POPULATION DYNAMICS AND MANAGEMENT OF INSECT PESTS OF CHILLI

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
ENTOMOLOGY
(Minor Subject: Plant Pathology)

By

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(L-2012-A-37-M)

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This is to certify that the thesis entitled**, "Population Dynamics and Management of Insect Pests of Chilli"** submitted for the degree of **Master of Science**, in the subject of **Entomology** (Minor subject: **Plant Pathology**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Gurlaz Kaur (L-2012-A-37-M)** under my supervision and that no part of this thesis/dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, **"Population Dynamics and Management of Insect Pests of Chilli"** submitted by **Gurlaz Kaur (L-2012-A-37-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science**, in the subject of **Entomology** (Minor subject: **Plant Pathology**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same, in collaboration with an external examiner.

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ACKNOWLEDGEMENTS

First of all I bow my head in reverence to the Almighty God, the most omnipotent, omnipresent, benevolent and merciful for blessing me with the strength and courage to accomplish this task. Indeed the words to my command are not adequate either in form or in spirit to convey depth of feelings of gratitude to my advisor ***Dr. K S Sangha****, Entomologist, Punjab Agricultural University, Ludhiana for suggesting the problem, valuable guidance, incessant encouragement, constructive criticism, expedient advise, greater care, affection during the course of study and preparation of this manuscript. I express my deep sense of gratitude with highest veneration to him for giving me the opportunity to work under his guidance.*

I take deep pleasure in acknowledging ***Dr. Koushik Mandal****, Asstt. Residue Analyst for providing help with the residue analysis of insecticides. I deem it a privilege to express my gratitude to* ***Dr. D. R. Sharma****, Senior Entomologist,* ***Dr. G. S. Rattan****, Senior Plant Pathologist and* ***Dr. D.S. Brar*** *(Nominee of the Dean PGS) for timely help, support and their immensely valuable suggestions help me a lot in the accomplishment of the daunting task. I am thankful to* ***Dr. Balwinder Singh,*** *Prof. & Head Deptt. of Entomology for his much needed support and help all through my stay in the department. I am really thankful to* ***Dr. Avtar Singh****, Head Deptt. Forestry and Natural Resources for providing me facilities for conducting this research.*

I acknowledge the help and support of Bharti Field Fresh Pvt. Ltd. for providing me facilities and funding to me for conducting this research. My heartly thanks to technical staff and lab attendants at Bharti Field Fresh, Ladhowal and also at farm of Forestry and Natural Resources, PAU for their helpful and cooperative attitude during the period of work.

It is not possible to express my gratitude to my parents Mr.Tejinder Singh and Mrs. Ranjit Kaur in few words. It is their hard work, love, encouragements and moral support that improve the quality of this work and made this tough task easier for me. Love received from my brother Anhad made me strong enough to complete this task.

The special thanks to my dear friends Gurvir, Manpreet and Gulab and my roommates Mandeep, Barinder and Jasmeet for always believing in me and encouraging me, also for sharing their unconditional friendship and time throughout my studies.

Last but not least, I wish to offer my thanks to all those names which could not be included but will always be fondly remembered.

Gurlaz Kaur

Title of the Thesis	:	Population Dynamics and Management of Insect Pests of Chilli
Name of the Student and Admission No.	:	Gurlaz Kaur (L-2012-A-37-M)
Major Subject	:	Entomology
Minor Subject	:	Plant Pathology
Name and Designation of Major Advisor	:	Dr. K. S. Sangha Entomologist
Degree to be awarded	:	M.Sc.
Year of award of Degree	:	2014
Total Pages in thesis	:	72+Vita
Name of the University	:	Punjab Agricultural University, Ludhiana-141004, Punjab, India

ABSTRACT

India is the largest producer and exporter of chilli (*Capsicum annuum*) in the world and attack of insect pests is a major constraint in its production. Present study was conducted during *kharif* 2013 at Bharti Field Fresh Farm, Ladhowal, Ludhiana and during *rabi* 2014 at Department of Forestry and Natural Resources Research Farm, PAU, Ludhiana. In the present study population dynamics of insect pests of chilli, efficiency of sticky traps for monitoring alate insects in chilli ecosystem and effectiveness of various insecticides in managing the insect pest population was worked out. Forty one arthropod species were found to be associated with the chilli crop among which fourteen species were each of pests and natural enemies, twelve species of casual visitors and one species of pollinator. Order coleoptera occupied the maximum share (26.83%) in arthropod fauna recorded on chilli ecosystem. Diversity indices represented a highly diverse arthropod fauna which was evenly distributed and without dominance of any species during both the seasons. Peak activity period for aphid and thrips was recorded during October and May, for whitefly it was September and June, for mite peak population was during October and fruit borer demonstrated highest activity during May. Rectangular yellow sticky traps proved to be better in capturing alate insect pests of chilli as compared to the cylindrical traps. Among the various insecticide treatments tested Thiocloprid 21.7 % SC @ 200 ml/acre proved to be best for management of aphid and whitefly whereas Buprofenzin 25 EC @ 240 ml/acre was the best for managing thrips and mite. In case of fruit borer, Chlorantraniliprole 18.5 SL @ 50 ml/acre performed better than the other treatments.

Key words: Aphid, thrips, whitefly, mite, fruit borer, population dynamics, diversity indices, sticky traps, chemical management

Signature of Major Advisor **Signature of the Student**

ਖੋਜ-ਨਿਬੰਧ ਦਾ ਸਿਰਲੇਖ	:	ਮਿਰਚਾਂ ਵਿੱਚ ਕੀਟ ਪਤੰਗਿਆਂ ਦੀ ਜੰਨਸੰਖਿਆ ਗਤੀਸ਼ੀਲਤਾ ਅਤੇ ਇਸਦੀ ਰੋਕਥਾਮ ਦਾ ਅਧਿਐਨ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਂ ਅਤੇ ਦਾਖ਼ਲਾ ਨੰਬਰ	:	ਗੁਰਲਾਜ ਕੌਰ (ਐੱਲ-2012-ਏ-37-ਐੱਮ)
ਮੁੱਖ ਵਿਸ਼ਾ	:	ਕੀਟ ਵਿਗਿਆਨ
ਉੱਪ ਵਿਸ਼ਾ	:	ਪੌਦਾ ਰੋਗ ਵਿਗਿਆਨ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ		ਡਾ. ਕੇ. ਐੱਸ ਸੰਘਾ ਕੀਟ ਵਿਗਿਆਨੀ
ਮਿਲਣ ਵਾਲੀ ਡਿਗਰੀ	:	ਐਮ.ਐਸ.ਸੀ.
ਡਿਗਰੀ ਮਿਲਣ ਦਾ ਸਾਲ	:	2014
ਖੋਜ-ਨਿਬੰਧ ਦੇ ਕੁੱਲ ਪੰਨੇ	:	72+ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ-141004, ਪੰਜਾਬ, ਭਾਰਤ

ਸਾਰ

ਪੂਰੇ ਸੰਸਾਰ ਵਿੱਚ ਭਾਰਤ ਮਿਚਰਾਂ (*ਕੈਪਸੀਕਮ ਐਨਮ*) ਦਾ ਸਭ ਤੋਂ ਵੱਡਾ ਉਤਪਾਦਕ ਅਤੇ ਨਿਰਯਾਤਕ ਦੇਸ਼ ਹੈ ਅਤੇ ਕੀਟ-ਪਤੰਗਿਆਂ ਦਾ ਹਮਲਾ ਮਿਰਚਾਂ ਦੇ ਉਤਪਾਦਨ ਵਿੱਚ ਇੱਕ ਵੱਡੀ ਰੁਕਾਵਟ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਭਾਰਤੀ ਫਿਲਡ ਫ੍ਰੈਸ਼ ਫਾਰਮ, ਲਾਡੋਵਾਲ, ਲੁਧਿਆਣਾ ਵਿਖੇ ਸਾਉਣੀ 2013 ਅਤੇ ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਦੇ ਫ਼ਸਲ ਵਿਗਿਆਨ ਵਿਭਾਗ ਅਤੇ ਕੁਦਰਤੀ ਸੰਸਾਧਨ ਖੋਜ ਫਾਰਮ ਵਿਖੇ ਹਾੜ੍ਹੀ 2014 ਦੌਰਾਨ ਕੀਤਾ ਗਿਆ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ ਮਿਚਰਾਂ ਵਿੱਚ ਕੀਟ-ਪਤੰਗਿਆਂ ਦੀ ਜਨਸੰਖਿਆ ਗਤੀਸ਼ੀਲਤਾ, ਮਿਚਰਾਂ ਦੀ ਪਰਿਆਵਰਣ ਪ੍ਰਣਾਲੀ ਵਿੱਚ ਅਲੇਟ ਕੀਟਾਂ (ਪੰਖਾਂ ਵਾਲੇ ਕੀਟ-ਪਤੰਗੇ) ਦੀ ਨਿਗਰਾਨੀ ਲਈ ਚਿਪਚਿਪੇ ਜਾਲਾਂ ਦੀ ਕਾਰਜ ਸਮਰੱਥਾ ਅਤੇ ਕੀਟ ਪਤੰਗਿਆਂ ਦੀ ਰੋਕਥਾਮ ਲਈ ਵੱਖੋ-ਵੱਖਰੇ ਕੀਟਨਾਸ਼ਕਾਂ ਦੇ ਪ੍ਰਭਾਵ ਦਾ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ। ਮਿਰਚਾਂ ਦੀ ਫ਼ਸਲ ਨਾਲ ਸਬੰਧਤ ਕੀਟ-ਪਤੰਗਿਆਂ ਦੀਆਂ ਕੁੱਲ 41 ਪ੍ਰਜਾਤੀਆਂ ਦੀ ਪਛਾਣ ਕੀਤੀ ਗਈ ਜਿਹਨਾਂ ਵਿੱਚੋਂ 15 ਪ੍ਰਜਾਤੀਆਂ ਕੀਟਾਂ ਅਤੇ ਕੁਦਰਤੀ ਦੁਸ਼ਮਣਾਂ ਦੀਆਂ, 12 ਪ੍ਰਜਾਤੀਆਂ ਆਮ ਫੇਰਾ ਪਾਉਣ ਵਾਲੇ ਅਤੇ ਇੱਕ ਪ੍ਰਜਾਤੀ ਪਰਾਗਣ ਕਰਨ ਵਾਲੇ ਕੀਟਾਂ ਦੀ ਸੀ। ਮਿਚਰਾਂ ਦੀ ਪਰਿਆਵਰਣ ਪ੍ਰਣਾਲੀ ਵਿੱਚ ਪਾਏ ਜਾਣ ਵਾਲੇ ਆਰਥੋਪੋਡ ਜੀਵਾਂ ਵਿੱਚੋਂ ਜ਼ਿਆਦਾਤਰ ਜੀਵ (26.83%) ਕੋਲੀਓਪਟ੍ਰਾ ਕਿਸਮ ਨਾਲ ਸਬੰਧਤ ਸਨ। ਵਿਭਿੰਨਤਾ ਸੂਚਕਾਂਕ ਬਹੁਤ ਵਧੇਰੇ ਮਾਤਰਾ ਵਿੱਚ ਵੱਖੋ-ਵੱਖਰੇ ਆਰਥੋਪੋਡ ਜੀਵਾਂ ਦਾ ਪ੍ਰਤੀਨਿਧ ਕਰਦਾ ਸੀ ਜੋਕਿ ਸਮਾਨ ਰੂਪ ਵਿੱਚ ਵਿਤਰਿਤ ਅਤੇ ਦੋਨਾਂ ਫ਼ਸਲੀ ਮੌਸਮਾਂ ਵਿੱਚ ਕਿਸੇ ਵੀ ਪ੍ਰਜਾਤੀ ਦੀ ਭਾਰੂ ਨਾ ਹੋਣ ਤੇ ਅਧਾਰਿਤ ਸੀ। ਤੇਲੇ ਅਤੇ ਥ੍ਰਿਪਿਸ (ਜੂੰ) ਦੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਗਤੀਵਿਧੀ ਅਕਤੂਬਰ ਅਤੇ ਮਈ ਮਹੀਨਿਆਂ ਵਿੱਚ, ਚਿੱਟੀ ਮੱਖੀ ਦੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਜੰਨਸੰਖਿਆ ਸਤੰਬਰ ਅਤੇ ਜੂਨ ਮਹੀਨਿਆਂ ਦੌਰਾਨ, ਮਾਈਟ (ਜੂੰ) ਦੀ ਸਭ ਵਧੇਰੇ ਜੰਨਸੰਖਿਆ ਅਕਤੂਬਰ ਦੌਰਾਨ ਅਤੇ ਫ਼ਲ ਛੇਦਕ ਸੁੰਡੀ ਦੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਗਤੀਵਿਧੀ ਮਈ ਮਹੀਨੇ ਦੌਰਾਨ ਵੇਖਣ ਨੂੰ ਮਿਲੀ। ਮਿਚਰਾਂ ਦੇ ਅਲੇਟ ਕੀਟ-ਪਤੰਗਿਆਂ ਨੂੰ ਫ਼ੜਣ ਲਈ ਵੇਲਣਾਕਏਰ ਜਾਲ ਦੇ ਮੁਕਾਬਲੇ ਪੀਲੇ ਆਇਤਾਕਾਰ ਚਿਪਚਿਪੇ ਜਾਲ ਵਧੇਰੇ ਕਾਰਗਾਰ ਸਿੱਧ ਹੋਏ। ਕੀਟਾਂ ਦੀ ਰੋਕਥਾਮ ਲਈ ਅਧਿਐਨ ਦੌਰਾਨ ਵਰਤੇ ਗਏ ਵੱਖੋ-ਵੱਖਰੇ ਉਪਚਾਰਾਂ ਵਿੱਚੋਂ, ਐਫਿਡ ਅਤੇ ਚਿੱਟੀ ਮੱਖੀ ਰੋਕਥਾਮ ਲਈ ਟ੍ਰਾਈਓਕਲੋਪ੍ਰਿਡ 21.7% ਐਸ.ਸੀ. @ 200 ਮਿ.ਲੀ./ਏਕੜ ਜਦੋਂਕਿ ਥ੍ਰਿਪਸ ਅਤੇ ਮਾਈਟ ਦੀ ਰੋਕਥਾਮ ਲਈ ਬੂਪਰੋਫੈਨਜ਼ਿਨ 25% ਈ.ਸੀ. @ 240 ਮਿ.ਲੀ./ਏਕੜ ਸਭ ਤੋਂ ਵਧੇਰੇ ਅਸਾਰਦਾਰ ਸਨ। ਫ਼ਲ ਦੇ ਗੜੂਏਂ ਦੀ ਰੋਕਥਾਮ ਲਈ ਬਾਕੀ ਸਾਰੇ ਉਪਚਾਰਾਂ ਦੇ ਮੁਕਾਬਲੇ ਕਲੋਰਾਐਂਥਰਾਨਿਲੀਪਰੋਲ 18.5 ਐਸ.ਐਲ. @ 50 ਮਿ.ਲੀ./ਏਕੜ ਵਧੇਰੇ ਪ੍ਰਭਾਵਸ਼ਾਲੀ ਸੀ।

ਮੁੱਖ ਸ਼ਬਦ: ਤੇਲਾ, ਥ੍ਰਿਪਸ, ਚਿੱਟੀ ਮੱਖੀ, ਜੂੰ, ਫ਼ਲ ਛੇਦਕ ਸੁੰਡੀ, ਜੰਨਸੰਖਿਆਂ ਗਤੀਸ਼ੀਲਤਾ, ਵਿਭਿੰਨਤਾ ਸੂਚਕਾਂਕ, ਚਿਪਚਿਪੇ ਜਾਲ, ਰਸਾਣਿਕ ਪ੍ਰਬੰਧਨ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Chilli (*Capsicum annuum* L.), also called hot pepper, chile pepper, chilli pepper, paprika and aji, is a member of nightshade family, Solanaceae. It is grown in both tropical and subtropical areas all over India. It is one of the important spice and vegetable crop. Chilli pods are used for culinary purposes as fresh green or dried. It is eaten raw in salad, cooked as a vegetable, pickled or used for flavouring different dishes. Capsaicin an active component of chilli is responsible for burning sensation and is used for medicinal purposes having analgesic properties. Capsaicin extracts are also used for making pepper spray. Red chillies are a rich source of vitamins and minerals. They contain high amount of vitamin C and B_6, and a small amount of beta carotene. Chillies have high amount of iron, potassium and magnesium (Anonymous 2013).

Origin and domestication of *Capsicum spp*. dates back to 6000 years in the Americas, where starch microfossils have been found from the regions of the Bahamas to the Southern Peru (Perry *et al* 2007). Whereas, the center of origin of *C. annuum* is in the Meso-America precisely in the central-eastern Mexico, as confirmed by molecular analysis (Clement *et al* 2010). Multiple lines of evidence indicate that the domestication of *C. annuum* is in the north-eastern Mexico (Kraft *et al* 2014). Portuguese traders introduced chilli peppers to India, Indonesia and other parts of Asia around 400-500 years ago, and it quickly adapted to wide range of agro-ecological zones found in Asia (Berke and Sheih 2000).

India is the largest producer of dry chillies and peppers in the world (Anonymous 2012). Chilli is the major spice crop in India, which has highest area under cultivation and a production share of 22.71 percent of all spice crops. India's total production in 2012-13 was 1304 thousand MT from an area of 794 thousand ha with a productivity of 1.6 MT/ha (Anonymous 2013a). The leading state in chilli production is Andhra Pradesh with a total production of 638298 tons from 195471 ha, followed by Karnataka, West Bengal and Madhya Pradesh. Punjab ranks 9th in chilli production in India with total production of 17912 tons in 2010-11, from an area of 10555 ha (Anonymous 2012a).

India is a world leader in chilli production but it ranks 45th in productivity of dry chillies and peppers as compared to developed countries like USA, China, South Korea, Taiwan etc. (Anonymous 2012). Among many other reasons responsible for the lower yield, damage done by insect pests holds a major share. A survey conducted in Benin for finding production constraints in chilli, ranked the attack of insect pests on leaves, flowers and fruits as first among all other constraints (Orobiyi *et al* 2013). Another survey conducted by Asian Vegetable Research and Development Committee in Asia indicated that the key insect pests of chilli are aphids (*Myzus persicae* Sulzer, *Aphis gossypii*, Glover), thrips (*Scirtothrips*

dorsalis Hood) and mites (*Polyphagotarsonemus latus* Banks) which act as limiting factors in chilli production. Fifty one species of insects and two species of mites belonging to 27 families under 9 orders were recorded on chilli transplanted crop. Further, *Gonocephalum dorsogranosum* Frm. (vegetable beetle), *Melanotus sp*. (wire worms), *Odontotermes obesus* (termite), *Holotrichia serrata* (white grub), *Helicoverpa armigera*, thrips (*S. dorsalis* and *Thrips flavus* Schrank) and mites (*P. latus* and *Tetranychus neocaledonicus* Andre) were considered as important pests (Reddy and Puttaswamy 1983). A similar study conducted in the nursery of chilli crop recorded 35 species of insects belonging to 6 orders and a species each of mite and snail and two species of millipedes and recognized ants, cutworms and crickets as important pests (Reddy and Puttaswamy 1984). The yield losses due to thrips and mites are estimated to the tune of 50 per cent (Ahmed *et al* 1987).

Among the sucking pests, the aphids can accumulate in high densities on young tender parts of the plants and suck the sap especially from the underside of the young leaves. Infested plants turn pale, leaves become distorted, curled and crinkled leading to stunted growth of the plants. Aphids secrete honey dew, which attracts ants and which can further deter natural enemies of aphids and may turn out to be pests on chilli plants, especially damaging the flowers. Excessive honey dew secretion can lead to the development of sooty mould which affects the photosynthesis and if present on the fruits reduce the market value of the produce.

Thrips cause necrosis of tissues by extracting contents from the epidermal cells. Both nymphs and adults suck the sap from tender crop canopy, resulting in shriveling of leaves, retarded shoot development and finally the leaves fall-off. In addition, eruption of internal areas, puckering of leaves and upward curling of leaves is also noticed (Reddy and Puttaswamy 1983). Thrips can be found along the mid vein or along the borders of damaged tissues. Infested leaves show crinkling, elongated petioles, development of brown or silvery areas between veins of both young and older leaves, feeding scars, distortion of leaf shape, reduction of leaf size and linear thickening of leaf lamina. Heavy infestation causes ‘chilli leaf curl’ also called ‘Murda disease’. Young buds become discoloured, distorted and brittle leading to early fall. Early infestation of thrips causes stunted growth of the plant, reduced flowering and fruit set. Infested fruits show development of corky and scarred tissue around the apex.

Broad Mites or Yellow Mites are mostly seen on the newest leaves and young small fruits. Mite’s toxic saliva causes twisting, hardening and distorted growth of apical parts of the plants. Reduction in photosynthesis and instability of water balance are some of the damaging effects to plants. Feeding damage also causes terminal leaves and flower buds to become cupped and distorted. Leaves turn downwards and because of feeding injury, corky brown areas appear between the main veins on the underside of the leaf. Young foliage is

deformed and becomes rust coloured. Blooms abort, and the plant growth is stunted. Damaged leaves often become discolored, thickened and brown. If the plant is attacked in the flowering stage, the flowers are transformed into leafy shoots and may wither and dry (Karupachamy *et al* 1993).

Whitefly damages the plants in three ways- firstly by causing chlorosis, leaf withering, premature leaf fall and wilting, secondly by excreting honey dew, which leads to development of sooty mould thus reducing the effective leaf area for photosynthesis, third and the most important one is the transmission of chilli leaf curl virus which accounts for major yield losses.

H. armigera commonly known as gram pod borer is a polyphagous pest. Katagihallimath (1963) reported complete destruction of the fruit contents by *H. armigera* larvae in chilli, which infested up to 92 per cent of the plants and caused 77 per cent fruit damage. It is observed to damage fruit capsules, particularly boring near the stalk and destroying the contents. Sometimes in chilli it completely enters inside the capsules, which otherwise is an exception to its feeding behavior of having it's posterior portion outside the bored material. The young capsules dry up and fall, whereas mature fruits remain on the plants. *Spodoptera litura* is another borer found on the chilli crop, it is also a polyphagous pest and damages by making holes in the leaves, scratching the young shoots and feeding on the fruits.

Major chilli producing states are Andhra Pradesh and Karnataka and most of the data available on insect pests of chilli is also from that region. However, not much data is available in literature about insect pest diversity of chilli crop from Punjab. So the need was felt to record the diversity of insect pests on chilli, to know the population dynamics during the season for efficient, accurate monitoring and standardization of trap designs. Effective traps can help in development of prediction models for speculating the insect pest infestation in advance for pest management. Symptomological studies are also lacking for determining the level and severity of infestation and accurate identification of the problem.

During the last two decades insecticidal control of chilli pests especially in irrigated crop is characterized by high pesticide usage and hence has posed problems of residues in the fruits (Nandihalli 1979, Awasthi *et al* 2001 and Joia *et al* 2001). Both significant domestic consumption and sizable export of chilli necessitates production of quality chillies devoid of contamination of pesticides, industrial chemicals and aflatoxins. But the presence of pesticide residues in spices in general and chillies in particular has been a major non-tariff barrier against export of chillies to developed countries. The reported presence of residues of many insecticides including ethion, chlorpyriphos, cypermethrin, endosulfan and quinalphos has seriously affected the export of chillies. It is learnt that chilli consignments are being detained at the ports of importing countries very often due to high pesticide usage in India.

Therefore, several issues are needed to be reexamined and put to evaluation so that sound management programme is evolved with judicious pesticide usage. Pesticidal interventions in reproductive phase of the crop targeting fruit borers often result accumulation of residues that are easily detectable in transit or before consumption. So, proper evaluation of various insecticides for their efficacy to control different insect pests of chilli, is needed such that they provide effective control and the residues are below Maximum Residue Limits (MRL). Evaluation of new and safe molecules is the need of the hour and economic feasibility of chemicals used should also be considered. The present investigations were thus, proposed on chilli crop with the following objectives:

i) To work out the insect pest diversity in chilli crop.

ii) To standardize the trap design for effective monitoring of sucking insect pests on chilli.

iii) To develop pest management strategy for key pests of chilli.

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the available research available on pest status, monitoring and survey studies, efficacy of sticky traps for capturing alate insects and management of insect pests associated with chilli. A pertinent effort has been made to review the literature under following titles:

2.1 Pest scenario

- 2.1.1 Survey/Monitoring of insect pests and other arthropods in chilli
- 2.1.2 Diversity indices
- 2.1.3 Population scenarios of fruit borers
  - 2.1.3.1 *Helicoverpa armigera*
  - 2.1.3.2 *Spodoptera litura*
- 2.1.4 Population scenarios of sucking insect pests
  - 2.1.4.1 Thrips
  - 2.1.4.2 Aphids
  - 2.1.4.3 Whitefly
- 2.1.5 Population scenarios of mites

2.2 Utilization of traps in monitoring and management of insect pests

2.3 Management of insect pests of chilli

- 2.3.1 Fruit borers
- 2.3.2 Sucking insect pests

2.1 Pest scenario

2.1.1 Survey/ Monitoring of insect pests and other arthropods in chilli

Kim *et al* (2000) surveyed for insect pests of egg plant, pepper, chinese cabbage, watermelon, cucumber and tomato seedlings in eleven propagation houses for 2 years and reported that ten species of insect pests belonging to nine genera representing eight families and two species of mites of a genus were infesting these crops. Three species of slugs or snails of three genera belonging to two families were also recorded on the seedlings of which *Bradysia agrestis* was the most serious pest. Yasaraknc and Hncal (2000) studied the pests and natural enemies on protected pepper (*Capsicum* sp.). Spider mite (*Tetranychus urticae*), aphids (*A. gossypii* and *M. persicae*), white flies (*Bemisia tabaci* and *Trialeurodes vaporariorum*), leaf hoppers (*Asymmetrasca decedens* and *Empoasca decipiens*), thrips (*Haplothrips distinguendus*) and leaf miners (*Liriomyza trifolii*) were the pests to be found infesting the protected pepper. Aphids and leaf miner densities reached their maximum at the beginning of the season whereas white flies, spider mites and leaf hoppers had high densities towards the end of the season. The population density of *H. distinguendus* was high during the middle of the season.

A survey of insect pests of *Capsicum annuum* var. frutescens showed that the occurrence of cutworm (30 to 40%), aphids (0.00 to 1.60 nymphs and adults/3 leaves), thrips (0.00 to 2.00 nymphs and adults/3 leaves), termites (0 to 20% damage), fruit borer (20.68 to 26.16% damage) and non insect pests viz., mites (0.00 to 2.60 nymphs and adults/3 leaves) and snails (20% damage) as major pests of the crop (Sunitha 2007).

In Jamaica, viruses (tobacco etch and potato Y), aphids (*M. persicae, A. gossypii*), the broad mite (*P. latus*) and gall midges (*C. lycopersici* and *P. longifila*) were the major arthropods infesting hot pepper (Lawrence *et al* 2000). Dhooria (2003) made extensive survey on mites in Punjab, India and revealed the occurrence of Tarsonemid mite, *P. latus* on chilli. A survey was conducted in Guntur district of Andhra Pradesh by Reddy *et al* (2011), who reported that among the sucking pests of chilli, mites and among fruit borers *Spodoptera litura* was the main problem. Maklad *et al* (2014) conducted a research on influence of climatic factors on major pests of pepper crop under Egyptian conditions and reported that whitefly (107.0 to 178.0 adult whitefly/ leaf) was the most severe as compared to the other pests. Population of aphid was moderately severe (105.0 to 150.0 adult aphids/ leaf) and the population of spider mite was least severe (79.5 to 88.5 adult spider mites/ leaf).

Monitoring results from 1919-2010 (Szwejda and Rogowska 2011) in Poland on three crops- Tomato, Paprika and Eggplant revealed forty one species of phytophagous pests on the paprika crop among which the major pests were found out to be onion thrips (*Thrips tabaci*), green peach aphid (*Myzus persicae*) and bug (*Lygus spp*.). Sarwar (2012) reported the detection and monitoring data of insect and mite fauna of chilli crop in Punjab province of Pakistan and showed that the major pests were *Helicoverpa armigera* (Hubner) (0.33) and Armyworm, *Spodoptera litura* (Hubner) (0.33) per pod that attacked the fruit and chilli thrips, *Scirtothrips dorsalis* Hood (9.33), green peach aphid *Myzus persicae* (Sulzer) (7.33), two spotted spider mite *Tetranychus urticae* Koch (4.33), whitefly *Bemisia tabaci* (Gennadius) (5.66) and leaf miner *Liriomyza sativae* Blanchard (2.33) per leaf that effect the foliage. Overall, thrips were reported as the only predominating pest present in relatively large numbers and leaf miner in small numbers were recorded from all plants sampled. Ssemwogerere *et al* (2013) conducted a survey on tomato and pepper crop plants for species composition and occurrence of thrips. They recorded *Frankliniella occidentalis, T. tabaci, S. dorsalis, Ceratothrips ericae* and *Megalurothrips sjostedti* thrip species on pepper crop and majority of thrip population was seen during flowering stage rather than the vegetative stage.

2.1.2 Diversity indices

Shannon-Weaver diversity indices (H') study for aphid species on four farms of pepper in Jamaica (during October 1998 through July 1999) indicated that the lowest species diversity occurred in October 1998 on farm 1 and 4, with *A. gossypii* accounting for 80 and 95 percent of total aphid species captured. On farm 3, the lowest diversity indices were observed

during November 1998 when *A. gossypii* represented 91 percent of all aphids captured. In farm 5, the lowest diversity indices were during January 1999, when *A. gossypii* and *Brachycaudus helichrysi* (Kaltenbach), each occupied 43 percent of total catch. Highest species diversity occurred in February 1999, May 1999 (in farm 1 and 3 respectively) and March 1999 (in farm 4 and 5), when no species was dominant (Mcdonald *et al* 2003).

Imura (2003) reported thirty nine herbivorous arthropod species on *Solanum carolinense* with homopterous species occupying 38 percent of total species followed by heteropterous species (20 %), coleopterous species (12.8 %), thysanopterous species (12.8 %) and lepidopterous species (10.3 %). The Shannon-Weaver diversity index indicated low species diversity as three species (*Epilachna vigintioctopunctata*, *Aulacorthum magnolia* and *Trialeurodes vaporariorum*) occupied more than 75 percent of total arthropod community. Evaluation of insect biodiversity in monoculture of tomato as compared to tomato-maize polyculture by using ecological indicators (Shannon-Weaver Biodiversity, Simpson's Dominance, Pielou's Uniformity and Margaleff's Richness), demonstrated that the polyculture cropping system had higher abundance and diversity of insects (Leon *et al* 2001).

2.1.3 Population scenarios of fruit borers

2.1.3.1 *Helicoverpa armigera*

Kurl and Kumar (2011) worked on the economic evaluation of *H. armigera* on tomato crop in Meerut district. They found that among the lepidopterous pests of tomato, *Helicoverpa* was the most damaging of all. Average fruit damage due to the fruit borer in three years was 24.2 percent and 11 percent respectively, on Dev and Pusa ruby varieties. Pod borer on chilli, *S. litura*, *H. armigera* on tomato, *Plutella xylostella* on cabbage, *Leucinodes orbonalis* on brinjal, *Earias fabia* on okra are major pests of these vegetables. Newer pesticides with novel mode of action were found to be the most effective against these pests (Chatterjee and Mondal 2012).

Studies on population dynamics of *Helicoverpa armigera* and *Campoletis chloridae* on chickpea, pigeonpea, tomato, sunflower and okra indicated that on chickpea *Helicoverpa* was observed from October onwards and the peak activity period was recorded during second fortnight of February and March. Chickpea and Pigeonpea were the most preferred hosts. Pest population was maximum at the pod development stage in chickpea and flowering and fruiting stage in pigeonpea. From tomato, it switched on to sunflower in May and then, pest population migrated to okra in June (Chandel *et al* 2005).

Incidence and population dynamics of *Helicoverpa armigera* on chickpea at Bangladesh revealed that population fluctuated according to the sowing dates of the crops (Hossain *et al* 2008). Population was higher in early sown crop, and decreased with delaying sowing dates. Both early and late sown crops had higher populations whereas mid sown crop had lower population.

Chatar *et al* (2010) reported an early peak activity period while investigating population dynamics of *H. armigera* on chickpea. They recorded that the pest appeared from 2nd week of December and the peak activity was observed during 2nd week of January. Pest population declined towards maturity of the crop. Jadhav *et al* (2010) studied the carryover of *Helicoverpa* in north-eastern zone of Karnataka and revealed that activity of pest started from 2nd fortnight of July in sunflower and cotton and was active upto September. Second peak period was seen in pigeonpea from September to January and during this period, it migrated to chickpea and sorghum during second week of October to February. Third peak was observed on chilli and tomato during March to May. Jadhav *et al* (2013) studied the incidence of winter and summer diapause of *H. armigera* in Andhra Pradesh and reported that winter diapause was induced by cooler weather and short day lengths of <12 hr in November-January and summer diapause was seen at temperature >32 degree during March-April and emergence took place during mid-June to early July.

H. armigera, population succession studies on tomato in UP showed that initial population remained confined during vegetative growth but increased rapidly during fruiting stage and attained a peak during 2nd week of April (Singh *et al* 2011). Rainfall and RH were negatively correlated with the pest activity. Seasonal incidence of fruit borers on chilli during kharif season revealed that the peak egg incidence was recorded during 2nd fortnight of September and peak incidence of larvae was found during 1st fortnight of November. The egg load during cropping period ranged from 1.63 to 2.22 eggs per plant and larvae ranged from 1.45 to 2.02 larvae per plant. Maximum temperature showed positive correlation with incidence of eggs and larvae (Nadaf and Kulkarni 2006).

Ravi *et al* (2005) studied the relative abundance of *H. armigera* on different crops (cotton, pigeonpea, chickpea, sunflower, corn, chilli, tomato, and okra) and reported that the populations on chickpea and pigeonpea were significantly greater than the other crops. Both egg and larval numbers on corn and chilli were not significantly different from those on cotton. Sharma *et al* (2012) monitored the populations of *Helicoverpa* male moths (pheromone traps) and larvae (per plant) on chickpea crop. The results indicated that maximum number of male traped were 105.66/trap/week and maximum larvae recorded were 30.0/10 plants during 3rd week of March. The maximum and minimum temperature had positive correlation with the population whereas RH was negatively correlated.

2.1.3.2 *Spodoptera litura*

Populations of *Spodoptera* on vegetables fluctuated throughout the season and the larval population was affected by age and availability of the host (Azidah 2007). Population was mainly affected by parasitoids and diseases but there was no significant role of temperature, relative humidity and rainfall. Idris and Emelia (2001) studied feeding behaviour of Spodoptera on different host plants (tomato, okra, onion, brinjal and chilli) and found that

number of larvae, pupae, adult and eggs differed significantly on different hosts. Larvae fed only on okra, onion and chilli in choice test. Survival rates and the fecundity was more on onion and okra than other hosts. Azidah (2006) monitored *Spodoptera exigua* adult populations using pheromone traps with highest catch per trap during August and lowest during November. Four capture peaks were observed during midyear i.e. from April to August.

2.1.4 Population scenarios of sucking insect pests

2.1.4.1 Thrips

Panickar and Patel (2001) reported from Anand (Gujrat) on the effect of weather factors on the activity of thrips infesting chilli. The incidence of *S. dorsalis* Hood on chilli was found during first week of September to second week of January. Lingeri *et al* (1998) studied seasonal incidence of thrips on chilli and noticed the peak periods of population during the months of December and January. Pest populations were favoured by a dry period and lower temperatures. In Maharashtra the incidence of chilli thrips started seven days after transplanting and peak populations were observed during the 40th meteorological week. Thrips showed negative correlation with RH and rainfall, whereas showed positive correalation with the sunshine hours (Bhede *et al* 2008).

Population dynamics studies of *S. dorsalis* on chilli crop revealed that population initiates during first week of September and prevails throughout the crop season till harvest, with a peak period in November and February-March (Patel *et al* 2009). Thrip populations were positively correlated with sunshine hours, maximum temperature and negatively correlated with RH and the population decreased with increasing rainfall. Investigations on the spatial distribution of thrips on pepper plants showed that adults and larvae were abundant on top young leaves followed by middle leaves, lower leaves, flowers and fruits. Distribution of thrip adult population was also found to be aggregated in larger plots but regularly distributed in small plots whereas, the larvae were distributed aggregately on top leaves irrespective of the plot size, thus showing that the infestation can be detected easily by examining the top leaves (Seal *et al* 2006).

Tillekaratne *et al* (2011) surveyed for thrip species and their distribution on various host plants (over thousand plant species comprising ornamentals, weeds, shrubs and trees on twenty two sites) in Sri Lanka and reported that thrip species *Microcephalothrips abdominalis*, *M. usitatus* and *S. dorsalis* are species with a large number of host records. Velayudhan *et al* (1985) studied pollination potential, population dynamics and dispersal of thrips species on *Dolichos lablab* L. (Fabaceae) and found that *S. dorsalis* occured in low frequencies within flowers during the month of April and its role in pollination was insignificant on the crop.

Temporal and spatial distribution of *S. dorsalis* on three host plants- cotton, peanut and pepper in greenhouse as well as under field conditions in Florida demonstrated that population density had negative correlation with plant height and thrips had aggregated distribution with a weak dispersal. Maximum abundance was during May-October and highest mean count during July-August. The peak flight activity was recorded during peak solar radiations (Kumar *et al* 2014).

2.1.4.2 Aphids

According to Varicek *et al.* (2001), among the insect pests of pepper (*C. annuum*) crop in Argentina, the aphids stand out, of which *M. persicae* is the key pest, followed by *Aphis solani* and *Macrosiphus meuphorbiae*. Evans and Halbert (2007) prepared a checklist of aphids of Honduras on different host plants and reported *A. gossypii* and *M. persicae* on *C. annuum*. Observations on the vegetative stage of peach trees and pepper crop for *M. persicae* showed that the first alate adults appeared from mid September to mid October and the peak populations were observed during October. Aphid population decreases to negligible from last week of November to first week of December. Second peak activity period was observed during May-June. First individuals were recorded on pepper during June and the peak populations were observed during July and September (Tancik 2001).

Temperature fluctuation effects on *M. persicae* activity on Chinese cabbage in Minnesota and North Dakota revealed that aphid developed faster and had greater fecundity under fluctuating conditions (Davis *et al* 2006). Musa *et al* (2004) surveyed potato fields for *M. persicae* in Kosovo and compared three locations and two varieties. Results depict that aphids occured in May-June and then were present throughout the season with peak activity during July-August. Athanassiou *et al* (2005) sampled tobacco fields for *M. persicae* and its predator mirid bug *Macrolophus costalis*, and recorded highest aphid densities during July-August, with higher numbers on upper plant canopy with aggregated population in the fields.

A. gossypii population started in August and attained a peak period in January and almost negligible population in April on *Solanum melangena* L. in Bangladesh (Karim *et al* 2001). Rajabpour and Yarahamadi (2012) studied seasonal population dynamics of *A. gossypii* on Hibiscus rosa-chinensis, and reported that the aphids migrate to the crop in November from weeds and attain a peak population during January-February with aggregated population in the field. Rondon *et al* (2005) reported that *A. gossypii* on strawberry under greenhouse conditions had higher mean nymph population on leaves as compared to the emerging buds. Peak nymphal density was in March whereas peak adult population density was in February and March. Alate aphids were higher in numbers on the buds than the leaves with peak populations during March and April.

Shah *et al* (2009) reported *A. gossypii* populations on okra crop to be prevalent from first week of May to first week of September with a peak population during last week of July.

Average sunshine and wind speed had positive correlation while the average humidity and rainfall had a negative correlation. Singh *et al* (2014) prepared a checklist for host plants of *A. gossypii* in India and recognized 29 plant species of the family Solanaceae to be host for the *A. gossypii* and recognized *C. annuum* as the most important host. Touhidur *et al* (2006) studied population abundance and spatial distribution of *A. gossypii* and its predator coccinellids on the chilli crop and reported that number of aphids per stratum of plant canopy was highest at the lower than middle and top whereas the coccinellids number per stratum was highest in the middle and top canopy. Peak population period for both pest and predator was highest at 56 DAT with aggregated aphid populations.

2.1.4.3 Whitefly

Khalid *et al* (2009) studied population abundance of whitefly on chilli crop by using yellow sticky trap and reported maximum population at 77 DAT and minimum population at 7 DAT. Rainfall, sunshine hours and RH had no significant correlation with the populations whereas wind speed had a positive correlation. *Bemisia tabaci* distribution on cucurbits and non-cucurbit crops (nymph and adult populations) was higher on cucurbits as compared to other crops except brinjal (Lanjar *et al* 2012). Further, the population density on chilli crop was 1.97 whiteflies per leaf and it was directly correlated to the pH of the leaves. Mansour *et al* (2013) estimated populations of whitefly on chilli alone and intercropped with other crops (brinjal, okra, tomato) under glasshouse conditions and found that the populations were higher on chilli alone than the intercropped plantation. The number of adults and eggs were higher on the upper canopy as compared to the middle and the lower, nymphal populations were however, higher in the middle canopy of the plants.

Fauziah *et al* 2009 studied population ecology of whitefly on brinjal and observed peak larval population at 4 to 7 weeks after transplanting and maximum numbers were observed on the middle canopy of the plants. In case of *B. tabaci* on cucumber, higher number of adults and nymphs were recorded on older plants. Adults preferred the top canopy whereas, higher larval population was recorded on the middle canopy (Leite *et al* 2006). Khan *et al* (2011) studied host plant selection and oviposition behaviour of *B. tabaci* under green house conditions with free choice of foraging to the pest and observed that the whitefly preferred brinjal over tomato and chilli crops. Chilli when intercropped with brinjal, exhibited negligible viral infection, whereas viral infection was found in monocroped chilli.

2.1.5 Population scenarios of mite

Romero and Pena (1998) studied responses of broad mite to four different phenological stages of pepper plants i.e. vegetative, flowering, early fruiting and late fruiting. Mites preferred undersides of leaves in all the stages and higher populations were found on vegetative, flowering and early fruiting stage as compared to the late fruiting stage. The plants infested at late fruiting stage showed lower yield loss. Rodriguez *et al* (2011) compared two

cultivars of *C. annuum* for influence of phenological stages on behaviour of broad mite and reported that the crop plants are most susceptible and showed maximum loss in yield when mites were released in vegetative stages of plant growth. Kamruzzaman *et al* (2013) compared different varieties with respect to mite infestation and concluded that the maximum numbers of mite stages were noted 90 days after sowing in jute crop.

Investigations on the seasonal incidence of mite pests on chilli and brinjal revealed that *P. latus* occured throughout the summers and population peaks were observed in April and May. During the *kharif* season, population initiated during October, with a peak population during November (Patil and Nandihalli 2009). Abou-Awad *et al* (2014) studied the bionomics and control of *P. latus* on three cultivars of pepper under nethouse conditions in Egypt and reported that population distribution on the plant depends on the position of the apical leaves. First and second apical leaves among the top five apical leaves showed the maximum number of mite pests irrespective of the cultivars. Lower surfaces of the leaves were more preferred for feeding and oviposition than the upper surfaces. Famales and larvae do not move from one leaf to another but the males transfer secondary female pupae from damaged to undamaged leaves.

Lingeri *et al* (1998) studied seasonal incidence of chilli mites at dharwad, Karnataka and noticed the peak activity periods of mites during November and February. Mite populations increased with increasing temperature, decreasing rainfall and humidity.

2.2 Utilization of traps in monitoring and management of insect pests

Chu *et al* (2006) evaluated the plastic cup trap (named CC trap) for thrips (*S. dorsalis*) and concluded that a combination of detective systems of visual observations, yellow sticky traps and CC traps may be an effective population monitoring system. Population dynamics of *H. armigera* with help of pheromone traps in chickpea with different intercrops was studied by Reena *et al* (2009). The borer population was highest in sole chickpea crop than intercrops and the catch peaked during 14th and 15th standard week. Moreau *et al* (2011) demonstrated that eggplant trap crops and eggplant combined with yellow sticky cards reduced adult settling of white flies on main crops by 31.5 and 40.9 percent respectively, on *C. annuum.*

Idris *et al* (2012) studied the effectiveness of trap designs and colours in trapping alate *B. tabaci* in Malaysia from September 2004 to August 2005. Different trap designs like horizontal, vertical and cylindrical with different colour combination like yellow, red, blue, green, white and black were evaluated. The cylindrical and yellow traps were most effective of all the traps for monitoring of whitefly. Rajabpour and Yarahamadi (2012) reported the yellow sticky traps to be suitable for early infestation detection and sampling tools for *A. gossypii*. Nandini *et al* (2012) monitored population of sucking pests (whitefly, thrips, red mite and leaf hopper) on capsicum through yellow sticky traps and found that side 1 captured

more number of insect pests than side 2, owing to the wind direction. Maximum number of whiteflies, mites and leaf hoppers were recorded during second fortnight of September but maximum number of thrips were recorded during first fortnight of September.

Bowie (2010) studied the effectiveness of different traps for studying wheat aphid and its natural enemy hoverfly. Results showed that yellow water pan traps captured equal number of hoverflies as yellow sticky traps. Lower numbers of aphids were caught on yellow sticky traps placed at ear level height. Evaluation of yellow sticky traps for cotton pests demonstrated that traps placed 25 cm above the plants captured highest number of thrips whereas highest whitefly and jassids were captured on traps placed 30 cm above the ground level (Gencsoylu 2007). Vertically positioned traps captured more number of thrips and jassids whereas, the position made no significant difference for whitefly numbers. More number of jassids and whiteflies were captured in the north-south direction whereas more number of thrips were collected more in the east-west direction.

Hoelmer and Simmons (2008) studied effectiveness of yellow sticky traps for capturing whitefly and its parasitoid, *Eretmocerus emiratus* and reported that in melon fields, highest number of whiteflies were caught on upper surfaces of the horizontally placed traps. However, the lower surfaces caught more numbers of the parasitoids and the parasitoid population was here density dependent. Hoddle *et al* (2002) studied attraction of different species of thrips to yellow, blue and white sticky cards. They reported that *S. perseae* in Avocado orchard was most attracted to the yellow colour but white colour captured more number of *F. occidentalis* and *Franklinothrips orizabensis*. However, *F. occidentalis* in sweet pepper was more attracted to blue, white-blue and white than the yellow sticky traps (Larrain *et al* 2006) in contrast to Hoddle *et al* (2002).

Yellow and blue sticky traps in orange and lemon orchards, attracted more thrips than yellow in both the orchards (Elekcioglu 2013). Yellow coloured sticky traps were more attractive for mango hopper, *Idioscopus clypealis* (Leith) as compared to pink and purple colour (Saeed *et al* 2013). Robacker and Rodriguez (2004) developed a cylindrical yellow sticky trap for capturing Mexican fruitflies and found it to be effective for population captures combined with lures hanging inside the cylinders.

2.3 Management of insect pests of chilli

2.3.1 Fruit borers

Gundannavar and Giraddi (2007) conducted a field experiment at Dharwad to evaluate the efficacy of different biorational approaches against chilli fruit borer (*H. armigera).* Among the different schedules, the Nimbecidine-Nimbecidine-Spinosad-Garlic Chilli Kerosene Extract-Spinosad treatment was effective against *H. armigera* and recorded least larval infestation and fruit damage. Bioefficacy tests of Indoxacarb 14.5 + Acetamprid 7.7SC (RIL 042 222 SC) against sucking pests and fruit borers on chilli revealed lowest thrip

population in case of RIL 042 222 SC @ 500 ml/ha followed by 400 ml/ha (Dharne *et al* 2009).

Among the various dosages of Flubendiamide 20 WG, Emamectin benzoate 5 SG and Spinosad 45 SC tested against chilli fruit borer (*H. armigera* and *S. litura*) Flubendiamide 20WG @ 60g a.i/ha recorded highest yield of 7.48 g/ha commensurate with the lowest fruit damage of 3.45 percent followed by Flubendiamide 20WG @ 40g a.i/ha, Emamectin benzoate 5 SG @ 11g a.i/ha and Spinosad 45 SC @ 75g a.i/ha (Tatagar *et al* 2009). Among the eight treatments consisting primarily the combined use of biopesticides (Bt, NPV, *Beauveria bassiana* with egg parasitoid *Trichogramma pretiosum*) and chemical spray schedule against *H. armigera*, four insecticide sprays- Endosulfan @ 1.6 l/ha, Cypermethrin @ 1.0 l/ha, Endosulfan @ 1.6 l/ha, Deltamethrin @ 0.8 l/ha ranked third in terms of cost effectiveness (Tyagi *et al* 2010).

Babariya *et al* (2010) tested chemicals for gram pod borer in pigeon pea and the results indicated that amongst the different insecticides tested, Indoxacarb 0.0075% gave highest mortality of pest followed by Spinosad @ 0.009%, Profenophos + Cypermethrin 0.044% and Endosulfan 0.07%. Indoxacarb 0.0075% also recorded significantly highest grain yield of 1486 kg/ha. Nethravathi *et al* (2011) tested bioefficacy of Bt isolates against lepidopteran pests and data revealed better performance of Dipel 8 L, HDI, K-82 and K-94. Further, the degree of pathogenecity, varied with concentration of bacterial isolates, period of exposure and the stage of metamorphosis of the larvae. Chavan *et al* (2012) evaluated various pest management modules against *H. armigera* in Navsari. The sole non-chemical modules were least effective whereas IPM and chemical control were at par with each other.

Evaluation of Emamectin Benzoate 5 SG foliar spray against thrips and fruit borer complex on grapes, found 11 and 22 gm a.i/ha dosages to be most effective when sprayed at 15 days interval and no adverse effect was noted on coccinellid predators with nil phytotoxicity on the plants (Muthukrishnan *et al* 2012). Zhang *et al* (2013) worked on sub-lethal effects of Chlorantraniliprole on *H. armigera* and found it to be effective both on the parent as well as offspring generations. Goud and Manasa (2013) evaluated compatibility of Spinosad with fungicides for management of fruit rot and fruit borer in chilli. All combinations showed synergistic effect on fungi as well as *H. armigera* and the efficiency of the chemical was increased. Sachan *et al* (2006) worked on the efficacy of Endosulfan, Monocrotophos and three other bio-control agents against *H. armigera* in capsicum crop. All the treatments were effective but combination of NPV with Monocrotophos was the most effective resulting in the lowest infestation and damage. Based on the effective cost-benefit ratio, Endosulfan (0.07%) and Monocrotophos (0.05%) were better economically. Gadhiya *et al* (2014) evaluated Emamectin benzoate 5 WG @ 0.002%, Thiodicarb 75 WP @ 0.075%, Indoxacarb 14.5 SC @ 0.007%, Spinosad 45 SC @ 0.018%, Novaluron 10 EC @ 0.01%,

Lufeneuron 5 EC @ 0.005%, Flubendiamide 480 SC @ 0.014%, Chlorantraniliprole 20 SC @ 0.006% and Metaflumizone 22 SC @ 0.044% against *H. armigera* and *S. litura* infesting groundnut crop. Chlorantraniliprole (0.006%), Spinosad (0.018%) and Emamectin benzoate (0.002%) were the most effective against both the borers.

Spinosad @ 73 to 84 g a.i/ha was more effective and safe to natural enemies of fruit borer (*H. armigera*) than Quinalphos, Cypermethrin and Lambda cyhalothrin (Gosh *et al* 2010). Kumar *et al* (2010) tested seven insecticides against *S. litura* in chilli fields and found Phosalone (0.04%) and Endosulfan (0.07%) most effective and the neem oil to be the least effective in reducing borer population. Reddy *et al* (2014) tested various insecticides against *S. litura* and *S. dorsalis* in chilli and reported that Flubendiamide 480 SC @ 48 and 60 g a.i ha^{-1} was effective against the pod borer whereas, Spirotetramate 150 OD @ 60 g a.i ha^{-1} followed by acephate 75% SP @ 468.75 g a.i ha^{-1} and Metasystox 25% EC @ 187.5 g a.i ha^{-1} was efficient against the thrips. Indoxacarb 14.5 SC @ 500 ml/ha, Acetamiprid 20 SP @ 200 g/ha and their combination was found effective against chilli thrips and fruit borers (Nandihalli 2009). Also, Chlorantraniliprole 20 SC (0.43), Flubendiamide 480 SC (0.59) and Spinosad 45 SC (0.85) effectively controlled *H. armigera* (Sreekanth *et al* 2014). Chlorantraniliprole and Flubendiamide had the highest cost-benefit ratio among the insecticides evaluated in pigeon pea crop. Wang *et al* (2008) reported that Spinosad was effective in reducing survival, reproduction and it also delayed development of *H .armigera* under laboratory conditions.

2.3.2 Sucking insect pests

Mallapur *et al* (2001) tested Ethion 50 EC for its effectiveness against chilli mites and thrips and found it to be successful in managing sucking pests but not borer complex. Ethion 50 EC @ 750 g a.i./ha was the most effective dose for managing chilli leaf curl complex. Soil application of neem cake as well as its integration with schedule of chemical sprays recorded significantly lower density of thrips comparable to chemical check and was significantly superior to untreated control (Varghese and Giraddi 2005). Spinosad, Imidacloprid, Chlorfenapyr, Novaluron, Abamectin, Spiromesifen, Cyfluthrin, Methiocarb, and Azadirachtin were tested against *S. dorsalis* on pepper plants and Chlorfenapyr was found to be the most effective followed by Spinosad and Imidacloprid (Seal *et al* 2006). Application of new acaricide, Fenpropathrin @ 2 ml/l exhibited 82.16 and 81.32 percent reduction in mite populations (Jeyarani and Chandrasekhran 2006). Sarkar *et al* (2007) reported that tank mixing of Dicofol with with IGRs like Clofentezine and Flufenzin did not affect the efficacy of acaricides in controlling the yellow mite in chilli ecosystem.

Evaluation of Fenzaquin, Abamectin and Clofentezine in two different dosages revealed that Abamectin was most suitable at both the dosages (9g, 5g) followed by Fenazaquin @ 100g a.i/ha (Sarkar *et al* 2008). Application of Phosphamidon 40% +

Imidacloprid 2% SP @ 700g/ha was most effective for suppression of thrip population and it also increased the yield (Bhede *et al* 2008). Spinosad 45 SC @ 125 ml/ha exhibited equal efficacy at higher doses (162.5 and 200 ml/ha) and was superior to Endosulfan, Fipronil and Chlorpyriphos when tested against thrips and pod borer (Prasad and Ahmed 2009). Venkateshalu *et al* (2009) evaluated herbal pesticide Stanza against *S. dorsalis* and *P. latus* and found it at par with Fipronil in effectiveness against pest and showed higher yields and net profits.

Rathod *et al* (2010) showed that Imidacloprid 70 WS @ 5g/kg of seed was most effective followed by Imidacloprid 200 SL @ 0.5 ml/l at 20 and 30 days after emergence in minimizing average population of whiteflies. Further, Imidacloprid 200 SL @ 0.5 ml/l was most effective in minimizing thrip population followed by Monocrotophos @ 0.005% and Azadiractin 1500 ppm @ 2 ml/l. Mandal (2012) field evaluated alternate uses of insecticides against chilli thrips. A package of treatments comprising sprays of Difentheuron (Pegasus 50 WP @ 1 g/l) followed by Acetamprid (Ekka 20 SP @ 1 g/l) at 10 days interval 30 days after transplanting of the crop, was found to be superior over all other packages in terms of significantly lower thrips population count and highest per cent reduction of curly leaves with significantly higher yields over untreated control.

Gopalaswamy *et al* (2012) showed that the whitefly population as well as yellow mosaic virus incidence were less in Diafenthiuron 50 WP @ 600 g/ha, Imidacloprid 70 WG @ 75 g/ha and Thiamethoxam 25 WG @ 100 g/ha treatments compared to the untreated control. Maximum grain yield of 22.4 q/ha was realized in Imidacloprid 70WG treatment. He *et al* (2013) assessed potential sublethal and lowlethal effects of concentrations of four widely used insecticides on fecundity, honeydew excretion and feeding behavior of *Bemisia tabaci* adults. Results indicated that Imidacloprid and Bifenthrin caused reduction in phloem feeding even at sublethal concentrations while Chlorpyriphos and Carbosulfan were not much effective. Abou-Awad *et al* (2014) treated pepper cultivars with Abamectin, Fenproximate, Azadirachtin, sulphur, *Beauveria bassiana*, jujube and mint oil against *P. latus* and reported Abamectin and Fenproximate to be the most effective. Chakarbarti and Sarkar (2014) studied different acaricides and found Diafenthiuron (300 g a.i./ha) as most effective against *P. latus*.

CHAPTER III

MATERIAL AND METHODS

Experiments on population dynamics and management of insect pests of chilli were conducted during *kharif* 2013 at Bharti Field Fresh Farm, Ladhowal, Ludhiana and during *rabi* 2014 at Department of Forestry and Natural Resources Research Farm, PAU, Ludhiana. The details of materials used and methodology followed are discussed in this chapter as per following titles:

3.1 Raising of Crop

3.2 Experimental layout

3.3 Monitoring of insect pests

- 3.3.1 Target insect pests and mites
  - 3.3.1.1 Aphids (*M. persicae* and *A. gossypii*)
  - 3.3.1.2 Thrips (*S. dorsalis*)
  - 3.3.1.3 Whitefly (*B. tabaci*)
  - 3.3.1.4 Fruit borers (*H. armigera* and *S. litura*)
  - 3.3.1.5 Mite (*P. latus*)
- 3.3.2 Non-Target insects
  - 3.3.2.1 Coccinellids and other coleopterans
  - 3.3.2.2 Spiders
  - 3.3.2.3 Other insects
- 3.3.3 Statistical analysis for monitoring

3.4 Yellow sticky traps

- 3.4.1 Shape of the trap
- 3.4.2 Observations
- 3.4.3 Statistical analysis

3.5 Management of insect pests of chilli

- 3.5.1 Management of sucking insect pests of chilli (aphids, thrips, whitefly and mites)
- 3.5.2 Management of chilli fruit borer (*H. armigera*)
- 3.5.3 Observations
- 3.5.4 Statistical analysis

3.6 Residue analysis

- 3.6.1 Instruments
- 3.6.2 Extraction and cleanup
- 3.6.3 Estimation

3.1 Raising of crop

The chilli jalapeño variety PEP-1 was sown in zigzag manner on the beds on August 26, 2013 in the field at Bharti Field Fresh Ladhowal, Ludhiana and chilli hybrid variety CH-1 was sown on beds on February 25, 2014 in the research field area at Forestry and Natural Resources Research Farm, PAU, Ludhiana. The crop was raised following all the recommended Package of Practices for chilli crop except management of insect pests (Anonymous 2012b).

3.2 Experimental layout

Three experiments were laid out in a Randomized Block Design (RBD) with 17 treatments. Each treatment was replicated 3 times in plots measuring 6 X 3.5 m (21 m^2) during *kharif* 2013 at Bharti Field Fresh, Ladhowal, Ludhiana. Each replication had 7 plots. Crop for conducting the same experiments with same treatments and replications was sown in plots measuring 5 X 5m (25 m^2) during *rabi* 2014 at Forestry and Natural Resources, Research Farm, PAU, Ludhiana. Treatments included:

(i) Population counts of aphids, thrips, yellow mite, white fly, fruit borers encountered during the raising of crop

(ii) Two treatments for design of sticky traps

(iii) Six treatments comprising different insecticides and an untreated control each for sucking insect pests and fruit borer management.

3.3 Monitoring of insect pests

For monitoring purpose the chilli crop experimental plots were examined on weekly intervals for counting the insect populations encountered and categorized into target and non-target insects.

3.3.1 Target insect pests and mites

3.3.1.1 Aphids (*M. persicae* and *A. gossypii*)

In order to study the population dynamics of aphids infesting the chilli crop, the population data for the number of aphid individuals (nymphs and adults) were counted from four leaves/plant (two from upper canopy and two from lower canopy) of 5 randomly selected plants from each plot out of a total of seven plots in each replication. A magnifying hand lens (10 X) was used to see the aphid adults and nymphs present on the leaves (both upper and lower surface).

3.3.1.2 Thrips (*S. dorsalis*)

Five plants were selected randomly from each plot and observed for presence of thrips adults and nymphs using a 10 X magnifying hand lens. During vegetative stage the number of thrips (adults and nymphs) were counted from leaves (2 leaves from each canopy) and during reproductive stage the flowers and fruits were also observed along with leaves for the presence of thrips.



(a)



(b)

Plate 1: Trial at Bharti field fresh, Ladhowal, Ludhiana

3.3.1.3 Whitefly (*B. tabaci*)

Adult population of whitefly was counted from leaves of five randomly selected plants (2 leaves each from upper and lower canopy) from each plot. The plants were approached slowly without disturbing and the selected leaves were observed for presence of whitefly adult firstly on upper surface and then slowly by turning it to examine the lower surface of the leaf and number of whitefly adults encountered per leaf were recorded.

3.3.1.4 Fruit borers (*H. armigera* and *S. litura*)

The population of fruit borers was counted on whole plant basis from randomly selected 10 plants per plot. The plant was searched thoroughly for presence of larvae of *H. armigera* and *S. litura* and their number counted and noted down if present. For examining the damage done by borers, ten plants were selected randomly per plot and counted for total number of fruits and the number of damaged fruits per plant at weekly intervals after transplanting.

3.3.1.5 Mite (*P. latus*)

Mite (adult and nymph) populations were counted from five randomly selected and tagged plants in each plot. The plants were untagged after recording the mite population from four leaves (2 from each upper and lower canopy) from each tagged plant in the plot. These six leaves were plucked and collected in polythene bags, which were marked with the plot number, and examined under stereo binocular microscope in laboratory for counting the total number of mites per leaf.

3.3.2 Non-Target insects

3.3.2.1 Coccinellids and other coleopterans

The adult coccinellids were counted on the whole plant basis when encountered during data recording for the insect pests of chilli. The coleopterans which are well recognized for being coccinellids like lady bird beetle (*Coccinella septempunctata*) and *Menochilus sexmaculatus* were counted and their numbers were recorded and grouped into coccinellids whereas the other beetles were counted and grouped into coleopterans for diversity studies.

3.3.2.2 Spiders

Spiders were also counted on whole plant basis from the randomly selected plants for insect pest population studies and their number noted under the group spiders due to lack of identification of the species.

3.3.2.3 Other insects

All the other insects encountered were grouped under their respective orders and their numbers were counted from randomly selected plants (same plants which were selected for studying population of insect pests). Dipterans included syrphid flies, robber flies; Hemipterans were hoppers and jassids; and butterflies and moths were grouped under lepidopterans etc.

3.3.3 Statistical analysis for monitoring

The mean populations for each insect pest and other insects were calculated in Microsoft Excel® and using the computer programme CPCS 1. Percentage of number of species encountered was calculated order-wise to see which insect order occupies the maximum percentage among all the insect species. Peak activity periods were worked out based on the month wise population counts of the insects. Diversity, evenness and dominance indices were calculated. Correlation of insect pest populations with weather parameters (maximum, minimum and mean temperature, relative humidity, rainfall and sunshine hours) was calculated in Microsoft Excel® and their significance was tested with student's t-test for correlation coefficient. The formulas used for diversity indices are as follows:

(i) Simpson's index of diversity (Simpson, 1949)

$$\text{Simpson's index } (D_s) = \sum_{i=1}^{s} \frac{n_i (n_i - 1)}{N (N - 1)}$$

where, n_i = number of individuals in the ith species

N = total number of individuals in the sample

Reciprocal of Simpson's index of diversity ($1/D_s$) was used to express the diversity of species so that as the index goes up, so does the diversity.

(ii) Index of species diversity (Shannon and Weaver, 1963)

Shannon Weaver's index (H') = $- \Sigma p_i \log_e p_i$

where, p_i = the proportion of individuals of species i (n_i/N)

n_i = number of individuals in the ith species

N = total number of individuals of all the species

(iii) Evenness index (Pielou, 1966)

Evenness index (J) = $H'/ \log_e S$

Where, H' = Shannon-Weaver's index

S = number of species

(iv) Index of Dominance (Southwood, 1978)

Index of dominance (D) = 1-J

where, J = Evenness index

3.4 Yellow sticky traps

3.4.1 Shape of the trap

Two different shapes/designs of traps were tested in this experiment: vertical rectangular trap and vertical cylindrical trap. The traps were arranged in a row in the field with one trap per 50 m^2 (Each trap in the middle of two plots). The wooden poles, on which the traps were fixed, were installed 90 cm above the ground level within the chilli plots.

Construction of the traps:

(a) Vertical trap: Vertical traps were made of rectangular wooden boards [size 6 X 27 X 1 cm] using scrap wood. These rectangular wooden boards were then fixed on vertical wooden poles. Three such traps were made and used as three replications in the experimental plots. Each trap was fixed in the middle of two plots (1 trap per 50 m^2).

(b) Cylindrical trap: Cylindrical traps were made from two litre empty transparent plastic bottles each of same diameter. The upper and lower ends of the bottles were cut to keep it's length at 30 cm. These bottles were then attached to vertical wooden poles by iron nails and then fixed in the chilli field plots in three replications. Each trap was fixed in the middle of two plots (1 trap per 50 m^2).

(c) Sticky cards: Yellow sticky cards available in the market were bought and used on the surface of the traps. For rectangular traps the sticky cards were made to stick on both the surfaces of the rectangular wooden boards and stapled on the corners, so two cards were used for one rectangular sticky trap. For cylindrical traps, a single sticky card was wrapped around the each bottle and stapled where the ends overlapped.

3.4.2 Observations

The population of trapped insects were counted on the sticky cards at weekly intervals between 8 am to 10 am with the help of a 10 X magnifying hand lens and then replaced with the new sticky cards during *rabi* 2014.

3.4.3 Statistical analysis

Analysis of variance in Randomized Block Design (RBD) was performed on the mean populations trapped on sticky traps per month with shape, month and insect pest as independent variables using computer programme CPCS 1.

3.5 Management of insect pests of chilli

The treatments for managing the insect pests of chilli were grouped into two – management of sucking insects and management of fruit borers. The following treatments were applied to the chilli crop raised in the field in RBD with three replications:

3.5.1 Management of sucking insect pests and mites of chilli (aphids, thrips, whitefly and mites):

a) Thiomethoxam 25WG @ 30 g/acre
b) Thiomethoxam 25 WG @ 40 g/acre
c) Thiocloprid 21.7% SC @ 150 ml/acre
d) Thiocloprid 21.7% SC @ 200 ml/acre
e) Buprofenzin 25 EC @ 120 ml/acre
f) Buprofenzin 25 EC @ 240 ml/acre
g) Control

3.5.2 Management of chilli fruit borers (*H. armigera*):

a) Spinosad 48 SL @ 50 ml/acre

b) Spinosad 48 SL @ 60 ml/acre

c) Chlorantraniliprole 18.5 SL @ 40 ml/acre

d) Chlorantraniliprole 18.5 SL @ 50 ml/acre

e) Emamectin benzoate 5% SG @ 80 g/acre

f) Emamectin benzoate 5% SG @ 100 g/acre

g) Control

3.5.3 Observations

The population count of aphids, thrips, whitefly and mites before treatment and at 5, 7 and 15 days after treatment were recorded. Procedure followed for counting the insect pest population was same as used for the monitoring purpose. Larvae populations of *H. armigera* were examined before and after the treatment at same intervals. Total number of fruits and damaged fruits were counted on randomly selected 5 plants per plot. Residue analysis for the chemicals was done by the staff at Residue Analysis Lab, Department of Entomology, PAU, Ludhiana.

3.5.4 Statistical analysis

Mean populations of aphid, thrips, whitefly, mites and fruit borer were calculated using Microsoft Excel. Percentage fruit damage by fruit borers was calculated. ANOVA (RBD) performed separately for sucking insect pests and fruit borers in CPCS1 after transferring the mean populations to $\sqrt{x} + 1$. Percentage data was subjected to analysis of variance after arc sine transformation.

3.6 Residue analysis

3.6.1 Instruments:

The quantification of emamectin benzoate, thiacloprid and thiamethoxam residues were done by using high performance liquid chromatograph (HPLC). The high performance liquid chromatograph (Model DGU-2045) equipped with reverse phase (RP) C_{18} column and photo diode array (PDA) detector, dual pump was supplied by M/S Shimadzu Corporation, Kyoto, Japan. The HPLC column, a Luna 5µm C_{18} column (250 x 4.6 mm size, 5.20±0.30 µm particle size, 2.20±0.30 (90%/10%) particle distribution, 95±15 A° pore diameter, 430±40 m^2 g^{-1} surface area, < 55.0 ppm metal content, 19.00±0.70 % total carbon and 3.25±0.50 µmoles m^{-2} surface coverage) was obtained from M/S Spincotech Pvt. Ltd. Chennai, India. The sample injector was equipped with a 20 µL loop. For instrument control, data acquisition and processing, LC Solution software was used.

The residues of spinosad were quantified using a MSD sciex Applied Biosystem API 2000 Q-Trap mass spectrometer. The LC-MS was operated in the positive ion mode using multiple reaction monitoring (MRM) *i.e.* Declustering Potential (DP), Focusing Potential (FP), Entrance Potential (EP) and Collision Cell Entrance (CEP) of the transitions m/z 732.3 → 142.3. Collision energy (CE) and collision cell exit potential (CXP) were optimized for each transition monitored.

3.6.2 Extraction and cleanup:

(a) Emamectin benzoate:

A representative 20 g sample of chopped and macerated chilli fruits was placed overnight into a mixture of 50 mL methanol, 50 mL acetonitrile, 50 mL methanolic solution of 1% ammonium acetate and 1 mL triethanol amine in an Erlenmayer flask. The extract was filtered through glass wool plugged in filtering funnel into one litre separatory funnel. The residual material was rinsed with methanol and transferred to the same separatory funnel. The contents of separatory funnel were diluted with 600 mL brine solution and partitioned thrice into 100, 75 and 75 mL dichloromethane and was dried over anhydrous sodium sulfate. The organic layer was collected into 500 mL beaker and dried over anhydrous sodium sulfate. The extracts were cleaned up by using silica gel as an adsorbent. Before use, silica gel was activated at 110 °C for 2 hours. A glass column (60 cm x 1.5 cm i.d.) was packed with activated silica gel (10-12 g) in between the two small layers of anhydrous sodium sulphate supported on glass wool. The column was pre-washed with dichloromethane, following which the concentrated extract was poured over it. The glass beaker was rinsed with dichloromethane and the extract was transferred to the column. The extract was eluted with a freshly prepared solvent mixture of dichloromethane and ethyl acetate (2:1, v/v). The filtrate was concentrated to near dryness on a rotary evaporator under vacuum at < 35 °C to completely remove the traces of dichloromethane and the final volume was reconstituted to 5 mL with HPLC grade methanol.

(b) Thiacloprid and Thiamethoxam:

The chilli fruit samples were prepared following QuEChERS method for the determination of thiacloprid and thiamethoxam residues. A sub sample of 15 g of chilli fruit was weighed into a 50 mL centrifuge tube and then 15 mL acetonitrile was dispensed into it. The sample was homogenized using high speed homogenizer (Heidolph Silent Crusher-M®) for 2-3 min at 14,000-15,000 rpm. Sodium chloride (NaCl) 10 ± 0.1 g was added to homogenize the sample for phase separation. The contents were centrifuged at 2,500-3,000 rpm for 3 min. An aliquot of 15 mL acetonitrile layer was transferred over 10 ± 0.1 g sodium sulfate (Na_2SO_4) in a test tube. The acetonitrile extract was then subjected to cleanup by

dispersive solid phase extraction (DSPE). An aliquot of 6 mL acetonitrile was taken in a test tube containing 0.15 ± 0.01 g PSA sorbent, 0.90 ± 0.01 g anhydrous $MgSO_4$ and 0.05 ± 0.01 g graphitic carbon black and the contents were thoroughly vortexed on vortex shaker. Again it was centrifuged at 2,500-3,000 rpm for 1 min. 4 mL aliquot of this acetonitrile extract was taken for HPLC analysis.

(c) Spinosad:

Electrospray (ESI) was tested for determination of spinosad in both the positive and negative mode, respectively. ESI in the negative mode did not give any signal for spinosad, whereas in positive mode, the compound was detected with infusion at the rate of 0.6 mL/h of standard solutions of spinosad at 5000 µg/L. The experimental conditions were as follow: ionspray voltage (IS) 5500V; curtain gas 10 psi; temperature 250 ºC; ion source gas (1) 40 psi ion; source gas (2) 40 psi. The analyte ESI-MS/MS (±) transitions and instrument conditions employed were as follows: Precursor mass (m/z): 732.3 → 142.3, DP(V): 91, FP(V): 60, EP(V): 9.50, CE(V): 49, CEP(V): 42.0.

The residues of spinosad were quantified using a MSD sciex Applied Biosystem API 2000 Q-Trap mass spectrometer. The LC-MS was operated in the positive ion mode using multiple reaction monitoring (MRM) *i.e.* Declustering Potential (DP), Focusing Potential (FP), Entrance Potential (EP), Collision energy (CE) and Collision Cell Entrance (CEP) of the transitions m/z 732.3 → 142.3.

3.6.3 Estimation:

(a) Emamectin benzoate:

The HPLC analysis was carried out at column temperature 25ºC under isocratic condition methanol: water (80 : 20, v/v) with pump flow @ 0.5 mL min^{-1}. The instrument was set at wavelength of 245 nm. An injection volume of 20 µl was used in all experiments. Residues of emamectin benzoate were quantified by comparison of peak height/peak area of standards with that of unknown or spiked samples run under identical conditions. Under these operating conditions the retention time of emamectin benzoate was found to be 10.50 min.

(b) Thiacloprid and Thiamethoxam:

The HPLC analysis was carried out at column temperature 25ºC under isocratic conditions i.e. acetonitrile with pump flow @ 0.3 mL min^{-1}. The instrument was set at wavelength of 254 nm. Under these operating conditions the retention time of thiacloprid and thiamethoxam were found to be 9.9 and 9.6 min, respectively.

(c) Spinosad:

Electrospray (ESI) was tested for determination of spinosad in both the positive and negative mode, respectively. ESI in the negative mode did not give any signal for spinosad, whereas in positive mode, the compound was detected with infusion at the rate of 0.6 mL/h of

standard solutions of spinosad at 5000 μg/L. The experimental conditions were as follow: ionspray voltage (IS) 5500V; curtain gas 10 psi; temperature 250 ºC; ion source gas (1) 40 psi ion; source gas (2) 40 psi. The analyte ESI-MS/MS transition and instrument conditions employed were as follows: Precursor mass (m/z): 732.3 → 142.3, DP(V): 91, FP(V): 60, EP(V): 9.50, CE(V): 49, CEP(V): 42.0.

CHAPTER IV

RESULTS AND DISCUSSION

The study of population dynamics and management of insect pests of chilli was carried out at Bharti Field Fresh, Ladhowal, Ludhiana and at Forestry and Natural Resources Research Farm, PAU, Ludhiana during *kharif* 2013 and *rabi* 2014, respectively. The results of which are presented below under following titles:

4.1 Arthropod fauna chilli crop

4.2 Diversity indices of arthropods

4.2.1 Arthropod diversity

4.2.1.1 Arthropod diversity in *kharif* 2013 sown chilli

4.2.1.2 Arthropod diversity in *rabi* 2014 chilli crop

4.2.2 Diversity of major insect pests of chilli crop

4.3 Population dynamics and peak periods of activity of insect pests of chilli

4.3.1 Seasonal incidence of insect and mite pests of chilli

4.3.1.1 Aphids

4.3.1.2 Thrips

4.3.1.3 Whitefly

4.3.1.4 Mite

4.3.1.5 Fruit borer (*H. armigera*)

4.3.2 Correlation of insect and mite populations with weather parameters

4.4 Symptomology of various key insect and mite pest attack on chilli

4.4.1 Aphid

4.4.2 Thrips

4.4.3 Mite

4.4.4 Whitefly

4.4.5 Fruit borers

4.5 Efficiency of different trap shapes for capturing various insect pests of chilli

4.6 Management of insect pests of chilli

4.6.1 Management of sucking insect pests of chilli

4.6.1.2 Management of thrips

4.6.1.3 Management of mite

4.6.1.4 Management of whitefly

4.6.2 Management of fruit borer of chilli

4.6.3 Residue analysis of the chemicals

4.1 Arthropod fauna on chilli crop

During the present studies, 41 species of arthropods were found to be associated with the chilli crop at Ladhowal and at PAU, Ludhiana (Table 1). These arthropod species included 14 species of pests (P) of chilli constituting major, minor and sporadic pests (herbivorous arthropods), 14 species of natural enemies or beneficial (B), 12 species of casual visitors (C) and 1 species of pollinator (O). Among the total arthropod fauna, maximum number of species belonged to Coleoptera (11 species) representing 6 families, followed by Lepidoptera (6 species) representing 4 families, Hemiptera (4 species) representing 4 families, Hymenoptera (4 species) representing 3 families, Orthoptera (4 species) representing 2 families, Diptera, Odonata, Isoptera, Mites (2 species each), Dictyoptera, Thysanoptera, Neuroptera (1 species each). Among the beneficial insect species, order Coleoptera constituted the maximum (4 species), followed by Diptera, Hymenoptera and Odonata (2 species each). Amongst the chilli pest complex, order Orthoptera constituted the maximum (4 species), followed by Hemiptera (3 species), Lepidoptera and Isopteran (2 species each), Hymenoptera, Thysanoptera and mite (1 species each). Majority of the casual visitors on chilli crop were from order Coleoptera (7 species), followed by Lepidoptera (4 species) and Hemiptera (1 species). Mites belonged to mainly 2 families, Tarsonemidae and Phytoseiidae. The family Phytoseiidae includes predatory mites. Among the predatory insects, Coccinellids (*C. septempunctata, M. sexmaculatus* and *B. suturalis*), spiders and ants were the dominant species while beetles, butterflies and plant bugs were the prominent casual visitors on the chilli crop. Amongst various insect orders which were found associated with the chilli crop, order Coleoptera occupied 26.83 percent followed by Lepidoptera (14.63 percent), Hemiptera, Hymenoptera and Orthoptera (9.76 percent each). Diptera, Isoptera and Odonata occupied 4.88 percent each followed by Dictyoptera, Neuroptera and Thysanoptera (2.22 percent each). Other unidentified arthropod species and spiders represented 2.42 percent of total arthropod fauna associated with the chilli ecosystem (Table 2, Figure 1).

Earlier, Reddy and Puttaswamy (1983) recorded 51 species of insects and 2 species of mites belonging to 27 families under 9 orders in transplanted chilli crop of variety Byadgi at Dharwad, Karnataka. Reddy and Puttaswamy (1984) also recorded 35 species of insect pests and 1 species each of mite and snail infesting nursery of chilli crop at Dharwad, Karnataka.

Table 1: Arthropod fauna encountered in chilli ecosystem during *kharif* 2013 and *rabi* 2014

S.No.	Common/Scientific name	Family	Plant part harboured
Order: Coleoptera			
Beneficial arthropods/natural enemies			
1.	Lady bird beetle, *Coccinella septempunctata* (Linnaeus)	Coccinellidae	Aphids*
2.	*Menochilus sexmaculatus* (Fabricius)	Coccinellidae	Aphids*
3.	*Brumoides suturalis* (Fabricius)	Coccinellidae	Aphids*
4.	Rove beetle, *Paederus fuscipes* (Curtis)	Staphilinidae	Small insects*
Casual visitors			
5	*Rodolia cardinalis* (Mulsant)	Coccinellidae	Leaves
6.	*Zygogramma bicolorata* (Pallister)	Chrysomelidae	Leaves
7.	*Alticia cyanea* (Weber)	Chrysomelidae	Leaves
8.	Red pumpkin beetle, *Aulacophora foveicollis* (Lucas)	Chrysomelidae	Leaves
9.	*Myllocerus* spp.	Curculionidae	Leaves
10.	*Oxycetonia versicolor* (Fabricius)	Cetonidae	Flowers
11.	*Monolepta signata* (Olivier)	Galeuricidae	Leaves
Order: Dictyoptera			
Beneficial arthropods/natural enemies			
12.	European mantid, *Mantis religiosa* (Linnaeus)	Mantidae	Caterpillars, other insects*
Order: Diptera			
Beneficial arthropods/natural enemies			
13.	Syrphid fly, *Eristalis quinquestriatus* (Fabricius)	Syrphidae	Aphids*
14.	Robber fly, *Philodicus femoralis* (Ricardo)	Asilidae	Other insects*
Order: Hemiptera			
Pests			
15.	Whitefly, *Bemisia tabaci* (Gennadius)	Aleyrodidae	Leaves
16.	Aphid, *Myzus persicae* (Sulzer)	Aphididae	Leaves

17.	Jassid, *Amrasca biguttula biguttula* (Ishida)	Cicadellidae	Leaves
Casual visitors			
18.	Horn bug, *Oxyrhachis* spp. (Walker)	Membricidae	Leaves
Order: Hymenoptera			
Pests			
19.	Leaf ant, *Solenopsis geminate* (Fabricius)	Formicidae	Leaves, Flowers
Beneficial arthropods/natural enemies			
20.	*Eretomocerus* spp.	Aphelinidae	Whitefly*
21.	Black ant, *Polyrhachis simplex* (Mayr)	Formicidae	Small insects*
Pollinator			
22.	Carpenter bee, *Pithitis smaragdula* (Fabricius)	Anthophoridae	Flowers
Order: Isoptera			
Pests			
23.	*Microtermes obesi* (Holmgren)	Termitidae	Stem base, roots
24.	*Odontotermes obesus* (Rambur)	Termitidae	Stem, roots
Order: Lepidoptera			
Pests			
25.	*Helicoverpa armigera* (Hubner)	Noctuidae	Leaves, Fruits
26.	*Spodoptera litura* (Fabricius)	Noctuidae	Leaves, Fruits
Casual visitors			
27.	*Earias insulana* (Boisduval)	Noctuidae	Leaves
28.	Bihar hairy caterpillar, *Spilosoma obliqua* (Walker)	Arctiidae	Leaves
29.	Rice skipper, *Pelopidas mathias* (Fabricius)	Hesperidae	Leaves
30.	Cabbage butterfly, *Pieris brassicae* (Linnaeus)	Pieridae	Flowers
Order: Neuroptera			
Beneficial arthropods/natural enemies			
31.	Green lace wing, *Chrysoperla carnea* (Stephens)	Chrysopidae	Aphid, whitefly. Mite, small insects*

Order: Odonata			
Beneficial arthropods/natural enemies			
32.	*Pantala flavescens* (Fabricius)	Libellulidae	Small insects*
33.	*Coenagrion puella* (Linnaeus)	Coenagriidae	Small insects*
Order: Orthoptera			
Pests			
34.	Surface grasshopper, *Chrotogonus trachepaterus* (Blanchard)	Acrididae	Leaves
35.	*Acrida exaltata* (Walker)	Acrididae	Leaves
36.	*Oxya hyla hyla* (Serville)	Acrididae	Leaves
37.	Field cricket, *Gymnogryllus* spp.	Gryllidae	Leaves
Order: Thysanoptera			
Pests			
38.	*Scirtothrips dorsalis* (Hood)	Thripidae	Leaves, flower buds, fruits
Order: Araneae			
Beneficial arthropods/natural enemies			
39.	Spiders	-	Other insects*
Mites			
Pests			
40.	Yellow mite, *Polyphagotarsonemus latus* (Banks)	Tarsonemidae	Leaves, buds, fruits
Beneficial arthropods/natural enemies			
41.	Predatory mites, *Amblyseius* spp.	Phytoseiidae	Mites, thrips*

* Host/prey of beneficial arthropod species

Table 2: Percentage occupied status of different arthropod orders and families in chilli ecosystem during *kharif* 2013 and *rabi* 2014

Order	Family	Number of Insect spp. in family	% Occupied (Family wise)	% Occupied (Order wise)
Coleoptera	Coccinellidae	4	9.76	26.83
	Chrysomelidae	3	7.32	
	Curculionidae	1	2.44	
	Cetonidae	1	2.44	
	Staphilinidae	1	2.44	
	Galeuricidae	1	2.44	
Dictyoptera	Mantidae	1	2.44	2.44
Diptera	Syrphidae	1	2.44	4.88
	Asilidae	1	2.44	
Hemiptera	Anthophoridae	1	2.44	9.76
	Formicidae	2	4.88	
	Aphelinidae	1	2.44	
Isoptera	Termitidae	2	4.88	4.88
Hymenoptera	Anthophoridae	1	2.44	9.76
	Formicidae	2	4.88	
	Aphelinidae	1	2.44	
Lepidoptera	Noctuidae	3	7.32	14.63
	Arctiidae	1	2.44	
	Hesperidae	1	2.44	
	Pieridae	1	2.44	
Neuroptera	Chrysopidae	1	2.44	2.44
Odonata	Libellulidae	1	2.44	4.88
	Coenagriidae	1	2.44	
Orthoptera	Acrididae	3	7.32	9.76
	Gryllidae	1	2.44	
Thysanoptera	Thripidae	1	2.44	2.44
Mites	Tarsonemidae	1	2.44	4.88
	Phytoseiidae	1	2.44	
Others	Spiders and other insects	-	-	2.42

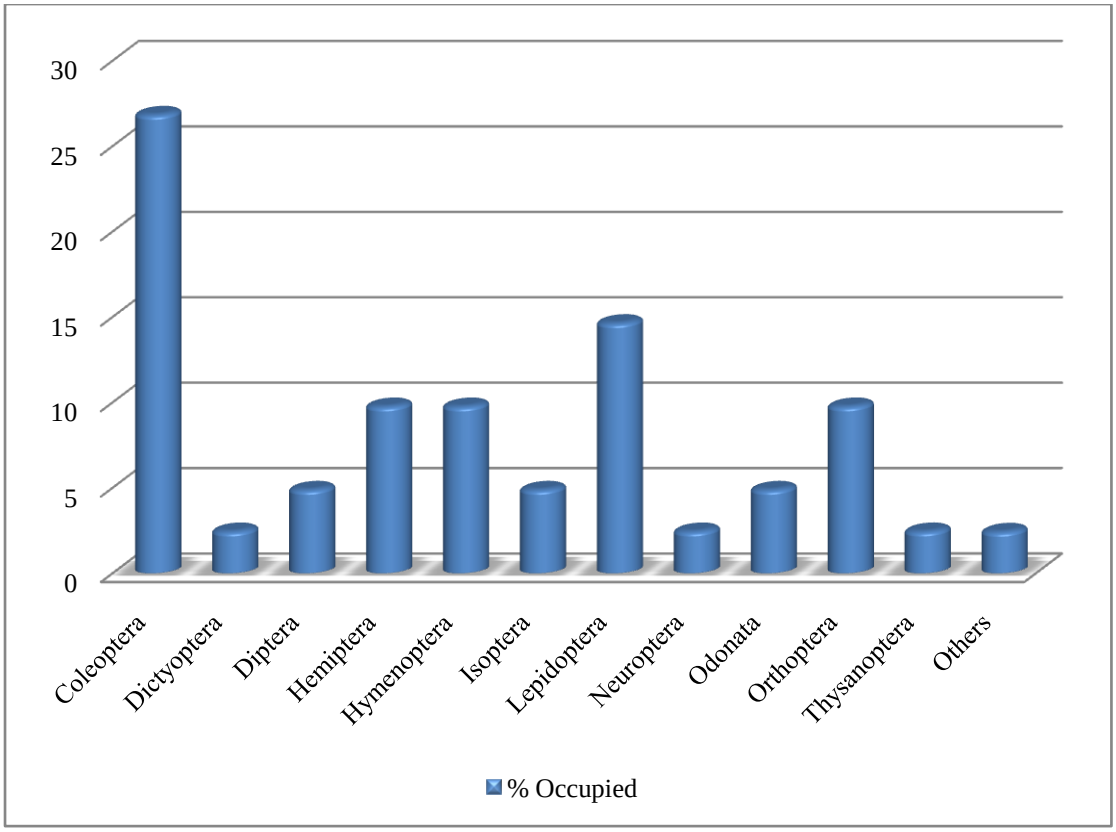

Fig. 1: Percentage occupied by different insect orders in total arthropod fauna found in chilli ecosystem

A total of 293 insect and mite species infest pepper plants in the field and some attack pepper fruits in storage. Some species such as aphids, thrips and mites attack more than one plant part. *M. persicae* (Sulzer) an aphid species which is an important virus vector is the most widespread insect infesting pepper in 37 countries including several tropical countries. Two other well-known virus vectors, an aphid (*A. gossypii* Glover) and a whitefly (*Trialeurodes vaporariorum* Westwood) occur in 13 and 10 countries, respectively. *A. gossypii* occur in the tropics as well as temperate areas. Two mite species, (*Hemitarsonemus latus* and *T. urticae* Koch) are also widespread and found in the tropics (Anonymous, 1987). Lawrence *et al.* (2000) reported that viruses (tobacco etch and potato Y), aphids (*M. persicae, A. gossypii*), the broad mite (*P.latus*) and gall midges (*Contarinia lycopersici* and *Prodiplosis longifila*) were the major pests of hot pepper. Extensive survey made on mites in Punjab, India by Dhooria (2003) revealed the occurrence of Tarsonemid mite, *P. latus* on chilli.

4.2 Diversity indices of arthropods

4.2.1 Arthropod diversity

The results determining the overall index values of arthropods belonging to different insect orders and mites encountered during monitoring studies of insect pests of chilli are presented in tables 3-4 and figures 2-4.

4.2.1.1 Arthropod diversity in *kharif* 2013 sown chilli

The diversity indices of arthropod fauna recorded in chilli ecosystem during *kharif* 2013 is represented in Table 3 and Figure 2. The Simpson's index of diversity (1/Ds) ranged from 1.98 to 3.88 during the *kharif* season with highest diversity during October (3.88) and lowest diversity during November (1.98). Similarly, The Shannon Weaver's Diversity index (H') varied from 0.99 to 1.52 in the recorded arthropod fauna with maximum diversity seen during October (1.52) and minimum during November (0.99). The diversity of arthropod fauna started increasing from September and reached its peak in October and declined again in November. The rise of diversity again in December is mainly due to appearance of some hairy caterpillars which were not present during November. Throughout the crop season in *kharif* the species were evenly distributed with low Dominance index and higher Evenness index except during November, where dominance index (0.55) is higher than the evenness index (0.45). Reason for high dominance is due to the higher number of thrips species present in November, when the other species number declined during this month. Overall diversity indices show that the arthropod community recorded in chilli ecosystem is a relatively diverse community with all the species distributed evenly during the *kharif* season. Overall Simpson's diversity index (3.17) ans Shannon Weaver's index (1.41) clearly show that the arthropod fauna associated with the chilli ecosystem is quite diverse. Evenness index (0.64) demonstrates the even distribution of all the species in the chilli crop without dominance of any particular species; same is also proved by the Dominance index (0.36) that no species was found to be dominant in the chilli crop during *kharif* 2013.

Table 3: Diversity indices of arthropods during *kharif* 2013

Month	Simpson's index (1/Ds)	Diversity index (H')	Evenness index (J)	Dominance Index (D)
September	3.27	1.49	0.68	0.32
October	3.88	1.52	0.66	0.34
November	1.98	0.99	0.45	0.55
December	2.27	1.05	0.65	0.35
Overall	3.17	1.41	0.64	0.36

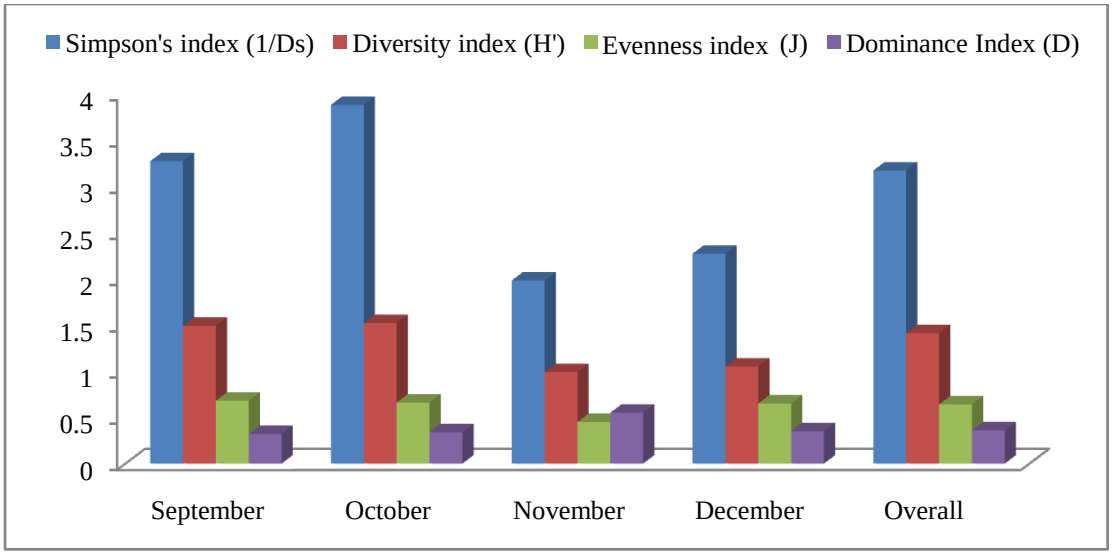

Fig. 2: Diversity indices of arthropod fauna during *kharif* 2013

4.2.1.2 Arthropod diversity in *rabi* 2014 chilli crop

The diversity indices worked out for *rabi* 2014 are shown in Table 4 and Figure 3. The maximum diversity can be seen during April (5.88) by Simpson's index but in May (1.76) by Shannon Weaver's index. Minimum diversity for both the diversity indices is same in March (2.33 and 0.88 in Simpson's and Shannon-Weaver's index, respectively). So, the maximum number of species were found in April and May and least number of species were found in March during *rabi* 2014. Overall diversity indices represent a relatively diverse community of arthropod fauna in chilli ecosystem with overall diversity index values of 4.92 and 1.76 in Simpson's index and Shannon Weaver's index, respectively. The higher values of diversity indices as compared to *kharif* season can be seen representing that the arthropod fauna was more diverse and more numbers of species were found during *rabi* season as compared to *kharif* season in chilli crop. Evenness index value (0.80) is also higher in *rabi* as compared to *kharif* (0.64) season demonstrating that the species recorded are more evenly distributed during *rabi* than the *kharif* season. Lower dominance (0.19) of species during *rabi* 2014 is comparatively lower than the dominance index (0.36) of kharif season proving that no species was dominant during both the seasons.

Table 4: Diversity indices of arthropods during *rabi* 2014

Month	Simpson's index (1/Ds)	Diversity index (H')	Evenness index (J)	Dominance Index (D)
March	2.33	0.88	0.80	0.19
April	5.88	1.68	0.94	0.06
May	4.99	1.76	0.85	0.15
June	3.92	1.64	0.79	0.21
Overall	4.92	1.76	0.80	0.19

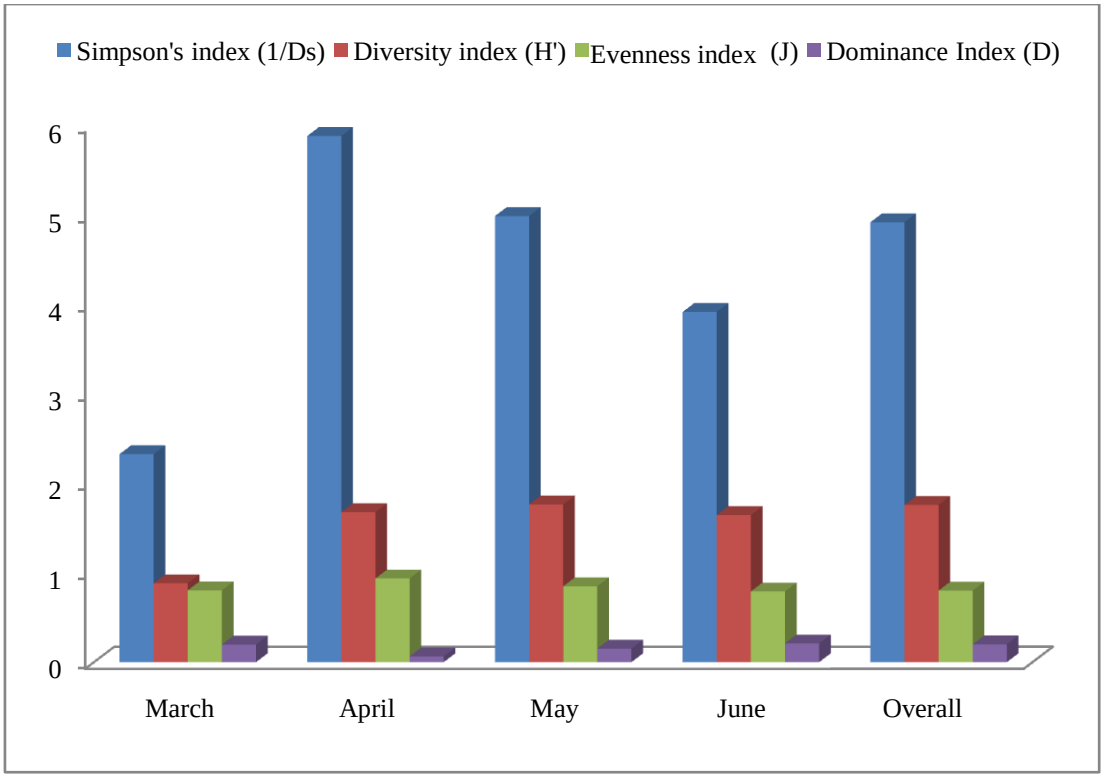

Fig. 3: Diversity indices of arthropod fauna during *rabi* 2014

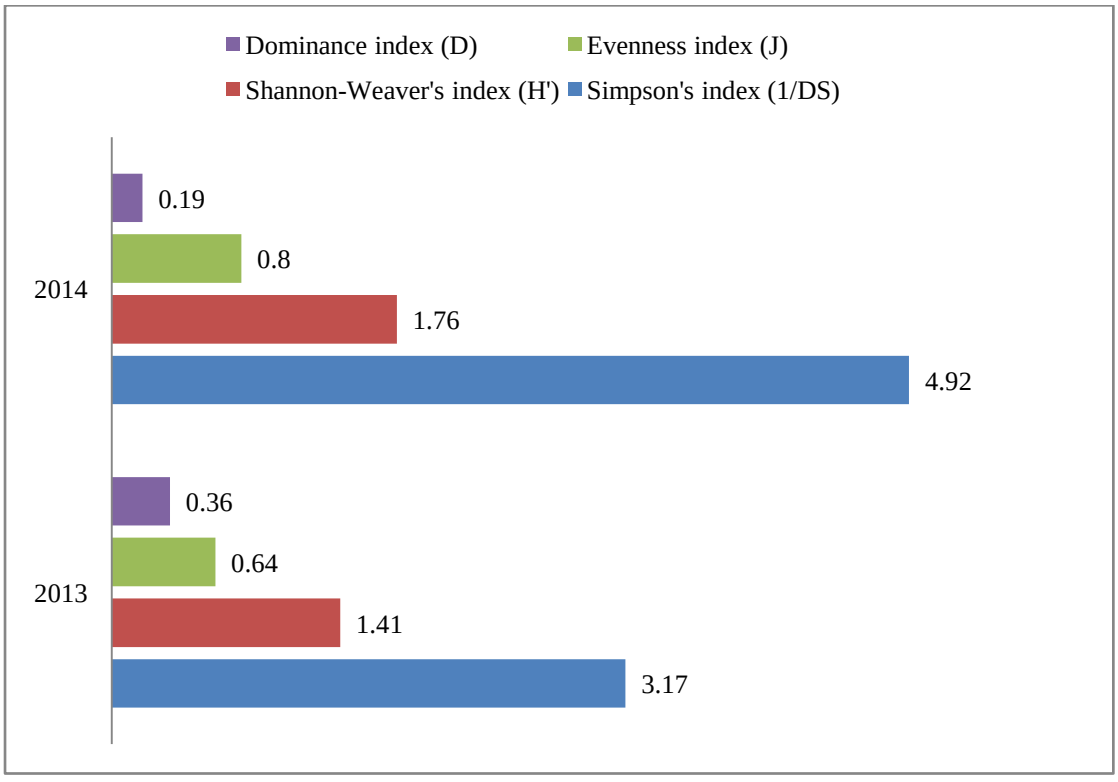

Fig.4: Overall diversity indices of arthropod fauna in chilli ecosystem during 2013 and 2014

4.2.2 Diversity of major insect pests of chilli crop

Thrips (*S. dorsalis*), Mite (*P. latus*), Whitefly (*B. tabaci*), Aphid (*M. persicae*) and Fruit borer (*H. armigera*) were recorded as the major pests of chilli crop during this study (Table 5). Maximum diversity of insect pests was observed during October 2013 and April 2014 according to the Simpson's index and during October 2013 and May 2014 according to the Shannon-Weaver's Index. Species were lastly evenly distributed during both the seasons except for September 2013 and March 2014 months which showed dominance of species rather than even distribution. During September 2013, there was dominance of thrips species as compared to other insect pest species and during March 2014 there was no other insect pest present except for aphids. Complete dominance is indicted by the maximum dominance index of 1 during March 2014.

Table 5: Diversity indices of major insect and mite pests of chilli during 2013 and 2014

Month-Year	Simpson's index (1/Ds)	Diversity index (H')	Evenness index (J)	Dominance index (D)
September	1.89	0.79	0.49	0.51
October	3.33	1.28	0.79	0.20
November	1.88	0.86	0.54	0.46
December	1.70	0.59	0.37	0.63
March	1	0	0	1
April	3.39	1.08	0.67	0.33
May	2.93	1.17	0.73	0.27
June	2.32	1.06	0.66	0.34

4.3 Population dynamics and Peak periods of activity of insect pests of chilli

4.3.1 Seasonal incidence of insect and mite pests of chilli

Seasonal incidence (weekly) and monthly population means were worked out for insect and mite pests of chilli crop during *kharif* 2013 and *rabi* 2014 (Table 6-7).

4.3.1.1 Aphids

The activity of aphids on chilli crop transplanted in fourth week of August (*kharif* crop) started in second week of September (0.32 aphid (adults and nymphs)/ four leaves). The population of aphids fluctuated throughout the season with a peak period of activity during second week of October (1.68 aphids/four leaves). From third week of October population started declining and reached to a lowest population of 0.24 aphids/four leaves during fourth week of November and thereafter, no population of aphids was seen during December (Table 6).

Aphid population started appearing during first week of March (0.45 aphids/four leaves) on *rabi* crop transplanted in last week of February. Population declined during April and then reached a peak in second week of May (1.14 aphids/four leaves). There was a gradual decrease in aphid population and reached a lowest population of 0.25 aphids/four leaves during second and third week of June. The aphid monitoring data exhibited peak monthly populations during October (1.17 aphids/four leaves) and May (0.51 aphids/four leaves) in *kharif* and *rabi* transplanted crop respectively (Table 7).

Tancik, 2001 reported that *M. persicae* started appearing from September and reached a peak firstly during October and then during May-June on peach trees and pepper crop in Slovakia. Peak populations of aphids were observed during first and second week of September on chilli crop in Rajasthan (Meena *et al* 2013). Peak activity of aphids is reported during July-August on potato (Musa *et al* 2004), tobacco (Athanassiou *et al* 2005) and okra (Shah *et al* 2009). In case of brinjal and hibiscus rosa-chinensis, peak population is reported during January (Karim *et al* 2001, Rajabpour and Yarahamadi 2012, respectively).

4.3.1.2 Thrips

Population of thrips also started appearing during September (0.84 thrips adults and nymphs/four leaves) in *kharif* crop. A gradual increase in population was observed with a peak population recorded during third week of October (10.17 thrips/four leaves). Population declined after that and a lowest population was observed during first week of December. A slight increase in population was observed in second and third week of December and the thrips population persisted till the crop was destroyed by frost.

During first week of April (0.11 thrips/four leaves) thrips population started appearing in *rabi* crop and gradually increased to a peak activity period in third week of May (0.37 thrips/four leaves). Population of thrips then declined and persisted upto second week of June (0.12 thrips/four leaves). Monthly population means represent the peak populations of thrips during October (5.90 thrips/four leaves) and May (0.33 thrips/four leaves). Results show similarity with previous studies on chilli thrips, which also showed that thrips population initiates during first week of September (Panickar and Patel 2001, Bhede *et al* 2008, Patel *et al* 2009). The peak activity periods are reported during December-January in Karnataka (Lingeri *et al* 1998), November and February-March in Gujarat (Patel *et al* 2009) and during 40th meteorological week in Maharashtra (Bhede *et al* 2008).

4.3.1.3 Whitefly

Whitefly population initiated during second week of September (0.17 whitefly adults/four leaves) and continuously persisted till the crop season (*kharif*). Peak activity period for whitefly was observed during third and fourth week of September (1.31 whitefly/four leaves). Population fluctuated throughout the season and minimum population of whitefly was recorded during fourth week of November (1.43 whitefly/four leaves). During

the *rabi* season chilli crop whitefly population started appearing in first week of May (0.45 whitefly/four leaves) and gradually reached to a peak population of 1.54 whitefly/four leaves in second week of June. Population persisted till the crop ended in third week of June with a minimum recorded population (0.45 whitefly/four leaves) in the same week. Populations of whitefly demonstrated peak activity periods during September (0.93 whitefly/four leaves) and June (0.97 whitefly/four leaves), respectively in *kharif* and *rabi* crop.

Earlier studies represent that the peak activity periods of whitefly population was at 77 days after transplanting in chilli (Khalid *et al* 2009) and 4-7 weeks after transplanting in case of brinjal (Fauziah *et al* 2009). Meena *et al* (2013) reported peak activity period of whitefly to be first and second week of September in chilli crop.

4.3.1.4 Mite

Mite populations were observed in *kharif* season crop only and not in *rabi* season crop. The reasons for that are believed to be sowing of *rabi* season crop in an isolated field which was surrounded by popular plantation and no initial inoculum was present in the field. The population of mite initiated in first week of October (2.77 mite adult and nymphs/four leaves) in *kharif* crop and increased to reach a peak population of 4.80 mites/four leaves in third week of October after that population declined and reached at a lowest population (0.74 mites/four leaves) in fourth week of November. Monthly mean populations of mite represented a peak activity period during May (3.89 mites/four leaves) in *kharif* transplanted crop.

Mite population reached at peak activity period in second week of September (Meena *et al* 2013) and during November and February (Lingeri *et al* 1998) in chilli crop. Patil and Nandihalli (2009) reported peak populations of mite in October and April-May in brinjal. In case of jute crop maximum populations of mite were observed ninety days after sowing (Kamruzzaman *et al* 2013).

4.3.1.5 Fruit borer (*H. armigera*)

The populations of *H. armigera* were recorded on chilli variety CH-1 (*rabi* crop) only and not in case of PEP-1 because of the failure of penetration by the larvae inside fruits of PEP-1 variety. Population of helicoverpa larvae started appearing during first week of April (0.05 larvae/plant) and peak activity was observed during third week of May (0.96 larvae/plant) in February transplanted crop. Lowest population was recorded in third week of June (0.04 larvae/plant). Helicoverpa demonstrated a peak activity period during the month of May (0.67 larvae/plant) based on the monthly mean populations. Peak incidence of larvae is reported during first fortnight of November in chilli crop (Nadaf and Kulkarni 2006). In chickpea crop peak activity periods reported are during third week of March (Sharma *et al* 2012), second week of April (Singh *et al* 2011), second week of January (Chatar *et al* 2010) and second fortnight of February and March (Chandel *et al* 2005).

Table 6: Incidence of major insect and mite pests of chilli crop during *kharif* 2013 and *rabi* 2014

Month-year	Week	Aphids/4 leaves	Thrips/4 leaves	Whiteflies/4 leaves	Mites/4 leaves	Helicoverpa Larvae/plant
September-2013	II	0.32	0.84	0.17	0	0
	III	0.31	0.85	1.31	0	0
	IV	0.11	0.88	1.31	0	0
October- 2013	I	0.74	2.11	0.31	2.77	0
	II	1.68	5.40	0.51	4.02	0
	III	1.08	10.17	0.40	4.80	0
November-2013	I	0.77	9.11	0.22	2.68	0
	II	0.70	7.73	0.31	1.14	0
	III	0.42	4.74	0.17	1.68	0
	IV	0.25	2.00	0.14	0.74	0
December-2013	I	0	1.00	0.20	0	0
	II	0	1.20	0.68	0	0
	III	0	1.14	0.57	0	0
March- 2014	I	0.45	0	0	0	0
	II	0.51	0	0	0	0
	III	0.54	0	0	0	0
April- 2014	I	0.45	0.11	0	0	0.05
	II	0.14	0.17	0	0	0.11
	III	0.11	0.20	0	0	0.14
	IV	0.08	0.25	0	0	0.17
May- 2014	I	0.66	0.24	0.45	0	0.08
	II	1.14	0.37	0.74	0	0.95
	III	1.05	0.37	0.94	0	0.96
June- 2014	I	0.12	0.20	0.95	0	0.25
	II	0.25	0.12	1.54	0	0.30
	III	0.25	0	0.45	0	0.04

Table 7: Mean populations of insect and mite pests of chilli during different months

Month	Aphid	Thrips	Whitefly	Mite	Helicoverpa
September	0.25 (1.12)*	0.86 (1.36)	0.93 (1.04)	0.00 (1.00)	0.00 (1.00)
October	1.17 (1.46)	5.90 (2.55)	0.41 (1.19)	3.89 (2.20)	0.00 (1.00)
November	0.54 (1.24)	5.21 (2.41)	0.26 (1.12)	1.56 (1.58)	0.00 (1.00)
December	0.00 (1.00)	1.14 (1.46)	0.43 (1.19)	0.00 (1.00)	0.00 (1.00)
March	0.50 (1.22)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
April	0.20 (1.09)	0.10 (1.05)	0.00 (1.00)	0.00 (1.00)	0.10 (1.05)
May	0.51 (1.21)	0.33 (1.15)	0.71 (1.31)	0.00 (1.00)	0.67 (1.03)
June	0.21 (1.00)	0.11 (1.05)	0.97 (1.39)	0.00 (1.00)	0.20 (1.09)
CD (5%)	NS	(0.70)	(0.14)	(0.27)	(0.29)

* Figures in paranthesis are square root transformed values

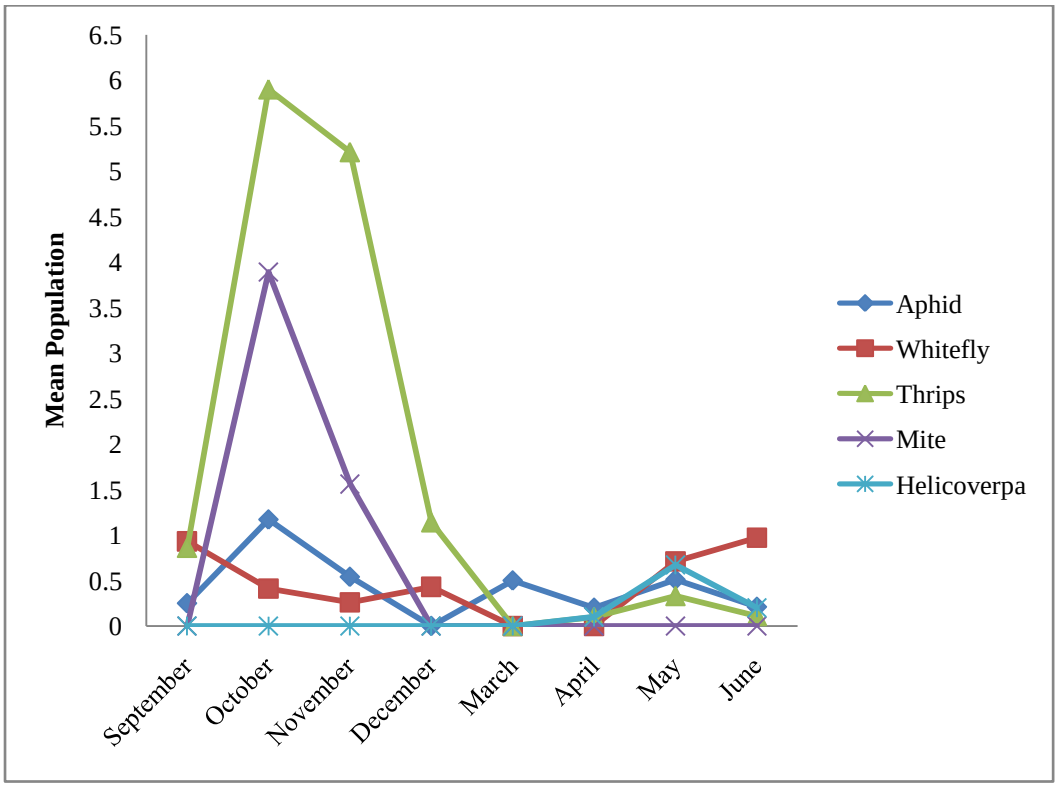

Fig. 5: Mean populations of insect and mite pests of chilli during different months

4.3.2 Correlation of Insect and mite populations with weather parameters

The data represented in table 8 reveals the correlation of insect and mite populations with meteorological factors (maximum temperature, minimum temperature, mean temperature, RH, rainfall and sunshine hours). The aphid population exhibited a significant positive correlation with maximum temperature, minimum temperature, mean temperature, RH and rainfall while the correlation was negative with sunshine hours. The findings confirmed the results obtained by Meena *et al* 2013 who reported a positive correlation with minimum and mean temperature, RH and average rainfall whereas, negative correlation is reported with maximum temperature. Bhatnagar *et al* 2012 reported positive correlation with maximum and minimum temperature while a negative correlation with RH and rainfall in potato crop. In case of brinjal aphid, populations showed negative correlation with mean temperature and RH whereas a positive correlation with sunshine hours (Karim *et al* 2001). Correlation studies on okra revealed a positive correlation with mean temperature and sunshine hours while a negative correlation with RH and rainfall (Shah *et al* 2009).

Whitefly populations had a significant positive correlation with maximum, minimum and mean temperature whereas a negative correlation with RH (corroborated by Khalid *et al* 2009, Selvaraj and Ramesh 2012 and Meena *et al* 2013) and rainfall. Other previous studies revealed that the whitefly population had positive correlation with maximum and minimum temperature but negative correlation with RH (Akram *et al* 2013, Umar *et al* 2003 and Khalid *et al* 2009). Thrips population had a significant negative correlation with minimum temperature and rainfall. Maximum and mean temperature, RH and sunshine hours had no significant correlation with thrips population. Results are supported by Meena *et al* 2013, Bhede *et al* 2008 and Patel *et al* 2009 who reported a negative correlation of thrips population with minimum and mean temperature, RH and rainfall.

Correlation studies of mite population revealed that there is a significant positive correlation with minimum and mean temperature and rainfall while a significant negative correlation is found with maximum temperature, RH and sunshine hours. The present findings concord with the findings of Patil and Nandihalli (2009) who reported that the yellow mite population showed negative correlation with morning and evening humidity, rainfall and age of crop. Chavan *et al* (2003) reported significant and positive correlation between temperature and mite population, while relative humidity and rainfall showed negative correlation with the pest, similar results were also obtained by Bhede *et al* (2008) who observed that the correlation of minimum temperature, morning and evening relative humidity with mite population was negative and non significant. Meena *et al* 2013 reported a negative correlation with maximum temperature and positive correlation with minimum temperature, mean temperature, RH and rainfall.

Population of fruit borer (*H. armigera*) represented a significant negative correlation with RH and rainfall and a non-signiifcant positive correlation with maximum, minimum and mean temperatures and sunshine hours. The results are similar to earlier reports by Singh *et al* 2011 and Sharma *et al* 2012 that showed a positive correlation with maximum and minimum temperature and a negative correlation with RH and rainfall in tomato crop and chickpea respectively whereas, Nadaf and Kulkarni (2006) reported positive correlations of Helicoverpa populations with all the weather parameters in chilli crop. The results do not match with the Chatar *et al* 2010 who reported a negative correlation of Helicoverpa population with maximum, minimum and mean temperature and a positive correlation with RH in chickpea.

Table 8: Correlation (r) between field incidence of insect pests and weather parameters in chilli ecosystem

S. No.	Weather parameter	Aphid	Whitefly	Thrips	Mite	Helicoverpa
1.	Maximum Temperature (^{o}C)	0.058*	0.508*	-0.192	-0.054*	0.691
2.	Minimum Temperature (^{o}C)	0.226*	0.465*	-0.114*	0.075*	0.462
3.	Mean Temperature (°C)	0.145*	0.505*	-0.159	0.009*	0.598
4.	Relative Humidity (%)	0.132*	-0.606*	-0.077	-0.065*	-0.055*
5.	Rainfall (mm)	0.094*	-0.089*	-0.121*	0.012*	-0.081*
6.	Sunshine (hrs)	-0.227*	0.075	-0.396*	-0.365*	0.551

* Significant at 5 per cent level

4.4 Symptomology of various key insect and mite pest attack on chilli

4.4.1 Aphid

Aphid populations mainly attacked the tender plant parts like shoots, leaves and flower buds. Populations of aphids were distributed aggregately in the field and on the plants also. Distribution of aphid population on plants was more towards the apical parts (plate 2d). The specific symptoms observed on the plant parts are described below:

(i) Leaves: The attacked leaves shrivelled, curled and drooped. Chlorosis was also observed on the leaves with higher populations of aphids. On some plants in the field due to excessive population on the younger leaves, black sooty mold development was also observed.

(ii) Flower buds: The flower buds were severely attacked; flower petals and sepals curled downwards and even fell off before they fully opened. There was less or no fruit setting on the branches which were heavily infested with the aphid adult and nymphal populations.



P. latus adults feeding on chilli leaf



Adult of *S. dorsalis*



Nymph and adult of *B. tabaci*



M. persicae adults and nymphs



H. armigera larva on chilli plant



S. litura larva on chilli plant

Plate 2: Insect and mite pests of chilli



(a) Damage of *P. latus* on leaves and fruits of chilli



(b) Damage of *S. dorsalis* on fruits and leaves of chilli

Plate 3: Damage symptoms of insect and mite pests of chilli



(c) Chilli leaf curl virus infected plant



(d) Damage of leaf feeding beetles





(e) Damage of *H. armigera* on PEP-1 and CH-1 variety of chilli

Plate 3: Damage symptoms of insect and mite pests of chilli

(iii) Overall plant: Plants which were infested in their early stages of growth showed stunted growth and yield was affected due to heavy infestation on flower buds during reproductive stage, which resulted in lower fruit development. Honey dew secreted by aphids attracted ants in high numbers and thus the plants infested with aphids were able to be identified even from a distance due to presence of ants in high numbers on these plants.

4.4.2 Thrips

Thrips were also observed mainly on upper plant parts, flowers and fruits. On leaves thrips were seen mostly around the mid rib of lower surface and inside the curled margins of the leaves (plate 2b). Thrips feeding caused following symptoms on different plant parts:

(i) Leaves: Infestation of thrips on the leaves caused upward curling of the leaves which initially started from the corners of the leaves and in severe infestations complete upward curling of the leaves was observed (plate 3b-i). Infested leaves showed puckering, thickening of the leaf lamina, appearance of silvery tissue on underside of leaf surfaces.

(ii) Flowers and buds: Flowers and young buds affected with thrips shrivelled and fell off early and showed less fruit setting.

(iii) Fruits: Infested fruits had a typical symptom of formation of brown coloured scars and corky tissue near the base of the fruits caused by the scratching of the thrips (plate 3b-ii).

4.4.3 Mite

Mite populations were observed on upper as well as lower canopy of the plants but nymphal populations were mainly found on the young tender leaves from the apical part of the plants. Population was mainly found feeding on the lower surface (plate 2a) only however occassionally the adult mites were sometimes also observed on the upper surface of the leaves.

(i) Leaves: Infested leaves showed downward curling, cupping, elongated petioles, thickening of leaf lamina and also colour of the leaves turned to dark green rather than the normal green leaves (plate 3a-i).

(ii) Fruits: Infested fruits were deformed and had a corky tissue development on the surface which resulted in constricted fruits (plate 3a-ii). Plants infested at early stages showed stunted growth and reduced fruit setting.

4.4.4 Whitefly

Whitefly adults were found equally on upper and lower canopy of the plants (plate 2c). Following symptoms were observed due to whitefly infestation:

(i) Leaves: Infested leaves exhibited chlorosis, withering, early leaf fall and even wilting in severe cases. There was also sooty mold development on few plant leaves due to honey dew excretion by whiteflies.

(ii) Virus transmission: Whitefly transmitted chilli leaf curl virus which was observed to be the major damaging symptom responsible for higher yield losses. The plants infected with virus demonstrated yellowing and severe curling (plate 3c).

4.4.5 Fruit borers

Fruit borers *H. armigera* (plate 2e) and *S. litura* (plate 2f) were observed during monitoring of the insect pests of the chilli. Helicoverpa was more predominant among the two and populations were found hiding under leaves during daytime. Helicoverpa damage symptoms were seen on tender twigs as well as the fruits.

(i) Twigs: It cut the tender apical twigs which hang from the cut point downwards and dries with time.

(ii) Fruits: On the fruits, typical symptom of fruit borer feeding was seen near the base of the fruit i.e. towards the stalk. The larvae were sometimes seen to be completely entered inside the fruit. During *kharif* season Jalapeno variety PEP-1 was transplanted, although no larval population was observed on this variety but slight feeding symptoms (plate 3e-i) were observed on the surface of few fruits of plants growing on margins of the field. Larvae did not show penetration inside the fruit instead the feeding holes made on fruits, near base of the fruit, were limited to the surface only. Whereas, in case of *rabi* transplanted variety CH-1 larvae showed complete feeding symptoms with boring inside the fruit near stalk end (plate 3e-ii) and even completely feeding inside the fruit. Spodoptera was found rarely and was seen feeding on the leaves mainly. The feeding holes on fruits were not limited to a particular part of the fruit in case of spodoptera.

4.5 Efficiency of different trap shapes for capturing various insect pests of chilli

During 2014 *rabi* crop, mean number of aphid (*M. persicae*), whitefly (*B. tabaci*), coccinellids (*C. septumpunctata* and *M. sexmaculatus*), dipterans, hymenopterans and hoppers trapped on sticky traps are presented in table 9 and figure 6. The highest mean populations of aphids trapped were 33.33 and 21.33 aphids/trap on rectangular and cylindrical yellow sticky traps respectively, during the month of June. It was followed by March (18.67 and 12.00 aphids/trap) and April (1.67 aphids/trap on each trap shape). Mean number of aphids trapped fluctuated in different months with no population trapped in the month of May. The data demonstrates that in each month the mean populations of aphids trapped on yellow sticky traps were higher in case of rectangular shape as compared to the cylindrical shape (Figure 7).

Rectangular shaped yellow sticky traps were also better to trap whitefly adults than the cylindrical traps throughout the crop season except during the month of March when the whitefly adults trapped were higher in case of cylindrical traps (figure 8). Highest population of whitefly was trapped during June in case of both rectangular and cylindrical yellow sticky traps (57.00 and 38.33 whitefly adults/trap, respectively) followed by May (15.67 and 8.67 whitefly/trap),

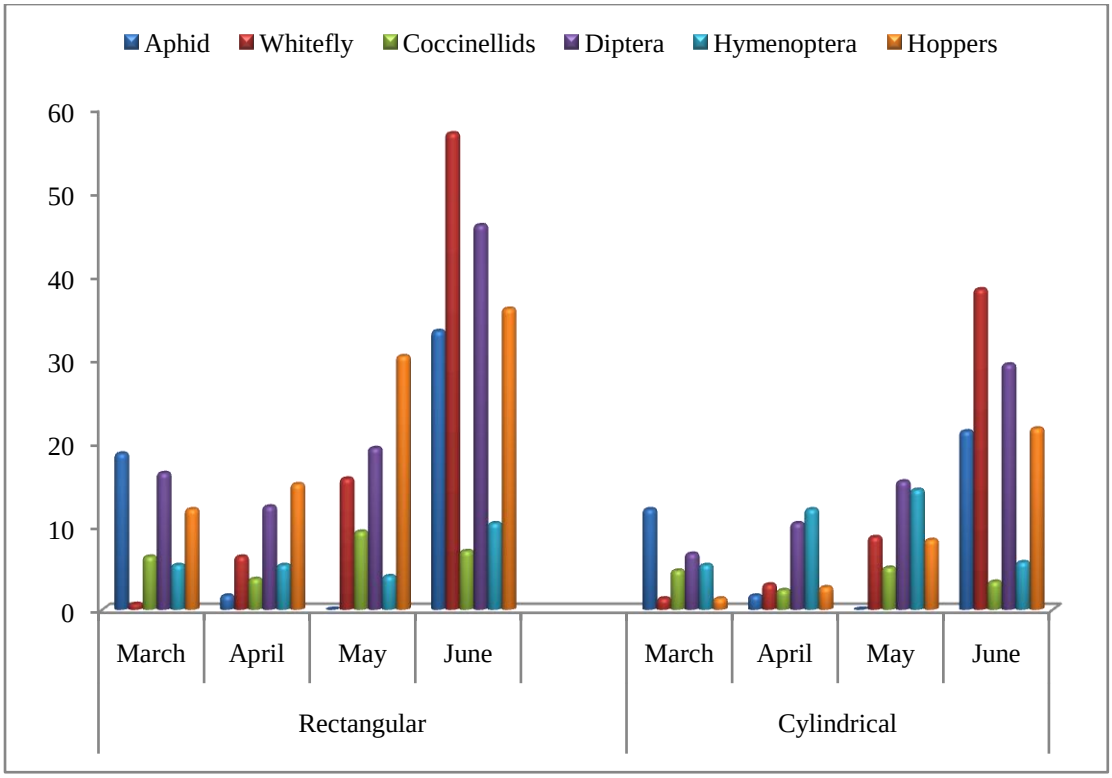

Fig. 6: Mean populations of insects trapped on rectangular and cylindrical traps during different months (2014)

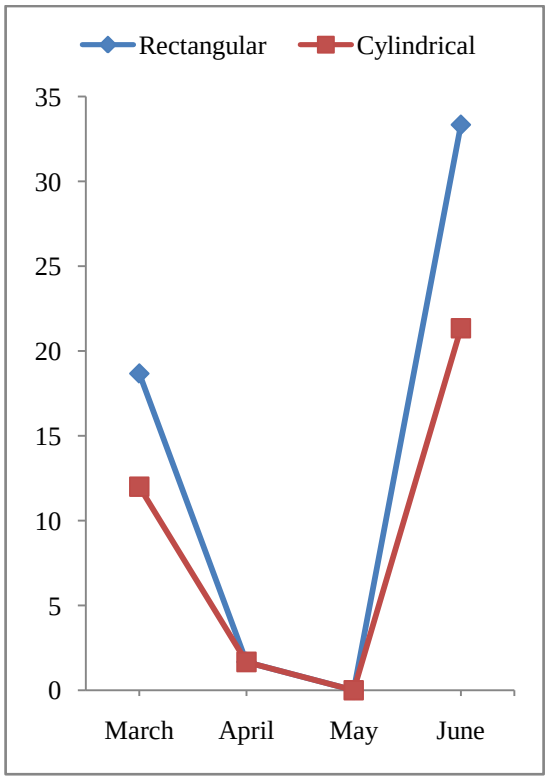

Fig. 7: Mean population of aphids trapped on yellow sticky traps

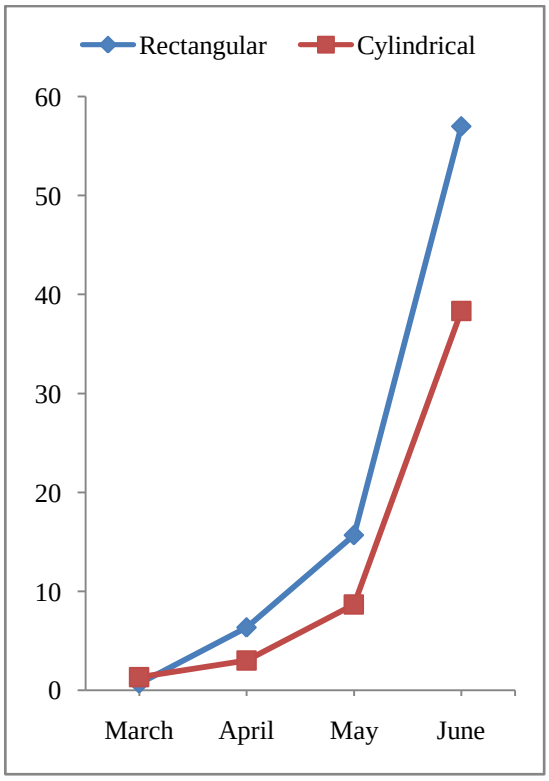

Fig. 8: Mean population of whitefly trapped on yellow sticky traps

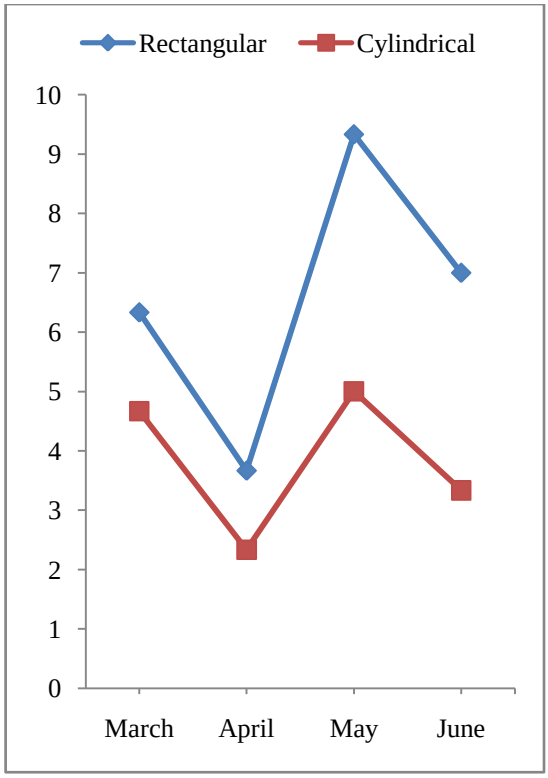

Fig. 9: Mean population of coccinellids trapped on yellow sticky traps

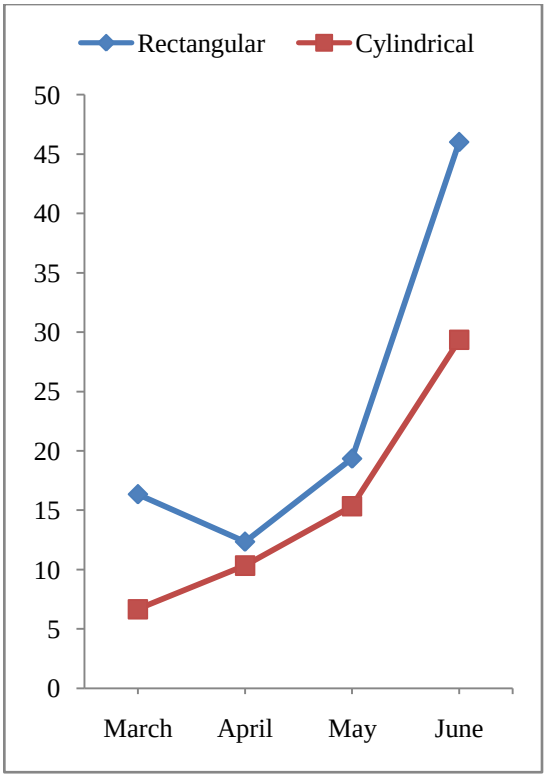

Fig. 10: Mean population of dipterans trapped on yellow sticky traps

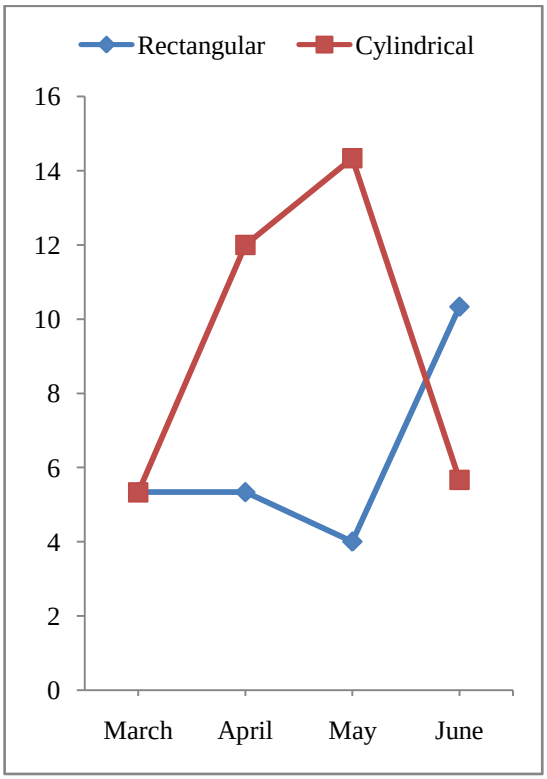

Fig. 11: Mean population of hymenopterans trapped on yellow sticky traps

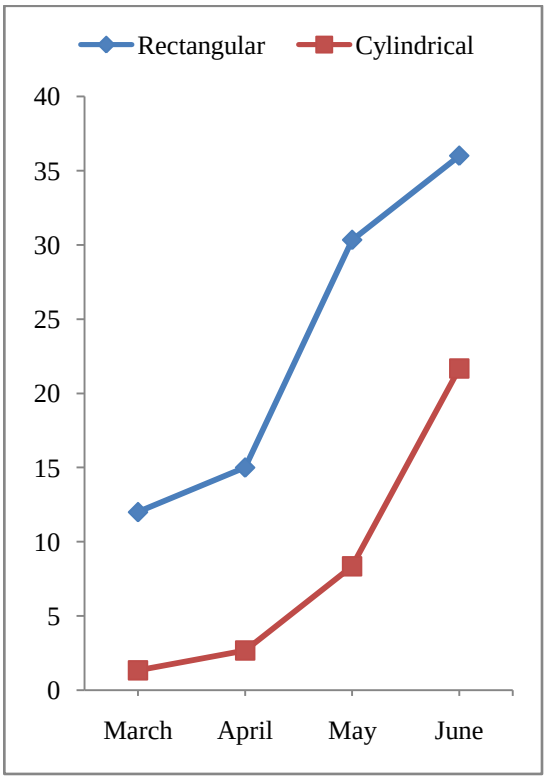

Fig. 12: Mean population of hoppers trapped on yellow sticky traps

April (6.33 and 3.00 whitefly/trap) and March (0.67 and 1.33 whitefly/trap). Thus, it can be concluded that the whitefly populations increased gradually from March to June. In case of coccinellids the highest population was trapped during May in both rectangular and cylindrical yellow sticky traps (9.33 and 5.00 coccinellids/trap, respectively) followed by March (6.33 and 4.67 coccinellids/trap), June (7.00 and 3.33 coccinellids/trap) and April (3.67 and 2.33 coccinellids/trap). The population of coccinellids also fluctuated during different months and rectangular traps were better than the cylindrical traps to capture the coccinellids (Figure 9).

The dipteran flies trapped were highest in the month of June (46.00 flies/trap) followed by March (16.33 flies/trap), May (19.33 flies/trap) and April (12.33 flies/trap) on the rectangular yellow sticky traps. On cylindrical yellow sticky traps highest population was also during June (29.33 flies/trap) followed by May (15.33 flies/trap), April (10.33 flies/trap) and March (6.67 flies/trap). Rectangular sticky traps were comparatively better than the cylindrical traps in catching the dipteran insects throughout the crop season (Figure 10).

Hymenopterans demonstrated an opposite trend of the populations trapped on yellow sticky traps as the cylindrical traps performed better than the rectangular sticky traps (figure 11) during all the months except during June where, rectangular traps captured more population than the cylindrical sticky traps. The highest population trapped on rectangular yellow sticky traps was during June (10.33 hymenopterans/trap) followed by May (4 hymenopterans/trap), April and March (5.33 hymenopterans/trap each). On cylindrical yellow sticky traps highest number of hymenopterans were trapped during May (14.33 hymenopterans/trap) trailed by April (12.00 hymenopterans/trap), June (5.67 hymenopterans/trap) and March (5.33 hymenopterans/trap).

Hopper populations trapped on yellow sticky trap exhibited higher catch intensity on the rectangular sticky traps as compared to the cylindrical sticky traps (figure 12). Population of hoppers fluctuated during the season with a maximum trapped population during June (36.00 and 21.67 hoppers/trap) on rectangular and cylindrical traps both. Least trapped population was recorded during March (12.00 and 1.33 hoppers/trap). Monthly means of combined insect populations trapped on yellow sticky traps represented that the maximum insect populations were trapped during June on both rectangular and cylindrical sticky traps (31.61 and 19.94 insects/trap, respectively). Second highest peak population trap was during May (13.11 and 8.61 insects/trap) in both shapes of traps followed by May (9.89 insects/trap) in case of rectangular traps and April (5.33 insects/trap) on cylindrical sticky traps.

The trap shape significantly affected the amount of insects trapped on the yellow sticky cards. On basis of overall insect populations trapped on both shapes of sticky traps the dipteran population (19.46 dipterans/trap) was the highest in numbers as compared to other insects followed by whitefly (16.38 whitefly/trap), aphid (11.08 aphids/trap), hymenopterans

Table 9: Mean number of insect trapped on rectangular and cylindrical sticky traps during different months (2014)

Trap	Months	Aphid[1]	Whitefly[2]	Coccinellids[3]	Diptera[4]	Hymenoptera[5]	Hoppers[6]	Mean
Rectangular	March	18.67	0.67	6.33	16.33	5.33	12.00	15.50
	April	1.67	6.33	3.67	12.33	5.33	15.00	
	May	0.00	15.67	9.33	19.33	4.00	30.33	
	June	33.33	57.00	7.00	46.00	10.33	36.00	
Cylindrical	March	12.00	1.33	4.67	6.67	5.33	1.33	9.78
	April	1.67	3.00	2.33	10.33	12.00	2.67	
	May	0.00	8.67	5.00	15.33	14.33	8.33	
	June	21.33	38.33	3.33	29.33	5.67	21.67	
Mean ($\overline{X}$)	-	11.08	16.38	5.21	19.46	7.79	0.92	

CD (5%): Shape = 2.09 Shape X Time = 4.18 Shape X Time X Insect = NS
Time = 2.95 Shape X Insect = 5.12
Insect = 3.62 Time X Insect = 7.24

1. *M. persicae* (aphid)
2. *B. tabaci* (whitefly)
3. *Coccinella septempunctata* (lady beetle) and *Menochilus sexmaculatus*
4. *Musa domestica* (Housefly), *Eristalis quinquestriatus* (Syrphid fly) and *Philodicus femoralis* (Robber fly)
5. Unidentified hymenopterans
6. Unidentified hoppers

Table 10: Mean populations of insects trapped on sticky trap designs (pooled months)

Insect / Shape	Aphid	Whitefly	Coccinellids	Diptera	Hymenoptera	Hoppers	
Rectangular	13.42	19.92	6.58	23.50	6.25	23.33	15.50
Cylindrical	8.75	12.83	3.83	15.42	9.33	8.50	9.78
	11.08	16.38	5.21	19.46	7.79	0.92	

CD (5%) Trap shape= 1.74; Insect= 3.02; ShapeXInsect= 4.27

Table 11: ANOVA table for interacting factors in traps catches

SOURCE	d.f.	Sum of squares	F-value	CD (5%)
Shape	1	1178.78	29.56	2.09
Time	3	2892.49	72.55	2.95
Insect	5	731.21	18.34	3.62
Shape X Time	3	154.17	3.87	4.18
Shape X Insect	5	213.51	5.36	5.12
Time X Insect	15	485.98	12.19	7.24
Shape X Time X Insect	15	34.79	0.87	NS
Error	94	39.87		

(7.79 insects/trap), coccinellids (5.21 coccinellids/trap) and hoppers (0.92 hoppers/trap). After pooling the monthly data to obtain the mean values of each insect per rectangular and cylindrical trap represented that for all the insects except hymenopterans, the rectangular traps were a better option than the cylindrical traps (Table 10). The mean populations of alate insects captured on rectangular yellow sticky traps (15.50) were also higher than the cylindrical yellow sticky traps (9.78).

There was a significant difference in different trap shapes i.e. rectangular and cylindrical traps ($F=29.56$, $df=1$ and 94, $p<0.05$) (Table 11) in catching alate insects. A significant difference was also found between time i.e. different months ($F=72.55$, $df=3$ and 94, $p<0.05$) and different insects trapped ($F=18.34$, $df=5$ and 94, $p<0.05$). The interaction between trap shape, time and insects trapped was found to be non-significant whereas, interactions between trap shape and time ($F=3.87$, $df=3$ and 94, $p<0.05$), trap shape and insect ($F=5.36$, $df=5$ and 94, $p<0.05$) and time and insect ($F=12.19$, $df=15$ and 94, $p<0.05$) were observed to be significant.

Previous studies by Moreau *et al* (2011) reported effectiveness of using yellow sticky cards in capturing whitefly population, which resulted in less settling of whiteflies on *C.*

annuum. Rectangular yellow sticky traps are reported to be effective in monitoring the insect pests (whitefly, thrips and leaf hopper) of capsicum (Nandini *et al* 2012). Our results are however not in accordance with the earlier reports of Idris *et al* (2012) who reported cylindrical yellow sticky traps as most effective in trapping whitefly as compared to other colours and shapes of sticky traps. Rajabpour and Yarahamadi (2012) also reported the effectiveness of yellow sticky traps in catching early populations of aphids. Effectiveness of rectangular yellow sticky traps equivalent to yellow water pan traps have been reported by Bowie (2010). Vertical position of yellow sticky traps is reported to be better than the horizontal position in trapping thrips and jassids whereas whiteflies demonstrated no significant difference in position of trap (Gencsoylu 2007). In case of thrips, blue (Elekcioglu 2013), white-blue and white trap colours have been reported to be better than the yellow sticky traps (Larrain *et al* 2006).

4.6 Management of insect pests of chilli

Different insecticides and various dosages were tested for their efficacy against key sucking insect pests and Fruit borer (*H. armigera*) during 2014. The data with the various insecticides were recorded before spray (pre treatment) and after 5, 7 and 15 days of sprays.

4.6.1 Management of sucking insect pests of chilli

All the insecticides sprayed were significantly better than the untreated control for managing the sucking pests (aphids, thrips, mites and whitefly). Effectiveness of different insecticides on different insects is discussed as below.

4.6.1.1 Management of aphids

There was a significant difference in all the treatments of insecticides applied after five, seven and fifteen days of spray. Five days after the insecticides application the results showed that all the treatments were significantly better than the control. The average lowest pest populations were recorded with Thiocloprid 21.7 % SC @ 200 ml per acre (5.85 aphids/leaf) followed by Thiocloprid 21.7 % SC @ 150 ml per acre (6.14 aphids/leaf) and Thiomethoxam 25 WG @ 40 (6.93 aphids/leaf) and 30 (7.57 aphids/leaf) g per acre, respectively. The highest populations were recorded with Buprofenzin 25 EC @ 120 and 240 ml per acre (9.30 and 8.77 aphids/leaf). All the treatments were statistically at par with each other after five days of the treatment. Untreated control had a population of 40.25 aphids/leaf.

At seven days after transplanting, the lowest populations of aphids were recorded in plots treated with Thiocloprid 21.7 % SC @ 200 and 150 ml per acre (12.08 and 12.13 aphids/leaf, respectively) followed by Thiomethoxam 25 WG @ 40 and 30 g per acre (12.86 and 13.71 aphids/leaf). The highest populations were recorded with Buprofenzin 25 EC @ 120 and 240 ml per acre (15.43 and 15.03 aphids/leaf). All the treatments were at par with each other statistically seven days after treatment whereas at fifteen days after treatments,

Thiocloprid 21.7 % SC @ 200 and 150 ml per acre were at par with each other and also had the lowest population observed i.e. 10.08 and 15.36 aphids/leaf. It was followed by Thiomethoxam 25 WG @ 40 and 30 g per acre (16.67 and 17.03 aphids/leaf). Both the dosages of Thiomethoxam and Buprofenzin and lower dose of Thiocloprid (150 ml per acre) were statistically at par with each other, where Buprofenzin had the highest population (19.95 and 18.38 aphids/leaf, respectively at the dosages of 120 and 240 ml per acre). Untreated control population was 39.32 and 41.43 aphids/leaf respectively, at seven and fifteen days after treatment.

Mean populations data of aphids after the treatments revealed that Thiocloprid 21.7 % SC @ 200 ml per acre (9.34 aphids/leaf) was the most effective insecticide in controlling aphid populations followed by Thiocloprid 21.7 % SC @ 150 ml per acre (11.21 aphids/leaf). Buprofenzin 25 EC @ 120 and 240 ml per acre were the least effective insecticide treatments which represented the highest aphid populations (14.89 and 14.06 aphids/leaf). Overall mean population for untreated control was 40.33 aphids/leaf.

Syed *et al* 2005 reported Thiamethoxam 25 WG @ 24 g a.i/acre to be the best treatment for management of aphids on tobacco crop and Spinocyd 240 SC @ 66 ml a.i/acre as the least effective dose. Thiamethoxam also proved to be the best treatment (in comparison to Imidacloprid) on the basis of LC 50 analysis done by Gavkare *et al* 2013 whereas, Khan *et al* 2011 reported Imdicloprid to be more effective than the Thiamethoxam. Buprofenzin was least effective in managing aphids on cucumber providing least mortality of 55.08 percent as compared to Pyriproxyfen, Flufenoxuron, Azadirachtin and Pymetrozine (Makareminia *et al* 2014).

4.6.1.2 Management of thrips

The data recorded five days after imposition of treatments indicated that Buprofenzin 25 EC @ 240 ml per acre was the most effective with the lowest population of thrips (0.05 thrips/leaf) followed by Thiocloprid 21.7 % SC @ 200 ml per acre (0.07 thrips per four leaves) and Buprofenzin 25 EC @ 120 ml per acre (0.09 thrips/leaf). Thiocloprid 21.7 % SC @ 150 ml per acre (0.11 thrips/leaf), Thiomethoxam 25 WG @ 30 (0.16 thrips/leaf) and 40 (0.13 thrips/leaf) g per acre also demonstrated a significant control over the untreated control (0.82 thrips/leaf). All the treatments were statically at par with each other in controlling the thrips populations and were significantly superior over the control.

Seven days after the treatment the most effective insecticides were observed to be Thiocloprid 21.7 % SC @ 200 ml per acre (0.04 thrips/leaf) and Buprofenzin 25 EC @ 240 ml per acre (0.05 thrips/leaf). These were followed by Thiocloprid 21.7 % SC @ 150 ml per acre and Thiomethoxam 25 WG @ 40 g per acre (0.07 thrips/leaf each). The highest population of thrips was recorded with Buprofenzin 25 EC @ 120 ml per acre (0.11 thrips/leaf) and Thiomethoxam 25 WG @ 30 g per acre. However, all the treatments were

significantly better in efficacy as compared to the untreated control and were statically at par with each other.

The post treatment data at fifteen days after spraying showed that Thiocloprid 21.7 % SC @ 150 ml per acre (0.11 thrips/leaf) and Buprofenzin 25 EC @ 240 ml per acre (0.13 thrips per acre) were the most effective treatments in reducing the thrips populations. The next best treatments were Thiomethoxam 25 WG @ 40 and 30 g per acre (0.16 and 0.18 thrips/leaf, respectively). Thiocloprid 21.7 % SC @ 200 ml per acre and Buprofenzin 25 EC @ 120 ml per acre treated plots had the highest thrips populations of 0.27 and 0.22 thrips/leaf. However, all the treatments were significantly superior than the control and statically at par with each other.

Overall mean efficacy of treatments revealed that Buprofenzin 25 EC @ 240 ml per acre was the most effective dose with highest reduction in thrips population (0.07 thrips/leaf) followed by Thiocloprid 21.7 % SC @ 150 ml per acre (0.09 thrips/leaf). Thiomethoxam 25 WG @ 30 g per acre and Buprofenzin 25 EC @ 120 ml per acre were the least effective dosages with highest mean thrips populations of 0.14 thrips/leaf each. However, as all the treatments were statically at par with each other and there is very less significant difference (0.05) between these trearments, so all are eqally effective. Seal and Kumar (2010) tested neonicotinoids, spinosyns, pyrethroids and entomopathogenic fungus against *S. dorsalis* infesting jalapeno *C. annuum* and reported that Imidacloprid was the most effective of all. Thiamethoxam 0.005 % and Acetamiprid 0.004 % was found to be the most effective in managing thrips as compared to the neem pesticide 0.4 % and *B. thuringenesis* (Mandi and Senapati 2009). Sontakke and Mohapatra (2014) reported Buprofezin 25 SC @ 75 and 150 g a.i./ha to be the most effective against thrips and mites on chilli and safest to natural enemies in comparison to Ethion 225 g a.i./ha and Profenofos 500 g a.i./ha. Buprofezin 25 EC @ 75 and 150 g a.i./ha was also effective against sucking insect pests of cotton (whitefly, jassid, aphid and thrips) (Sontakke *et al* 2013).

4.6.1.3 Management of mite

Among the different insecticide treatments, higher dose of Buprofenzin 25 EC (240 ml per acre) gave the best result in managing mite populations (0.76 mites/leaf) five days after treatment followed by lower dose of 120 ml per acre of Buprofenzin 25 EC (1.24 mites/leaf). Thiomethoxam 25 WG @ 40 g per acre and Thiocloprid 21.7 % SC @ 200 ml per acre were equally effective in controlling mite population (1.29 mites/leaf). Thiocloprid 21.7 % SC @ 150 ml per acre was the least effective dose with recorded highest mite population of 1.40 mites/leaf. All the treatments were significantly better than the control and Buprofenzin 25 EC @ 240 ml per acre was statically superior to all other treatments. All the remaining treatments were at par with each other in their performance.

Seven days after the application of treatments again the higher dose of Buprofenzin was the most effective (0.04 mites/leaf) followed by Thiocloprid 21.7 % SC @ 200 ml per acre (0.30 mites/leaf). Thiomethoxam 25 WG @ 40 g per acre and Buprofenzin 25 EC @ 120 ml per acre demonstrated the equal effectivity in reducing mite population (0.31 mites/leaf each). The highest population of mites was recorded with Thiocloprid 21.7 % SC @ 150 ml per acre (0.44 mites/leaf). Buprofenzin 25 EC @ 240 ml per acre was significantly superior to all other treatments, which were statically at par with each other. Data recorded fifteen days after treatments application represented that Buprofenzin 25 EC @ 120 ml acre had the lowest recorded population of mite (0.37 mites/leaf) followed by Buprofenzin 25 EC @ 240 ml per acre (0.44 mites/leaf). Thiocloprid 21.7 % SC @ 200 and 150 ml per acre (0.80 and 0.93 mites/leaf) and Thiomethoxam 25 WG @ 40 and 30 g per acre (0.81 and 1.00 mites/leaf) were statically at par with each other with the highest population recorded in lower dose of Thiomethoxam.

Cummulative average of all the treatments showed that all the treatments were significantly superior to the untreated control. Buprofenzin 25 EC @ 240 ml per acre was the most effective (0.41 mites/leaf) and Thiocloprid 21.7 % SC @ 150 ml per acre was the least effective (0.92 mitesleaf) treatment for reducing the mite population in chilli crop. Previous studies by bioassay method demonstrated that Spiromesifen was the most toxic to the adults of *P. latus* followed by Fenazaquin and Abamectin as compared to Buprofezin, Propargite, Triazophos, Neem oil, Azadirachtin and Petroleum spray (Alexander *et al* 2014).

4.6.1.4 Management of whitefly

Record of population data five days after the imposition of all the treatments on chilli crop demonstrated that the lowest population of whitefly was present in plots treated with Buprofenzin 25 EC @ 240 ml per acre and Thiocloprid 21.7 % SC @ 200 ml per acre (0.51 whitefly/leaf each). These were followed by Thiocloprid 21.7 % SC @ 150 ml per acre (0.60 mites/leaf), Buprofenzin 25 EC @ 120 ml per acre (0.93 whitefly/leaf) and Thiomethoxam 25 WG @ 40 g per acre (1.29 whitefly/leaf) and these all treatments were at par with each other and also with the most effective dosages. Highest population was recorded with Thiomethoxam 25 WG @ 30 g per acre (2.07 whitefly/leaf) and also it was statically different from all other treatments except the lower dose of Thiomethoxam.

Seven days after the treatments population records of whitefly demonstrate that the most effective treatment was Thiocloprid 21.7 % SC @ 200 ml per acre with lowest whitefly population of 0.45 whitefly/leaf. It was followed by Buprofenzin 25 EC @ 240 ml per acre (0.63 whitefly/leaf) and Thiocloprid 21.7 % SC @ 150 ml per acre (0.78 whitefly/leaf). The highest population was recorded in Thiomethoxam 25 WG @ 30 g per acre (2.40 whitefly/leaf) which was at par with the higher dose of 40 g per acre (1.62 whitefly/leaf).

The most effective treatments were Thiocloprid 21.7 % SC @ 200 ml per acre (0.75 whitefly/leaf) and Buprofenzin 25 EC @ 240 ml per acre (0.75 whitefly/leaf), based on the data recorded fifteen days after spraying the insecticides. These were statically at par with Thiocloprid 21.7 % SC @ 150 ml per acre (0.96 whitefly/leaf), Buprofenzin 25 EC @ 120 ml per acre (1.65 whitefly/leaf) and Thiomethoxam 25 WG @ 40 g per acre (1.95 whitefly/leaf). Again, the highest population was recorded in the plants treated with Thiomethoxam 25 WG @ 30 g per acre (2.73 whitefly/leaf) which was at par with its lower dose. Average of whitefly population after all the treatments represent that Thiocloprid 21.7 % SC @ 200 ml per acre (0.57 whitefly/leaf) was the most effective treatment and Thiomethoxam 25 WG @ 30 g per acre was the least effective treatment (2.40 whitefly/leaf).

Zhang *et al* 2011 reported Imidacloprid and Thiamethoxam to be the most effective in controlling *B. tabaci* under lab conditions and also in field when used as a seed treatment method. Toxicity studies of Buprofezin on various stages of green house whitefly (*T. vaporariorium*) revealed it to be better than chinomethiomate, methidathion and fenvarerate (Yasui *et al* 1985). Imidacloprid is reported to be the most effective against B. tabaci followed by Thiamthoxam and Diafenthiuron (Gopalaswamy *et al* 2012).

4.6.2 Management of fruit borers of chilli

Mean population of larvae of *H. armigera* (pre-spray, 5, 7 and 15 days after spray) and mean percentage of fruit damage was calculated and the results are represented in table 13. There was no significant difference between the larval populations before spray however; the difference was significant after the application of different treatments. Five days after the application of treatments lowest population (0.03 larvae/plant) of helicoverpa was present in plots treated with Chlorantraniliprole 18.5 SL @ 50 ml per acre and it was significantly superior to all the other treatments. Emamectin benzoate 5 % SG @ 100 g/acre represented another lower population record (0.09 larvae/plant) followed by Chlorantraniliprole 18.5 SL @ 40 ml/acre, Spinosad 48 SL @ 60 ml/acre (0.12 larvae/plant, each) and Spinosad 48 SL @50 ml/acre (0.22 larvae/plant). All these treatments were also statically at par with each other. The highest larval population was recorded in Emamectin benzoate 5 % SG @ 80 g/acre (0.29 larvae/plant), which was also at par with Chlorantraniliprole 18.5 SL @ 40 ml/acre, Spinosad @ 50 and 60 ml/acre whereas population in the untreated control was 1.68 larvae/plant.

After a week of treatment application, again the Chlorantraniliprole 18.5 SL @ 50 ml/acre represented the lowest population of helicoverpa larvae (0.03 larvae/plant) and Emamectin benzoate 5 % SG @ 80 g/acre showed the highest larval population (0.28 larvae/plant). Chlorantraniliprole 18.5 SL @ 50 ml/acre was statically superior to all other treatments whereas, Emamectin benzoate 5 % SG @ 50 ml/acre was at par with

Chlorantraniliprole 18.5 SL @ 40 ml/acre (0.14 larvae/plant), Spinosad 48 SL @ 60 (0.15 larvae/plant) and 60 ml/acre (0.20 larvae/plant). Emamectin benzoate 5 % SG @ 100 g/acre was the second best treatment for reducing the larval populations (0.10 larvae/plant) and it was also significantly superior as compared to other treatments.

Fifteen days past the imposition of insecticide treatments larval population was nil in plots treated with Chlorantraniliprole 18.5 SL @ 50 ml/acre followed by Spinosad 48 SL @ 60 ml/acre (0.09 larvae/plant), Emamectin benzoate 5 % SG @ 100 g/acre (0.12 larvae/plant), Chlorantraniliprole 18.5 SL @ 40 ml/acre (0.13 larvae/plant) and Spinosad 48 SL @ 50 ml/acre (0.16 larvae/plant). The highest population was recorded in Emamectin benzoate 5 % SG @ 80 g/acre (0.24 larvae/plant). Chlorantraniliprole 18.5 SL @ 50 ml/acre was statically superior to all the treatments and all the remaining treatments were at par with each other.

The cumulative mean population data demonstrates that Chlorantraniliprole 18.5 SL @ 50 ml/acre was the best dose in reducing the helicoverpa larval population (0.02 larave/plant) followed by Emamectin benzoate 5 % SG @ 100 g/acre (0.103 larvae/plant) and Spinosad 48 SL @ 60 ml/acre (0.120 larvae/plant). Emamectin benzoate 5 % SG @ 80 g/acre was the least effective treatment (0.27 larvae/plant). Based on the mean percentage of fruit damage done by the larval populations, again the Chlorantraniliprole 18.5 SL @ 50 ml/acre was the best treatment with minimum fruit damage of 3.10 percent followed by lower dose of Chlorantraniliprole 18.5 SL (3.45 percent). Maximum fruit damage was observed in Spinosad 48 SL @ 50 ml/acre (4.20 percent). All the treatments were significantly better in reducing the fruit damage over the control.

The results of this study are nearly similar to the reports of Gadhiya *et al* 2014 who reported Chlorantraniliprole 0.006%, Spinosad 0.018 % and Emamectin benzoate 0.002 % as most effective treatments against *H. armigera* and *S. litura*. Sub-lethal effects of Chlorantraniliprole are also reported by Zhang *et al* 2013 on adult as well as offsprings of *H. armigera*. Lowest population of *H. armigera* and highest cost-benefit ratio is recorded with Chlorantraniliprole 20 SC, Flubendiamide 480 SC and Spinosad 45 SC (Sreekanth *et al* 2014). Spinosad is reported to have higher efficiency against fruit borer as compared to Quinalphos, Cypermethrin and Lmbda cyhalothrin (Gosh *et al* 2010). Under laboratory conditions also Spinosad proved to be effective against *H. armigera* (Wang *et al* 2008). Muthukrishnan *et al* 2012 reported Emamectin benzoate 5 SG @ 11 and 22 g a.i./ha to be effective against thrips and fruit borer complex on grapes. Babariya *et al* 2010 reported that Indoxacarb 0.0075 % resulted in highest mortality of pod borer in chickpea followed by Spinosad @ 0.009 %.

Table 12: Efficacy of different insecticides against sucking pests of chilli during 2014

Treatments	Dose g or ml/acre	Aphids/ leaf				Thrips/ leaf				Mites/ leaf*				Whitefly/ leaf			
		5 DAS	7 DAS	15 DAS	Mean	5 DAS	7 DAS	15 DAS	Mean	5 DAS	7 DAS	15 DAS	Mean	5 DAS	7 DAS	15 DAS	Mean
Thiomethoxam 25 WG	30	7.57 (2.92)	13.71 (3.84)	17.03 (4.24)	12.77 (3.67)	0.16 (1.07)	0.09 (1.04)	0.18 (1.08)	0.14 (1.07)	1.31 (1.51)	0.36 (1.16)	1.00 (1.41)	0.89 (1.37)	2.07 (1.75)	2.40 (1.84)	2.73 (1.93)	2.40 (1.84)
Thiomethoxam 25 WG	40	6.93 (2.82)	12.86 (3.72)	16.67 (4.21)	12.15 (3.58)	0.13 (1.06)	0.07 (1.03)	0.16 (1.07)	0.12 (1.06)	1.29 (1.51)	0.31 (1.14)	0.81 (1.34)	0.80 (1.33)	1.29 (1.51)	1.62 (1.61)	1.95 (1.72)	1.62 (1.62)
Buprofenzin 25 EC	120	9.30 (3.24)	15.43 (4.05)	19.95 (4.61)	14.89 (3.95)	0.09 (1.04)	0.11 (1.05)	0.22 (1.10)	0.14 (1.07)	1.24 (1.49)	0.31 (1.14)	0.37 (1.36)	0.79 (1.33)	0.93 (1.39)	1.29 (1.51)	1.65 (1.63)	1.29 (1.51)
Buprofenzin 25 EC	240	8.77 (3.09)	15.03 (4.00)	18.38 (4.47)	14.06 (3.84)	0.05 (1.02)	0.05 (1.02)	0.13 (1.06)	0.07 (1.04)	0.76 (1.32)	0.04 (1.02)	0.44 (1.20)	0.41 (1.18)	0.51 (1.23)	0.63 (1.27)	0.75 (1.32)	0.63 (1.28)
Thiocloprid 21.7% SC	150	6.14 (2.67)	12.13 (3.62)	15.36 (4.04)	11.21 (3.45)	0.11 (1.05)	0.07 (1.03)	0.11 (1.05)	0.09 (1.05)	1.40 (1.54)	0.44 (1.20)	0.93 (1.39)	0.92 (1.38)	0.60 (1.26)	0.78 (1.33)	0.96 (1.40)	0.78 (1.33)
Thiocloprid 21.7% Sc	200	5.85 (2.61)	12.08 (3.61)	10.08 (3.32)	9.34 (3.19)	0.07 (1.03)	0.04 (1.02)	0.27 (1.12)	0.13 (1.06)	1.29 (1.51)	0.30 (1.14)	0.80 (1.33)	0.79 (1.33)	0.51 (1.23)	0.45 (1.20)	0.75 (1.32)	0.57 (1.25)
Untreated control	-	40.25 (6.42)	39.32 (6.21)	41.43 (6.51)	40.33 (6.43)	0.82 (1.35)	1.11 (1.45)	1.15 (1.46)	1.03 (1.42)	3.93 (2.22)	3.95 (2.27)	4.17 (1.35)	5.44 (2.51)	8.22 (3.03)	8.07 (3.01)	8.37 (3.06)	8.22 (3.04)
CD (p=0.05)		(0.74)	(0.77)	(0.80)	(0.49)	(0.06)	(0.09)	(0.13)	(0.05)	(0.10)	(0.07)	(0.06)	(0.33)	(0.31)	(0.29)	(0.49)	(0.07)

Figures in paranthesis are $\sqrt{x}$ +1 transformed values; * 2013

Table 13: Efficacy of different insecticides against chilli fruit borer (*H. armigera*) during 2014

Treatments	Dose g or ml/acre	Mean no. of larvae/plant[1]					Mean % fruit damage[2]
		Before spray	5 DAS	7 DAS	15 DAS	Mean	
Spinosad 48 SL	50	1.60 (1.44)	0.22 (0.71)	0.20 (0.70)	0.16 (0.69)	0.19 (0.70)	4.20 (11.70)
Spinosad 48 SL	60	1.43 (1.35)	0.12 (0.62)	0.15 (0.68)	0.09 (0.41)	0.12 (0.57)	3.86 (11.30)
Chlorantraniliprole 18.5 SL	40	1.49 (1.30)	0.12 (0.67)	0.14 (0.67)	0.13 (0.55)	0.13 (0.63)	3.45 (10.90)
Chlorantraniliprole 18.5 SL	50	1.70 (1.46)	0.03 (0.10)	0.03 (0.16)	0.00 (0.00)	0.02 (0.09)	3.10 (10.66)
Emamectin benzoate 5 % SG	80	1.45 (1.42)	0.29 (0.88)	0.28 (0.82)	0.24 (0.92)	0.27 (0.87)	4.17 (11.67)
Emamectin benzoate 5 % SG	100	1.51 (1.44)	0.09 (0.41)	0.10 (0.46)	0.12 (0.64)	0.103 (0.50)	3.73 (11.10)
Untreated Control	-	1.53 (1.34)	1.68 (1.45)	1.73 (1.48)	1.79 (1.50)	1.73 (1.48)	10.40 (18.70)
CD (p=0.05)		NS	(0.30)	(0.20)	(0.28)	(0.26)	(0.67)

$\overline{X}^1$ **Figures in paranthesis are** $\sqrt{x}$ **+0.5 transformed values**

$\overline{X}^2$ **Figures in paranthesis are arc sine transformed values**

Table 14: Residue analysis of insecticides in chilli fruit

Insecticides	Dose	7 day	15 day
Thiocloprid	150 mL/acre	0.08±0.02	BDL
	200 mL/acre	0.14±0.02	0.05±0.01
Thiomethoxam	30 gm/acre	0.14±0.03	0.03±0.01
	40 gm/acre	0.20±0.02	0.04±0.01
Emamectin benzoate	80 gm/acre	0.09±0.01	BDL
	100 gm/acre	0.11±0.02	BDL
Spinosad	50 mL/acre	0.15±0.03	0.002±0.001
	60 mL/acre	0.22±0.02	0.003±0.001

BDL= below determination limit of 0.01 mg/kg

4.6.3 Residue analysis of the chemicals

The results of residue analysis of chemicals were done after seven and fifteen days of application of insecticides and the results obtained are given in table 14. Thiacloprid 21.7 % SC @ 150 ml/acre treated chilli fruits had a residue of 0.08±0.02 mg/kg at seven days after the treatment application but the residue was below detectable limit (BDL) at fifteen days after the spray. For the higher dose of Thiocloprid 21.7 % SC @ 200 ml/acre a residue of 0.14±0.02 mg/kg was detected after a week of insecticide spray and residue were also detected fifteen days after the spray (0.05±0.01 mg/kg). The maximum residue limit (MRL) for Thiocloprid is 1 mg/kg for peppers as per Codex Alimentarious recommendations (Anonymous 2007). Thus, both the dosages had residue limits which are safe for consumption. In case of Thiomethoxam 25 WG @ 30 g/acre, residue limits were detectable after seven and fifteen days of treatment (0.14±0.03 and 0.03±0.01 mg/kg, respectively). Thiomethoxam 25 WG @ 40 g/acre had a residue in fruits of 0.20±0.02 mg/kg, seven days after spray and 0.04±0.01 mg/kg, fifteen days after spray. Permitted residue limits for Thiomethoxam are 7 mg/kg (Anonymous 2011) and as both the dosages are having residues below this limit so are safe for consumption. Emamectin benzoate @ 80 g/acre showed a residue after seven days of treatment (0.09±0.01 mg/kg) but there was no detection of residue after fifteen days of treatment. Higher dose of Emamectin benzoate @ 100 g/acre demonstrated a residue of 0.11±0.02 mg/kg and it was not detectable at fifteen days after the application of chemicals. MRL for Emamectin benzoate is 0.2 mg/kg (Anonymous 2012c) and both the dosages were lower than this limit. Spinosad has a MRL of 0.3 mg/kg

in peppers and seven days spray residue detected were 0.15±0.03 mg/kg and 0.22±0.02 mg/kg, respectively for dose of 50 and 60 ml/acre, seven days after spray and 0.002±0.001 mg/kg and 0.003±0.001 mg/kg, fifteen days after spray. Hence all the chemical dosages applied were below the maximum residue levels prescribed and are hence safe for consumption by us.

CHAPTER V

SUMMARY

Chilli (*C. annuum*) belongs to solanaceae family and is a major spice and vegetable crop of India. India is the largest producer of chillies in the world but its productivity is very low as compared to other developed countries. Losses caused by insect pests are reported as a major constraint in successful production of chilli. The insects attacking chilli can be categorized into two types- sucking insect pests and fruit borers. Major sucking insect pests include aphids (*A. gossypii* and *M. persicae*), thrips (*Scirtothrips dorsalis*), mite (*Polyphagotarsonemus latus*) and whitefly (*B. tabaci*) whereas, the fruit borers include *H. armigera* and *S. litura*. Thrips and mites can cause yield losses to the tune of 50 per cent (Ahmed *et al* 1987) whereas fruit borers can cause fruit damage upto 77 per cent (Katagihallimath 1963). India is also a major exporter of chilli, but lately the chilli consignments are rejected due to presence of insecticide residues in the produce. Most of the work on insect pests of chilli is done in southern states of India and there is a lack of data about these insect pests in Punjab conditions. So the need was felt to conduct investigations on population dynamics of insect pests and their management.

The present investigation entitled "Population Dynamics and Management of Insect Pests of Chilli" was conducted at the Bharti Field Fresh Farm, Ladhowal during *kharif* 2013 and at Research farm of Deptt. of Forestry and Natural Resources, PAU, Ludhiana during *rabi* 2014. Monitoring of insect populations was done in both the seasons at weekly intervals for recording the arthropod fauna associated with the chilli crop in Punjab conditions. Trap designs (Rectangular and Vertical) were tested for their efficiency in trapping alate sucking insect pests of chilli during *rabi* 2014. Similarly, studies were also performed for the management of insect pests of chilli using different chemicals and their efficacy in terms of population control and residue analysis was done after 7 and 15 days after spray.

The focus of present study was mainly on the arthropod fauna and population dynamics of insect pests of chilli. In this investigation forty one species of arthropods were found to be associated with chilli crop in Punjab conditions. These arthropod species included 14 species of pests of chilli (major, minor and occasional), 13 species of natural enemies, 12 species of casual visitors and 1 species of pollinators. The order Coleoptera occupied the maximum share (26.83%) in the total number of species found with 11 species belonging to the order coleoptera, followed by Lepidoptera (6 species), Hemiptera, Hymenoptera and Orthoptera (4 species each). Insect pest species recorded as major insects of chilli are S. *dorsalis, P. latus, B. tabaci, M. persicae* and *H. armigera*.

Diversity indices of arthropod fauna revealed that, there was more diversity of arthropod fauna in *rabi* 2014 as compared to *kharif* 2013. In *kharif* season maximum diversity

was observed during October and during *rabi* season maximum diversity was observed in April. All the species were mostly evenly distributed except during November 2013 when the thrips species showed dominance. Diversity studies of insect pests of chilli showed that maximum diversity was found during October and April, with all the insect pests distributed evenly except during September, December and March when there was a dominance of thrips species (in Sept and Dec.) and aphid species (in March).

Studies for finding peak activity periods for insect pests of chilli revealed that peak activity for aphids and thrips was during October and May; for whiteflies was during September and June; October for mites and for Helicoverpa the peak period of activity was during May. Aphid population was positively correlated with mean temperature but negatively correlated with RH and rainfall. Whitefly populations were positively correlated with temperature and rainfall but negatively correlated with RH. Thrips and mite populations were positively correlated with RH whereas negatively correlated with mean temperature and rainfall. On the contrary, population of *H. armigera* was positively correlated with temperature and rainfall and negatively correlated with RH.

The rectangular trap design was significantly better than the cylindrical trap design in all the months and for all the insects except for the hymenopteran insects where the cylindrical trap design performed better than the rectangular one. The interactions as well as the independent factors (Trap shape, Time and Insect) were found to be statistically significant.

All the insecticide treatments were significantly better than the untreated control. Thiocloprid 21.7% SC @ 200 ml/acre proved to be the best in managing aphids and whitefly. But Thiocloprid 21.7% SC @ 150 ml/acre proved to be the best as per the residue analysis. As both the treatments of Thiocloprid were at par and lower dose showed no residues after 15 days of application, thus Thiocloprid 21.7% SC is preferred in the current studies over the higher dose. Buprofenzin 25 EC @ 240 ml/acre proved the best for the control of thrips and mites. Chlorantraniliprole 18.5 SC @ 50 ml/acre proved to be the best for managing *H. armigera*.

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