D2 and the minimum fruit infestation was observed at 75 DAT in D2.
- Tomato fruit borer *H. armigera* had significant effect on all tomato varieties under study throughout the study period. The variety Sakata-914 (V4) at 120 DAT was found to be more susceptible to *H. armigera* for both years of trials whereas the lowest was recorded in Local cultivar.

- Three major natural enemies was collected, identified and documented in tomato ecosystem during the year 2019-2020 and 2020-2021 i.e. coccinellids, parasitic waspand predatory spider.
- The coccinellid population was recorded highest at D3 (120 DAT) in both the research period whereas the lowest population was recorded during the initial period i.e., 45 DAT in D1.
- The variety Sakata-914 recorded the highest mean population of coccinellids in the first research period but for the second research period, the variety Rocky recorded the highest population whereas accounting the lowest population was in Local cultivar for both research trials.
- High rate of parasitism by parasitic wasp *Glyptapanteles sp* was observed at 60 DAT in D1 during the first year of experimental period likewise parasitism rate was recorded the highest at 75 DAT in D2 for the second research period whereas, the lowest was observed at 120 DAT in D2 and 45 DAT in D1 during 2019-2020 and 2020-2021 respectively.
- In both experimental years, *Glyptapanteles* sp. (Hymenoptera: Braconidae) was observed in field conditions actively parasitizing on *C.eriosoma* (Lepidoptera: Noctuidae) and thus effectively managing the pest (*C.eriosoma*) population in tomato ecosystem resulting in zero rate of parasitism in some dates of observation due to absence of host (*C.eriosoma*).
- In the field observation, larval parasitism of *C.eriosoma* by *Glyptapantele* sp. was recorded highest in Pusa Rohini foe both research periods. On the contrary, the lowest rate of parasitism was observed in Rocky and Pusa Rohini during the research period 20219-2020 and 2020-2021 respectively.

- It was observed that varieties infested with high density of host larvae attracted more parasitoids in the field.
- The highest incidence of spider population for the first research period was observed at 60 DAT in D3 while the lowest population was recorded at 45 DAT in D1. Whereas for second research period, the highest spider population was recorded on 105 DAT in D3 and lowest number of spider was recorded on 45 DAT in D1.
- According to the data analysis, the variety Pusa Rohini (V1) and Sakata-914 (V4) had the highest incidence of spider recorded while Local cultivar recorded the lowest incidence of spider in both experimental years.
- Six biopesticides viz. Marigold *Pusa Narangi* (T_1), Multineem 0.03% (T_2), Emamectin benzoate 5% SG (T_3), Spinosad 45% SC (T_4), *Beauveria bassiana* (T_5)and *Pongamia pinnata* (T_6) were evaluated against major insect pests viz. *Aphis spiraecola* and *Helicoverpa armigera* and its impact on natural enemy viz. coccinellids, *Glyptapanteles* sp. and spiders in tomato during the experimental trial (2019-2020 and 2020-2021).
- Throughout the entire investigation periods, it was found that the plots treated with emamectin benzoate 5% SG (T_3) and multineem (T_2) were found to give the highest reduction of *A. spiraecola* whereas, marigold as trap crop (T_1) showed little to no reduction in most of the plots.
- Results on the efficacy of different insecticides against *H. armigera* infestation have revealed that emamectin benzoate (T_3) and spinosad 45% SC (T_4) was recorded significantly superior and also all treatments under study showed significant reduction over control.
- The data recorded during the both the experimental year 2019-2020 and 2020-2021 on natural enemy population after 1st and 2nd sprays at different days of observation revealed that there was very little

difference among all treatments and also no treatment under study showed significant effect on the natural enemies population.

- The overall data of coccinellid population per fifteen plants was observed highest in multineem and *Beauveria bassiana* followed by Trap crop marigold, *Pongamia pinnata* and emamectin benzoate 5% SG and the least population was recorded in spinosad 45% SC.
- The overall data of spider population per fifteen plants was observed maximum in marigold (T_1) followed by *Beauveria bassiana* (T_5), *Pongamia pinnata* (T_6), emamectin benzoate 5% SG (T_3) and the minimum population was recorded in spinosad 45% SC (T_4) and multineem (T_2).
- DNA was successfully extracted from multiple specimens of 6 insect species and the final good quality nucleotide sequence length of partial COI gene varied from 621 - 675bp across the species.
- From the total 7 species, good quality sequence were obtained from 6 species but 1 species *viz., Oxyopes sp* resulted in poor sequence.
- All the sequences have been deposited to International GenBank (NCBI) with accession numbers ON460288,ON460289, ON461368, ON461370, ON489304 and ON496461.
- This study has generated DNA barcodes for 6 insect species
- The major insect pest *A. spiraecola* and *C. eriosoma* is reported for the first time infesting in tomato from Nagaland.
- The minor pests observed during the study period were Flea beetle (*Arthrotus flavocincta*), *Leafminer* (*Liriomyza trifolii*)and Tobacco cutworm (*Spodoptera litura*)
- The other natural enemies observed during the study period were parasitic wasp (*Charops annulipes*), Green lacewing (*Chrysoperla carnea*)and parasitic wasp (*Copidosoma sp.*)

Future thrusts:

- The use of insecticides has become indispensable because of its rapid effect, ease of application and availability. The chemical insecticides significantly curtailed the insect pests in the past but in due course it resulted in the development of resistance to insecticides in insects, environmental degradation and increase in the cost of cultivation. Inorder to combat such situations IPM must rapidly incorporate new technologies such as use resistant varieties, GMOs and precision agricultural tools into evolving pest management systems.
- The North Eastern region of India comprises of eight states namely Arunachal Pradesh, Assam, Manipur, Meghalaya,Mizoram, Nagaland, Tripura and Sikkim. It is considered as one of the biodiversity hot spots, and the climatic conditions of NE India are highly favourable for reproduction and development of insect species. Uniqueness about the NE region is, it shares international borders with five different countries and therefore trans-boundary insect migration is inevitable. Most of these borders are porous and the quarantine set up is almost poorly maintained. Thus the use of mtDNA, represents at present, a valuable addition or alternative to the classical methods of species identification especially when morphological approach is difficult or even impossible.
- It is said that around 98% of the insects pests are regulated naturally through natural enemies. Hence it is of outmost importance to conserve these biocontrol agents inorder to reduce the hazards caused by toxic insecticides. Classical biological control and use of predators and parasitoids is very well known and have high success rate. Similarly new trends such as hybrids of parasites, use of novel entomogenous fungi, viruses are to yet to be exploited. Lastly, more

emphasis on the conservation of these natural enemies should be incorporated in schools, universities and in the famers field.

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fungi, viruses needs to be exploited. The incorporation of biopesticides which are less toxic to the environment and pose no danger to natural enemies needs to be identified and employed in pest control suppression. Lastly, more emphasis on the conservation of natural enemies should be incorporated in schools, universities and in the farmer's field.

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APPENDICES

APPENDIX-A

Nucleotide sequences of six insect species with NCBI Accession Number

1. *Chrysodeixis eriosoma*

NCBI Accession no. ON460288

TACTTTATATTTTATTTTTGGAATTTGAGCTGGAATAGTAGGAACCT
CTTTAAGATTACTAATTCGAGCAGAATTAGGTACCCCCGGATCTTTAATT
GGTGATGATCAAATTTATAATACTATTGTAACAGCTCATGCATTTATTAT
AATTTTTTTTATAGTAATACCTATTATAATTGGAGGATTTGGTAATTGAC
TTGTCCCTCTTATATTAGGAGCCCCTGATATAGCTTTTCCTCGAATAAAT
AATATAAGTTTCTGACTTCTTCCCCCCTCATTAACTTTATTAATTTCTAGA
AGAATTGTAGAAAATGGAGCAGGTACTGGATGAACAGTTTATCCCCCCC
TTTCATCTAATATTGCTCATGGAGGCAGTTCAGTAGATTTAGCTATTTTTT
CTCTTCATTTAGCTGGAATCTCTTCAATTTTAGGAGCAATTAATTTTATTA
CAACAATTATTAATATACGTTTAAATAGTTTATCATTTGACCAAATACCT
TTATTCATTTGAGCAGTAGGAATTACAGCTTTTCTTTTATTATTATCTTTA
CCAGTATTAGCTGGAGCAATTACAATACTTTTAACTGATCGAAATTTAAA
TACTTCTTTTTTTGATCCTGCAGGAGGAGGAGATCCTATTTTATATCAAC
ATTTATTT

2. *Coccinella transversalis*

NCBI Accession no. ON460289

AACTTTATATTTCTTACTAGGTATGTGAGCAGGATTAATTGGAACT
TCTTTAAGAATTCTAATTCGATTAGAACTAGGAACTACCAATAGATTAAT
TGGTAATGATCAAATCTATAATGTAATCGTTACTTCTCATGCTTTCATTA
TAATTTTTTTTATAGTTATACCTATTATAATTGGGGGATTTGGAAATTGA
TTAGTACCTTTAATAATTGGAGCCCCTGACATAGCCTTCCCTCGTCTTAA
TAACATAAGATTTTGACTTCTTCCCCCAGCTCTTACTCTTTTAATTATTAG
AAGATTAGTTGAAATAGGGGCAGGAACAGGATGAACTGTTTACCCACCT
TTATCTTCAAATTTAGCACATAATGGACCTTCCGTGGACTTAGTAATTTT
TAGATTACATTTAGCAGGAATTTCCTCTATTTTAGGAGCTGTAAATTTTA
TTTCAACAATTATAAATATACGGCCATTTGGAATAAATTTAGATAAAAC
CCCTCTATTTGTTTGATCAGTTTTAATTACAGCAATTTTATTACTTTTATC
ATTACCTGTATTAGCTGGTGCAATTACAATATTACTTACTGACCGTAACA
TTAATACATCTTTTTTTGATCCTATGGGAGGAGGAGATCCTATTCTTTAC
CAACATTTATTT

3. Glyptapanteles sp.

NCBI Accession no. ON489304

GATTTTATATTTTATTTTTGGTCTTTGATCTGGTATATTAGGATTTTC
AATAAGTTTAATTATTCGTTTGGAGTTAGGAACTCCTGGAAGATTAATTG
GAAATGATCAAATTTATAATAGAATAGTTACATCTCATGCCTTTATTATA
ATTTTTTTTATAGTCATGCCTGTAATAATTGGTGGTTTTGGAAATTGATTA
GTTCCTTTAATATTAGGAGCTCCTGATATATCTTTTCCTCGAATAAATAA
TATAAGTTTTTGATTATTAATTCCTTCATTATTATTATTATTAAGAGG
ATTTATTAATACAGGTGTTGGTACTGGTTGGACTGTATATCCTCCATTAT
CTTTAATTTTAGGTCATGGTGGTATATCTGTTGATTTAGGAATTTTTTCTT

TGCATTTAGCTGGTTCTTCTTCAATTATAGGTGCTGTAAATTTTATTACTA
CTATTATAAATATACGAACGTTAATATTTTTTATAGATAAAATATCTTTA
TTTATTTGATCAGTATTTATTACTGCAATTTTATTATTATTATCTTTACCT
GTTTTAGCAGGTGCAATTACTATATTATTAACTGATCGAAATATAAATAC
AAGGTTTTTTGATCCATCAGGTGGTGGTGATCCTATTTTATATCAACATT
TATTT

4. *Aphis spiraecola*
NCBI Accession no. ON461370

AAATCATAAAGATATTGGAACTTTATATTTTTTATTTGGTATTTGAT
CAGGAATAATTGGATCTTCACTTAGAATTTTGATTCGATTAGAACTAAGT
CAAATCAATTCAATTATCAATAATAACCAATTATATAATGTAATTGTTAC
AATTCATGCTTTTATTATAATTTTTTTTATAACTATACCAATTGTAATTGG
TGGATTTGGAAATTGATTAATTCCTATAATAATAGGATGTCCAGATATAT
CTTTTCCACGATTAAATAATATTAGATTCTGATTATTACCACCCTCATTA
ATAATAATAATCTGTAGATTCATAATTAATAATGGAACAGGAACAGGAT
GAACTATTTATCCACCTTTATCAAATAATATTGCTCATAATAATATTTCA
GTTGATTTAACCATCTTCTCTCTTCACCTGGCAGGTATTTCATCAATTTTA
GGAGCAATTAATTTTATTTGTACAATTCTTAATATAATACCAAACAATAT
AAAATTAAATCAAATCCCACTATTTCCATGATCAATCTTAATTACAGCTA
TATTATTAATTTTATCTCTACCAGTTCTAGCTGGTGCTATTACTATATTAT
TAACTGATCGAAATTTAAATACATCATTTTTTGATCCA

5. *Coccinella septempunctata*
NCBI Accession no. ON461368

GGGACCTCTTTAAGAATTTTAATTCGTCTTGAATTAGGAACTACTA
ATAGATTAATTGGAAATGACCAAATTTATAATGTAATTGTAACAGCTCA
TGCCTTCATTATAATTTTTTTTATAGTTATACCAATTATAATTGGAGGATT
TGGAAATTGACTTGTTCCTTTAATAATTGGAGCACCTGACATAGCTTTCC
CTCGATTAAATAATATAAGATTTTGACTACTCCCACCTGCCTTAACCTTA
CTTATTATTAGAAGATTAGTGGAAATAGGTGCAGGAACTGGATGAACTG
TCTATCCTCCTTTATCCTCTAACTTAGCTCATAATGGGCCTTCAGTAGATT
TAGTAATTTTTAGTTTACACTTAGCAGGTATCTCATCTATTTTAGGAGCC
GTAAATTTTATTTCAACTATTATAAATATACGACCATTTGGCATAAACCT
TGATAAGACACCTCTTTTTGTATGATCAGTACTAATTACTGCTATTTTACT
TTTATTATCATTACCTGTATTAGCCGGGGCAATTACAATATTATTAACAG
ATCGTAATATTAATACTTCTTTTTTTGATCCAATAGGAGGGGGAGATCCC
ATCCTTTATCAACATTTATTTTGA

6. *Helicoverpa armigera*
NCBI Accession no. ON496461

ATTGGAACATTATATTTTATTTTTGGAATTTGAGCAGGAATAGTAGG
AACTTCTTTAAGTTTATTAATTCGAGCAGAATTAGGTAATCCTGGATCTT
TAATTGGAGATGATCAAATTTATAATACTATTGTTACAGCTCATGCTTTT
ATTATAATTTTTTTTATAGTTATACCAATTATAATTGGTGGATTTGGTAAT
TGACTTGTACCTTTAATATTAGGAGCCCCTGATATAGCTTTCCCCCGAAT

AAATAATATAAGTTTTTGATTACTTCCCCCTTCTTTAACTTTACTTATTTC
AAGAAGAATTGTAGAAAATGGAGCAGGAACAGGATGAACAGTTTACCC
CCCACTTTCATCTAATATTGCACATGGAGGAAGATCAGTAGACCTAGCT
ATTTTTTCTTTACATTTAGCTGGAATCTCATCTATTTTAGGAGCAATTAAT
TTTATTACTACTATTATTAATATAAAATTAAATAGCTTATCTTTTGATCAA
ATACCATTATTTATTTGAGCTGTAGGAATTACTGCATTTTTATTATTATTA
TCATTACCAGTTTTAGCAGGTGCTATTACTATACTTTTAACAGATCGAAA
CCTTAATACATCTTTTTTTGACCCTGCTGGAGGAGGTGATCCTATTTTAT
ATCAACATTTATTTTGATTTTTTGGA

APPENDIX-B

Protein sequences of six insect species

1. *Chrysodeixis eriosoma*

TLYFIFGIWAGMVGTSLSLLIRAELGTPGSLIGDDQIYNTIVTAHAFIMIFF
MVMPIMIGGFGNWLVPLMLGAPDMAFPRMNNMSFWLLPPSLTLLISSSIV
ENGAGTGWTVYPPLSSNIAHGGSSVDLAIFSLHLAGISSILGAINFITTIINMR
LNSLSFDQMPLFIWAVGITAFLLLLSLPVLAGAITMLLTDRNLNTSFFDPAG
GGDPILYQHLF

2. *Coccinella transversalis*

TLYFLLGMWAGLIGTSLSILIRLELGTTNSLIGNDQIYNVIVTSHAFIMIFF
MVMPIMIGGFGNWLVPLMIGAPDMAFPRLNNMSFWLLPPALTLLIISSLVE
MGAGTGWTVYPPLSSNLAHNGPSVDLVIFSLHLAGISSILGAVNFISTIMN
MRPFGMNLDKTPLFVWSVLITAILLLLSLPVLAGAITMLLTDRNINTSFFDP
MGGGDPILYQHLF

3. *Glyptapanteles* sp.

ILYFIFGLWSGMLGFSMSLIIRLELGTPGSLIGNDQIYNSMVTSHAFIMIFF
MVMPVMIGGFGNWLVPLMLGAPDMSFPRMNNMSFWLLIPSLLLLLLSGF
NTGVGTGWTVYPPLSLILGHGGMSVDLGIFSLHLAGSSSIMGAVNFITTIM
NMRTLMFFMDKMSLFIWSVFITAILLLLSLPVLAGAITMLLTDRNMNTSFF
DPSGGGDPILYQHLF

4.*Aphis spiraecola*

NHKDIGTLYFLFGIWSGMIGSSLSILIRLELSQINSIINNNQLYNVIVTIHAFI
MIFFMTMPIVIGGFGNWLIPMMMGCPDMSFPRLNNISFWLLPPSLMMMICS
FMINNGTGTGWTIYPPLSNNIAHNNISVDLTIFSLHLAGISSILGAINFICTILN
MMPNNMKLNQIPLFPWSILITAMLLILSLPVLAGAITMLLTDRNLNTSFFDP

5. *Coccinella septempunctata*

GTSLSILIRLELGTTNSLIGNDQIYNVIVTAHAFIMIFFMVMPIMIGGFGNW
LVPLMIGAPDMAFPRLNNMSFWLLPPALTLLIISSLVEMGAGTGWTVYPPL
SSNLAHNGPSVDLVIFSLHLAGISSILGAVNFISTIMNMRPFGMNLDKTPLF
VWSVLITAILLLLSLPVLAGAITMLLTDRNINTSFFDPMGGGDPILYQHLFW

6. *Helicoverpa armigera*

IGTLYFIFGIWAGMVGTSLSLLIRAELGNPGSLIGDDQIYNTIVTAHAFIMIFF
MVMPIMIGGFGNWLVPLMLGAPDMAFPRMNNMSFWLLPPSLTLLISSSIVE
NGAGTGWTVYPPLSSNIAHGGSSVDLAIFSLHLAGISSILGAINFITTIINMKL
NSLSFDQMPLFIWAVGITAFLLLLSLPVLAGAITMLLTDRNLNTSFFDPAGG
GDPILYQHLFWFFG