

**Studies on plant volatile mediating orientation  
behaviour of adult litchi fruit borer, *Conopomorpha  
sinensis* Bradley and evaluation of plant and animal  
derived natural formulations for its management**

# **Thesis**

**Submitted to the**



**G. B. Pant University of Agriculture & Technology  
Pantnagar-263145, Uttarakhand, India**

**By**

**Anjali Nautiyal**

**Id. No. 45819**

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF**

**Doctor of Philosophy**

**(Entomology)**

**March, 2023**

# ACKNOWLEDGEMENT

---

---

*I begin by bowing my head in deep gratitude, with all reverence and devotion, to the Almighty for showering His blessings upon me. It is He who has given me the opportunity to acknowledge wholeheartedly all those who have provided me with unwavering support throughout my thesis research.*

*With an overwhelming sense of pride and genuine obligation, I take this opportunity to express deep due sense of gratitude to the chairman of my Advisory committee, Dr. Poonam Srivastava, Professor for her excellent guidance, boundless encouragement, everlasting patience, love and affection throughout my studies, course of research work. I consider myself lucky to have such an excellence perceiving, ever co-operative and helpful personality as my guide.*

*I feel extremely privileged to express my veneration for the eminent member of my advisory committee Dr. M.S. Khan, Professor, Dr. R.M. Srivastava, professor, and Dr. K.P.S. Kushwaha professor, Department of Entomology, College of Agriculture for their authentic technical guidance, keen interest, and valuable criticism during the course of investigation and preparation of manuscript.*

*I would like to give my special thanks to our Head of Department Dr. Pramod Mall, for his Guidance, moral support and his timely suggestions during the entire period of my study.*

*I wish to extend my sincere thanks to all my Professors, Librarian, Director, University Experiment Station, Dean, College of Agriculture, Dean, College of Post Graduate Studies and Registrar for providing me the essential facilities to conduct the proposed investigation.*

*I extend my sincere thanks to Dean College of Agriculture and technology, dean Post Graduate Studies.*

*Indeed, it is difficult to acknowledge my deep sense of respect and personal obligation to my Grandparents Late. Tara Dutt Nautiyal and Late. Devkhi Nautiyal, my parents Colonel B.B.L Nautiyal and Savitri Nautiyal, for their appreciable patience, abundant love, affection, moral support, everlasting inspiration since my childhood to moment without which present arduous task could not have been achieved.*

*It is with a heart full of gratitude and a deep sense of admiration that I acknowledge the unwavering support and care provided to me by my dear brother Keshav Nautiyal, and my beloved sisters Manjali Nautiyal and Vandana Nautiyal. Their selfless love and genuine concern have played an indispensable role in my life, filling my days with boundless laughter and immeasurable happiness. Their constant presence, encouragement, and support have been a source of great strength for me,*

*enabling me to overcome obstacles and challenges along the way. Their kindness and generosity have left an indelible mark on my heart, and I am forever grateful for their love and unwavering support. Their presence in my life has been a true blessing, and I cannot imagine facing life's trials and tribulations without their innocent and selfless love. For all that they have done, and continue to do, mere words are inadequate to express my appreciation, but I am filled with deep gratitude and indebtedness towards them always.*

*I would like to take this opportunity to express my sincere gratitude and appreciation for the unwavering cooperation, valuable support, and generous help provided by my brilliant friends, Dr. Bhabani Mahankud, Dr. Vipul Nishad, Girish Chandra Pandey, Renu Adhikari, Dr. Himanshu Gauda, Dr. Varun Raturi, Dr. Rashmi Kaul, Abhisekh Kharola, and Naresh Kalotra.*

*Each of these individuals has played an integral role in my journey, providing valuable insights, feedback, and encouragement that have helped me to overcome obstacles and reach my goals. In particular, I would like to extend a special thank you to Dr. Bhabani Mahankud, who has been a true friend and guide, offering unwavering support and guidance throughout my life. Her wisdom, expertise, and generous spirit have been invaluable, and I am forever grateful for her contributions.*

*It was always delightful to have the loving and joyous company of my esteemed friends and juniors, including Geetanjali Bhandari, Priya Rai, Vishal Singh, Gunjan Kandpal, Dr. Harshita, Suman Kumari, Nalini Trivedi and Ankit Uniyal throughout the entirety of my degree program. I am immensely grateful to them for providing warm companionship, love, care, encouragement, and active support during our studies. The blissful moments shared with them will remain cherished memories forever.*

*Last but not the least, I express my heartfelt thanks to all who helped me either directly or indirectly during the study period.*

*Pantnagar  
March, 2023*



*(Anjali Nautiyal)  
Authoress*

## CERTIFICATE-I

This is to certify that the thesis entitled “**Studies on plant volatile mediating orientation behaviour of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulations for its management**” submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** with a major in **Entomology** and minor in **Plant Pathology** of the College of Post Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of bonafide research carried out by **Ms. Anjali Nautiyal, Id. No. 45819**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

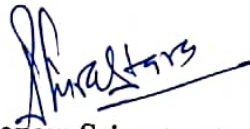
The assistance and help received during the course of this investigation and the source of literature have been duly acknowledged.

Pantnagar  
March, 2023

  
(Poonam Srivastava)  
Chairperson  
Advisory Committee

## CERTIFICATE-II

We, the undersigned, members of the Advisory Committee of **Ms. Anjali Nautiyal, Id. No. 45819**, a candidate for the degree of **Doctor of Philosophy** with major in **Entomology** and minor in **Plant Pathology**, agree that the thesis entitled “**Studies on plant volatile mediating orientation behaviour of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulations for its management**” may be submitted in partial fulfilment of the requirements for the degree.



(Poonam Srivastava)  
Chairperson  
Advisory Committee



(M.S. Khan)  
Member



(R.M. Srivastava)  
Member



(K.P.S. Kushwaha)  
Member



Head of the Department  
(Ex-Officio Member)

# CONTENTS

| S. No.   | CHAPTERS  | PAGE No.     |
|----------|---|--------------|
| <b>1</b> | <b>INTRODUCTION</b>   | <b>1-8</b>   |
| <b>2</b> | <b>REVIEW OF LITERATURE</b>   | <b>9-40</b>  |
| 2.1      | Diversity of insect fauna and population dynamics of major insect pests associated with litchi ecosystem  | 9            |
| 2.2      | Effect of climatic factors on the abundance of major insect pests of litchi   | 20           |
| 2.3      | Volatiles compounds from different litchi plant parts, including tender shoots, flowers, immature fruit, and mature fruit                                 | 24           |
| 2.4      | Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant.  | 27           |
| 2.5      | Olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits | 31           |
| 2.6      | Impact of Plant and animal based natural formulations on the olfactory response of litchi fruit borer adults  | 34           |
| 2.7      | Evaluation of different Plant and animal based natural based formulations against the of major pest associated with litchi                                | 36           |
| <b>3</b> | <b>MATERIALS AND METHODS</b>  | <b>41-58</b> |
| 3.1      | Diversity of insect fauna and population dynamics of major insect pests associated with litchi ecosystem  | 41           |
| 3.1.1    | Diversity of litchi mite  | 41           |
| 3.1.2    | Diversity of litchi fruit borer   | 42           |
| 3.1.3    | Diversity of litchi leaf roller   | 42           |
| 3.1.4    | Diversity of mealy bug  | 42           |
| 3.1.5    | Diversity of barkeating caterpillar   | 42           |
| 3.2      | Effect of climatic factors on the abundance of major insect pests of litchi   | 42           |
| 3.2.1    | Data analysis   | 43           |
| 3.3.     | Volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit                           | 43           |

---

|          |   |               |
|----------|---|---------------|
| 3.3.1    | Extraction of Phytochemicals  | 43            |
| 3.3.2    | Biochemical analysis  | 44            |
| 3.4      | Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant   | 46            |
| 3.4.1    | Plant Extract Preparation   | 46            |
| 3.5      | Olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flower, mature and immature fruits)           | 48            |
| 3.5.1    | Statistical analysis  | 48            |
| 3.6      | Impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults  | 49            |
| 3.6.1    | Statistical analysis  | 49            |
| 3.7      | Efficacy of plant and animal based natural based formulations against the major pests associated with litchi.   | 50            |
| 3.7.1    | Treatment details   | 50            |
| 3.7.2    | Method of preparation of different natural formulations   | 51            |
| 3.7.3    | Method of observation   | 52            |
| 3.7.4    | Statistical analysis  | 52            |
| <b>4</b> | <b>RESULTS AND DISCUSSIONS</b>  | <b>59-149</b> |
| 4.1      | Diversity of insect fauna and their associated natural enemies on litchi at Pantnagar, Uttarakhand.   | 59            |
| 4.1.1    | Population dynamics of major insect pests and their associated natural enemies on litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar | 63            |
| 4.1.2.   | Population dynamics of major insect pests and their associated natural enemies on litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar | 73            |
| 4.2.     | Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 and 2019 at Pantnagar, Uttarakhand       | 83            |
| 4.2.1.   | Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 at Pantnagar, Uttarakhand                | 83            |

---

---

|         |  |     |
|---------|--|-----|
| 4.2.2.  | Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2019 at Pantnagar, Uttarakhand                   | 88  |
| 4.2.3   | Multiple linear regression (MRL) for major insect pests  | 94  |
| 4.3     | Volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit.                                       | 100 |
| 4.3.1   | Biochemical analysis   | 100 |
| 4.3.2   | Isolation and identification of volatiles from different litchi tissues  | 100 |
| 4.3.1.1 | Litchi flower  | 101 |
| 4.3.2.2 | Litchi tender shoot  | 101 |
| 4.3.2.3 | Immature fruit   | 101 |
| 4.3.2.4 | Mature fruits  | 106 |
| 4.4     | Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant  | 107 |
| 4.4.1   | Isolation and identification of volatiles of mite infested and non-infested leaves of litchi   | 107 |
| 4.5     | To study the olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits | 116 |
| 4.6     | To study the impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults  | 126 |
| 4.7     | Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2018 and 2019  | 130 |
| 4.7.1   | Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2018   | 130 |
| 4.7.2   | Observations on mean number of infested fruit before first spraying (1 DBS)  | 130 |
| 4.7.3   | Observations on mean number of infested litchi fruits after different days of first spraying   | 131 |

---

---

|        |  |     |
|--------|--|-----|
| 4.7.4  | Observations on mean number of infested litchi fruits after different days of second spraying                | 131 |
| 4.7.5  | Observations on mean number of infested litchi fruits after different days of third spraying                 | 133 |
| 4.7.6  | Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2019 | 135 |
| 4.7.7  | Observations on number of infested litchi fruits before first spraying (1 DBS)                               | 138 |
| 4.7.8  | Observations on mean number of infested litchi fruits after different days of first spraying                 | 138 |
| 4.7.9  | Observations on mean number of infested litchi fruit after different days of second spraying                 | 138 |
| 4.7.10 | Observations on mean number of infested litchi fruit after different days of third spraying                  | 141 |
| 4.7.11 | Cumulative efficacy of different treatments against infested litchi fruits during the year 2018 and 2019     | 143 |
| 4.7.12 | Observations on cumulative mean population of infested fruits during the year 2018                           | 145 |
| 4.7.13 | Observations on cumulative mean population of infested fruits during the year 2019                           | 145 |
| 4.7.14 | Observation on pooled mean population of infested fruits during the year 2018 and 2019                       | 146 |
| 4.7.15 | Observation on pooled mean population of infested fruits during the year 2018 and 2019                       | 148 |

**5 SUMMARY AND CONCLUSION 150-156**

**LITERATURE CITED**

**CURICUCLAR VITAE**

**ABSTRACTS**

---

## LIST OF TABLES

| Table No. | Title  | Page No. |
|-----------|--|----------|
| 3.1       | Machine conditions   | 44       |
| 3.2       | Program  | 45       |
| 3.3       | Spectrometry table   | 45       |
| 3.4       | Oven temperature program   | 45       |
| 3.5       | Machine conditions   | 46       |
| 3.6       | Program  | 47       |
| 3.7       | Spectrometry table   | 47       |
| 3.8       | Oven temperature program   | 47       |
| 3.9       | Details of treatments used in the experiment   | 50       |
| 4.1       | List of different insect pests on litchi at HRC, Patharchatta, Pantnagar   | 60       |
| 4.2       | List of different natural enemies on litchi at HRC, Patharchatta, Pantnagar  | 61       |
| 4.3       | Population dynamics of major insect pests on litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar                                   | 66       |
| 4.4       | Population dynamics of natural enemies associated with litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar                         | 70       |
| 4.5       | Population dynamics of major insect pests on litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar                                   | 74       |
| 4.6       | Population dynamics of natural enemies associated with litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar                         | 80       |
| 4.7       | Correlation coefficient of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 at Pantnagar, Uttarakhand | 86       |
| 4.8       | Correlation coefficient of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2019 at Pantnagar, Uttarakhand | 93       |
| 4.9       | Shows the correlation coefficient (r) and regression equation for the major insect pests of litchi in relation to weather parameters for the year 2018           | 96       |

---

|      |   |     |
|------|---|-----|
| 4.10 | Shows the correlation coefficient (r) and regression equation for the major insect pests of litchi in relation to weather parameters for the year 2019.               | 97  |
| 4.11 | Relative contents of volatile compounds detected from different litchi tissues. ND: not detected; F: flower; TS: tender shoots; IF: immature fruit; MF: mature fruit. | 102 |
| 4.12 | Components detected in GC-MS analysis of methanolic extract of normal leaves of Litchi  | 110 |
| 4.13 | Components detected in GC-MS analysis of methanolic extract of mite infested leaves of Litchi   | 111 |
| 4.14 | Showing peak area percentages of notable phytochemicals in normal and mite infested leaves  | 113 |
| 4.15 | The mean orientation of the male and female adults of litchi fruit borer towards different host tissue solution was observed in 1hr, 2hr and 3hr intervals            | 119 |
| 4.16 | Two- way ANOVA results  | 120 |
| 4.17 | Difference between the sex groups in the mean orientation of Litchi fruit borer   | 120 |
| 4.18 | Pair wise comparison of different treatment groups  | 123 |
| 4.19 | Pair wise comparison of the interaction variable  | 124 |
| 4.20 | Mean orientation of litchi fruit borer adults after different time intervals  | 127 |
| 4.21 | One-way ANOVA results   | 129 |
| 4.22 | Mean number of infested litchi fruit after different days of first spraying during the year 2018  | 132 |
| 4.23 | Mean number of infested litchi fruit after different days of second spraying during the year 2018   | 134 |
| 4.24 | Efficacy of different treatments against infested fruits on litchi after 3 <sup>rd</sup> spray during the year 2018   | 136 |
| 4.25 | Efficacy of different treatments against infested fruits on litchi after 1st spray during the year 2019   | 140 |
| 4.26 | Efficacy of different treatments against infested fruits on litchi after 2 <sup>nd</sup> spray during the year 2019   | 142 |
| 4.27 | Efficacy of different treatments against infested fruits on litchi after 3 <sup>rd</sup> spray during the year 2019   | 144 |
| 4.28 | Cumulative efficacy of natural formulations against litchi fruit borer during 2018 and 2019 at Pantnagar, Uttarakhand   | 147 |

---

## LIST OF FIGURES

| Figure No. | Title  | Page No. |
|------------|--|----------|
| 4.1a       | Population dynamics of insect pests associated with litchi ecosystem during 2018                               | 68       |
| 4.1b       | Population dynamics of insect pests with smaller population associated with litchi ecosystem during 2018       | 68       |
| 4.2        | Population dynamics of natural enemies associated with litchi ecosystem during 2018                            | 72       |
| 4.3a       | Population dynamics of insect pests associated with litchi ecosystem during 2019                               | 77       |
| 4.3b       | Population dynamics of insect pests with smaller population associated with litchi ecosystem during 2019       | 77       |
| 4.4        | Population dynamics of natural enemies associated with litchi ecosystem during 2019                            | 79       |
| 4.5        | Biochemical graph of volatiles from litchi flower  | 103      |
| 4.6        | Biochemical graph of volatiles from tender shoot   | 103      |
| 4.7        | Biochemical graph of volatiles from immature fruit   | 104      |
| 4.8        | Biochemical graph of volatiles from mature fruit   | 104      |
| 4.9        | NMR analysis of the litchi flower (purple), tender shoot (green), immature fruit (red) and mature fruit (blue) | 105      |
| 4.10       | Biochemical graph of methanolic extract of normal Litchi leaves  | 109      |
| 4.11       | Biochemical graph of methanolic extract of mite infested Litchi leaves   | 109      |
| 4.12       | Bar graph showing the uncommon compounds present in both normal and mite infested litchi leaf                  | 112      |
| 4.13       | Bar graph showing the comparison of area% of normal and mite infested litchi leaf                              | 113      |
| 4.14       | Mean orientation o Litchi fruit borer for different time intervals   | 118      |
| 4.15       | Boxplot of mean orientation of Litchi fruit borer  | 118      |

---

|      |   |     |
|------|---|-----|
| 4.16 | Pair wise comparison of different treatment groups  | 121 |
| 4.17 | Pair wise comparison of the interaction variable  | 122 |
| 4.18 | Mean orientation of Litchi fruit borer for different time intervals                       | 126 |
| 4.19 | Pair wise comparison of different treatment groups  | 129 |
| 4.20 | Efficacy of different treatments against litchi fruit borer during the year 2018          | 137 |
| 4.21 | Efficacy of different treatments against litchi fruit borer during the year 2019          | 145 |
| 4.22 | Efficacy of different treatments against litchi fruit borer during the year 2018 and 2019 | 146 |

---

## LIST OF PLATES

| Plate No. | Title  | Page No. |
|-----------|--|----------|
| 1         | List of different major insect pests on litchi at HRC, Patharchatta, Pantnagar   | 53       |
| 2         | List of different natural enemies on litchi at HRC, Patharchatta, Pantnagar  | 54       |
| 3         | Sample Preparation litchi plant parts i.e., immature fruits and mature, tender shoots and flowers were collected from Horticulture Research Centre, Patharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand | 55-56    |
| 4         | Olfactometer set up  | 57       |
| 5         | Collection and preparation of spray material   | 58       |

## LIST OF ABBREVIATIONS

|               |   |
|---------------|---|
| %             | Percent   |
| °C            | Degree Celsius  |
| ABA           | Absciscic acid  |
| AEDA          | Aroma extract dilution analysis                                   |
| Cm            | Centimeter  |
| d.f           | Degree of freedom   |
| DBM           | Diamondback moth  |
| DMRT          | Duncan Multiple Range Test  |
| DTA           | Differential Thermal Analysis                                     |
| EAG           | Electroantennography  |
| EC            | Emulsifiable Concentrate  |
| <i>et al.</i> | and other   |
| FD            | Flavor dilution   |
| Fig.          | Figure  |
| g             | Gram  |
| ha            | Hectare   |
| HaNPV         | Helicoverpa armigera Nucleo Polyhedrosis Virus                    |
| HAR           | Hours after release   |
| HIS           | Herbivore-induced synomone  |
| HPLC          | High-Performance Liquid Chromatography                            |
| hrs           | Hours   |
| i.e.          | That is   |
| kg            | Kilogram  |
| m             | Meters  |
| MLR           | Multiple linear regressions                                       |
| MT            | Million tonnes  |
| No.           | Number  |
| NSKE          | Neem seed kernel extract  |
| OPLS-DA       | Orthogonal Projections to Latent Structures Discriminant Analysis |

|      |                                     |
|------|-------------------------------------|
| RH   | Relative Humidity                   |
| SAFE | Solvent assisted flavor evaporation |
| TCM  | Traditional Chinese medicine        |
| viz. | Videlicet                           |
| wt.  | Weight                              |



# *Introduction*



Lychee or Litchi (*Litchi chinensis* Sonn.) the queen of fruit is a only genus litchi in the soapberry family Sapindaceae family that is endogenous to Southern China and now planted widely in subtropical areas worldwide including India, Brazil, Malaysia, Mauritius, South Africa, Australia, New Zealand, Madagascar, Thailand, Vietnam, Myanmar, and Taiwan. The major litchi producing states in India are Bihar, Uttarakhand, West Bengal, Punjab, Uttar Pradesh, Jharkhand and Tripura (**Srivastava et al., 2020**).

It is an attractive, round-topped, dense tree with a smooth, gray, brittle trunk and limbs with a dark bark that covers its smooth, gray, brittle trunk and limbs. While they may reach 40 feet in height under ideal conditions, they are usually considerably smaller. When the trees are full of fruit, they are a spectacular sight. It has leathery foliage, and its leaves are pinnately divided into four to eight leaflets. When they're young, they're reddish, but when they get older, they're shiny and green. There is full foliage on Lychee trees, and some branches reach the ground. There are tiny yellowish-green flowers on lychees that are petalless and are borne in terminal clusters of up to 30 inches. Lychees look stunning during spring when they bloom in huge sprays adorning the tree. A flowering period precedes the maturity of a fruit by approximately 140 days.

A leathery rind, referred to as a pericarp, covers the fruit which ranges in color from pink to strawberry red in color and is rough in texture. Shape of the fruit can be oval, heart- shaped, or nearly round, and it is about 1 to 1-1/2 inches long. There is a white, translucent, firm, juicy and spongy edible portion called an aril. Taste-wise, it is sweet, aromatic, and delicious. A seed is enclosed within the aril, whose size varies considerably. In the most desirable varieties, the seeds are atrophied, which is what is called "chicken tongue". Their size is very small, about 1/2 inch long. Seeds with a larger size range between 1/2 inch and 1 inch and are plumper than chicken tongues. Furthermore, there is a distinction between lychees that leak juice when broken and those that are "dry and clean", which are more desirable. Occasionally, lychees are

alternate bearers in certain areas. Soil moisture fluctuation is usually responsible for fruit splitting.

Litchi pulp contains a variety of nutrients such as carbohydrates, proteins, lipids, vitamins and minerals but amounts vary with the litchi variant. In addition, the delicious fruit of litchi makes it popular, evidenced by many famous poems written in appreciation of litchi since Chinese ancient times. Litchi is traced back to China's ancient times as a medicinal herb.

According to historical records, litchi seed, pulp and whole fruit were all used as herbal formulations (**Yao *et al.*, 2021**). In traditional Chinese medicine (TCM), litchi has been deemed to exhibit positive effects on relieving dyspepsia, cough, diarrhea and pain. Clinically, litchi seed, pulp and whole fruit have been developed into decoctions and milled powders that can be used orally or externally to relieve or cure dizziness, irritability, and various swelling and pain symptoms, such as flatulence, testicular swelling, cough, chesttightness or chest pain, epigastric pain, testicular pain, toothache, neuralgia, and hernia pain.

India is the 2<sup>nd</sup> largest producer of litchi in the world after China in India, 568,200 metric tons of litchis are produced annually from 93,300 hectares (**Anonymous, 2018**). Litchi cultivation is now gaining its popularity in India due to its export potentiality, especially in the eastern part of the country where it provides livelihood to millions of people (**Srivastava *et al.*, 2020**). The area under production of litchi in India in 2018-19 and 2019-2021 was 96 hectares and 97 hectares, producing 721.0 MT in 2018-19 and 726.0 MT in 2019-2021, respectively. According to Uttarakhand government statistics, in 2018-2019 it was cultivated on 10.72 ha producing 24.72 MT of fruits. Government of India's ministry of agriculture and farm welfare reports that litchi production rates in year 2021 in other Indian states are as follows: Bihar 198 MT, West Bengal 76.63 MT, Assam 55.59 MT, Chhattisgarh 43.38 MT, Jharkhand 40.01 MT, Uttarakhand 35.98 MT, Punjab 34.88 MT (**Anonymous, 2021**).

Plants and insects together make up about half of all known species of multicellular organisms. Each plant interacts with insects in a different way; insects can

act as protection, dispersal or fertilizer for plants while plants can be food/ energy resources or nesting sites for insects. Plants have developed a complex defences system against a variety of pests and pathogens in response to insect attack. Plants have developed a variety of defences to reduce the risk of injury.

There are many factors that affect the cultivation and production of litchi, including soil fertility, moisture, climate, and pests (insects and diseases). The litchi crop is attacked by 40 different types of insects and mite species at different growth stages. Only two species, namely, erineum mite and bark eating caterpillar possessed serious threat to the litchi trees causing extensive damage (**Butani, 1977**).

Whereas, litchi fruit borer (*Conopomorpha sinensis*), litchi leaf curl mite (*Eriophyes litchi*), and litchi leaf roller (*Tortrix epicyrta*), have acquired the status of major pests and now, litchi looper (*Perixera illepidaria*), litchi bug (*Tessarotoma papillosa*) and bag worm (*Amicta quadrangularis*) are also emerging as pests of litchi (**Hameed et al., 1992**)

A good balance between pest and natural enemies is observed in horticultural cropping system as they are perennial in nature and therefore, incidence of natural enemies coincides with pest fauna. Various predators viz., *Chrysoperla carnea*, preying mantids, *Eucanthecona* bug, spiders and parasitoides viz. *Trichogramma sp.*, *Appentales sp.* on weevils and other defoliators were reported in litchi orchard maintaining the pest population below causing economic injury. Numerous species of predatory phytoseiidae mites have been recorded with litchi mite, *Aceria litchii* (**Wu et al., 1991**). Therefore, careful monitoring of the natural enemies' population in litchi crop and understanding of tritrophic interaction is must before formulating any management practices for the crop. Litchi fruit borer (*Conopomorpha sinensis* Bradley) is a major pest, responsible for infestation at different crop phases viz., leaf (09-70%) and fruit (25-60%), resulting severe economic loss (**Srivastava et al., 2016**).

It has been estimated that 25 to 60 percent of fruits are damaged by the litchi fruit borer (*Conopomorpha sinensis* Bradley), resulting severe economic loss (**Srivastava et al., 2016**). In their newly hatched state, larvae are milky white, very slender, with fine setae all over their body, but when fully grown, they become greenish

yellow in colour. In order to make a tunnel inside the tender shoots, litchi fruit borer larvae mine into newly emerged litchi leaves as leaf miners and then create tunnels within the tender shoots. As a leaf miner, it is active between August and February. Larvae feed on fruit pulp when it appears during April and May. Infested fruits cannot be consumed locally or exported. Growers often miss its hidden infestation of plants and discover it only when their plants begin to show symptoms of damage through dried shoots. This leads to severe losses for litchi growers who are unable to take appropriate control measures against the pest in time (**Lall and Sharma, 1978., Hameed et al., 1999, Sharma and Agarwal, 1988**).

It has been reported that the litchi leaf roller (*Platyepplus aprobola* Meyer) damages the foliage of litchi around Muzaffarpur in Bihar (**Singh, 1971a**). There are reports that it has also been reported to be a pest of several other fruit crops, such as apples, apricot, cherry, pear, plum, prune, quince, raspberry, currant, loganberry in Hawaii, South Africa, Australia and China. Litchi trees tend to have leaf rollers during the months of July to February, when new foliage is available.

As a result of the larvae's injury to the leaves, tender leaves roll and are fed upon from within. In August to February, leaf rollers damage between 16.70 and 71.60 percent of leaves, while tree infestations vary between 12.88 and 53.54 percent (**Lall and Rahman, 1975**). As a result of larval injuries, the infested twigs distort and wither. Litchi trees with severe infestation show very poor flowering, resulting into considerable reduction in crop yield (**Lall and Mallik, 1976**).

Litchi bug, *Tessaratomia javanica* Thunberg damages litchi crops primarily by eating the sap from leaf petioles, leaves, and young buds of a plant as well as the sap from young fruit stalks of a plant (**Kumar et al., 2007**). *T. javanica* is a yellow-red insect with a waxy ventral surface that causes significant damage to litchi plants.

There are also minor pests of litchi, such as leaf cutting weevils (*Mylloceris* species), litchi mealybugs (*Drosicha* species), *aleurocanthus husaini*, thrips (*Dolichothrips indicus*), whiteflies (*Aleurocanthus husaini*), and whiteflies (*Aleurocanthus indicus*) (**Hameed et al., 1992**).

Two species of bark-eating caterpillars exist. The first is *Indarbela tetraonis* Moore and the second is *Indarbela quadrinotata* Walker (**Verma and Khurana, 1974; Khurana and Gupta, 1972.**). This pest is distributed throughout the Indian subcontinent, mainly in Uttar Pradesh, Madhya Pradesh, Rajasthan, Haryana, Orissa, Andhra Pradesh, Tamil Nadu, and Maharashtra. Litchi, guava, mango, and ber are particularly vulnerable to *Indarbela quadrinotata* (**Sharma and Kumar, 1986**).

Plants serve as the rich source of secondary bioactive molecules with insecticidal properties. The plant kingdom is the most efficient producer of chemical compounds (primary and secondary metabolites) synthesizing many products having wide array of functions that are used in defence against herbivores (**Croteau et al., 2000**). Plant secondary metabolites have been exploited by humans for their benefit (**Balandrin et al., 1985**). Plant metabolites are grouped in three broad categories i.e., terpenes and terpenoids (~25000 types), alkaloids (~12000 types) and phenolics (~8000 types) (**Croteau et al., 2000**). Mixture of these compounds may be deterrent to insects for longer period than single compound. Both monoterpenes (C10) and diterpene acids (C20) are toxic to insects and deterrent to herbivores. The secondary metabolites and their constituents have received considerable attention in the search for new molecules having insecticidal activity, repellence, feeding deterrence, reproduction retardation, insect growth regulation against various insect species etc. (**Rice and Coats, 1994**). The secondary metabolites may not cause instant mortality, but their effects are manifested by an adverse impact on normal biochemical and physiological functions (**Prakash, 1997**). During the last two decades, considerable efforts have been directed toward screening plants for their biological activity against insects. **Moralla and Rejesus (1986)** published a review on “botanical insecticides against the diamondback moth”, which included the plants possessing insecticidal activity against DBM. Furthermore, the aim of our study will be to conduct various laboratory and field experiments to evaluate plant biological activity against major insect pest of litchi.

The selection and adaptation of insects to their hosts are the result of co-evolution. Both the highly sensitive olfactory system of the insect and the odor of the host plant play vital roles in insect survival and reproduction. Furthermore, the olfactometer study on repellent efficacy of plant and animal based natural formulations

will help us to find out which formulation will be the most effective in repelling the insect pest, as the sense of smell is one of the most important senses that insects use for long range host seeking. Insect olfaction has been extensively studied leading to the identification of the key proteins involved: odorant receptors, odorant receptor co-receptors, gustatory receptors, and odorant binding proteins are several approaches for evaluating the efficacy of insect repellents. Some of the bioassays that have been used include spatial repellency assay, host attraction-inhibition assay, landing inhibition (Kaupp, 2010). Assay, effective dose and duration assays, taxis cage assays, etc. (Lorenz *et al.*, 2013; Afify *et al.*, 2014 and Menger, 2014). Olfactometers are useful tools used in attraction-inhibition assays to test repellent efficacy. They allow the experimenter to perform the tests under very controlled conditions, thereby eliminating many variables that may alter experimental results in more open systems (McIndoo, 1926).

Study of olfactometer response of insects to volatile emission from different tissues of its host plant will help us to understand mechanisms underlying chemical communication between insects and plants which can provide a target for the development of highly efficient and specific regulators of insect behaviour. The aim of this study will be to identify the plant secondary metabolites or host plant volatiles which is responsible for selection of host plant

Pest management in the developing countries like India is mainly depends on the use of chemical pesticides as they are the most reliable and economical but indiscriminate use of them resulted in a series of problems in the agro-ecosystem, mainly the development of resistance in insects to the insecticides, resurgence of treated population, outbreak of secondary pests into primary nature, destruction of natural enemies, increase in input cost on chemicals, environmental pollution and pesticide residues etc. (Sundaramurthy and Basu, 1989). Indiscriminate use of chemical pesticides and their continuous application created intolerable environment to natural enemies and also preventing their reentry in treated areas.

The current global scenario firmly emphasizes on eco-friendly management practices. In horticultural crops like litchi, where the management of insect pests

heavily relies on their interaction with natural enemies; use of chemical insecticides have deleterious effects on natural enemies resulting in disturbances in the tritrophic interaction. Our ancient literatures like Vrikshayurveda (Science of plant life) deals with growing and nourishing plants with liquid manure. It has mention of various natural formulations having several benefits towards plant growth, soil health as well as possession of insecticidal properties, which are safe to the non-target organisms with no risk for human consumption.

Panchagavya is a natural formulation that acts as a plant growth promoter and soil health enhancer and also possess insecticidal properties against different insects (**Sarkar *et al.*, 2014**). Dashparni is a mixture of ten different leaves in cow urine. All these leaves possess insecticidal properties. A vermiwash is a liquid substance that is obtained by saturating the vermicompost substrate with excess water. The mixture is composed of excretory products and mucus produced by earthworms along with nutrients from the soil (**Ram and Pathak, 2016**).

Neem seed kernel extract has the excellent property of repelling and deterring various insect pests. The seed extract is non-toxic to man and animals and is non-phytotoxic (**Matharu and Chahil, 2013**). The leaf extract of the lantana plant has ovicidal, repellent, antifeedant, and toxic effects on insect's pest. In addition, it is a source of biopesticides for environmentally friendly and economical pest control strategies against insect pests.

Considering the earlier mentioned constraints, the present studies on “**Studies on plant volatile mediating orientation behaviour of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulations for its management**” have been taken up with following objectives:

1. To study the diversity of insect fauna and population dynamics of major insect pests and their associated natural enemies on litchi ecosystem.
2. To study the effect of climatic factors parameters on the abundance of major insect pests and their associated natural enemies on litchi.

3. To analyze volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit.
4. Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant.
5. To study olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits.
6. To study the impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults.
7. To evaluate the efficacy of different plant and animal based natural based formulations against the major pest associated with litchi.



*Review  
of  
Literature*



The available literature pertaining to the different areas of investigation has been reviewed and presented in chronological order objective wise.

- 2.1 Diversity of insect fauna and population dynamics of major insect pests associated with litchi ecosystem.
  - 2.2 Effect of climatic factors on the abundance of major insect pests of litchi.
  - 2.3 Volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit
  - 2.4 Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant.
  - 2.5 Olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits.
  - 2.6 Impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults.
  - 2.7 Evaluation of different Plant and animal based natural based formulations against the of major pest associated with litchi.
  - 2.8 Work done on diversity, plant volatiles compounds, olfactory response, and plant and animal based natural formulations at the institution (G.B.P.U.A & T, Pantnagar)
- 2.1 Diversity of insect fauna and population dynamics of major insect pests associated with litchi ecosystem.**

Insects are one of the most important groups in the natural world. They affect the life and welfare of humans in different ways. While some insects are referred to as pests, others are beneficial to humans. For example, they may serve a function as pollinators of many cultivated plants, as natural enemies of harmful species, or as producers of valuable materials such as honey and silk. Several insect species, however, are not currently known as being harmful or beneficial. Nevertheless, they are extremely important as essential components of both natural and modified ecosystems (You-Minsheng *et al.*, 2005).

**Chang (1970)** observed that *Anoplophora macularia*, a serious insect pest of litchi whose larva bore into trees and it could kill the tree in a few months by damaging the conducting elements of the lower trunk. According to **Singh (1971)** *Myloccerus discolor* Boh and *M. undecimpustulatus* Faust were found for the first time attacking litchi in India. Populations of the weevil were largest during November-February and smallest during April-July, Heavy infestations resulted in damage to most of the leaves and very low yields in the subsequent season.

In a study, a species of *Salagena* found to attack on litchi, In South Africa the larvae tunnel first in the bark and later in the wood, generally entering at a fork. Large quantities of frass round the openings of the tunnels indicate the sites of attack. Though the larvae do not kill the trees, they cause die-back (**Villiers, 1973**)

At Chettalli, Mysore (India), in December 1970, *Xyleborus fornicatus* Eichh. was found infesting litchi for the first time. The beetles made numerous tunnels in branches 34 cm in diameter, and infested branches gradually withered and died, often breaking at the points where larval galleries were located (**Rai and Bhandary, 1973**).

**Storey and Rogers (1980)** reported 34 lepidoptera species on litchi with their symptoms of damage and peak months of activity in northern Queensland, Australia.

**Prasad and Singh (1981)** conducted a study on the occurrence of *A. litchi*, the most serious pest of litchi in Bihar. They showed that the spread of the pest varied from season and it was estimated that 300-500 fruits per 100 infested twigs were lost due to its attack. At the last stage of infestation there were 50-60 mites per leaf and 1800-3000 per shoot. Trees with dense foliage were preferred by the mite. Infestation began in February- March, reached peak in May-June and continued until October.

**Kumar and Lall (1984)** reported the incidence of insect pests of litchi in different localities of Bihar and recorded, Grainary beetle, *Carpophilus obsoletus* Er.; Date palm beetle, *C. mutilates* Er.; Litchi fruit moth, *Platyepela illepidata* Meyr.; Fruit fly, *Dacus dorsalis*, and Fig moth, *Ephestia cautella* Walk, damaging litchi fruits.

**Kumar and Lall (1984)** surveyed several districts in Bihar where litchi was grown and measured pest incidences viz. fruit borer (*Carpophilus* species, leaf roller

(*Platyepela aprobola* Meyrick) and fruit fly (*Dacus dorsalis* Hendel) of litchi. Based on the findings of the survey, borer infestations ranged from 21.40 percent to 34.40 percent, with the highest infestations found in Muzaffarpur.

**Sharma (1985)** reported that litchi mite (*Aceria litchii* Keifer) and the litchi fruit borer (*Acrocercops cramerella* Snellen) as the main pests of litchi in Bihar. Both pests caused significant damage to the crop.

**Thakur (1991)** conducted a survey in the several litchi-growing districts of Bihar to collect data on litchi mite prevalence, *Aceria litchii* Keifer. According to the results, leaf infestation ranged between 78.25 and 84.62 percent, whereas tree infestation ranged between 65.99 and 89.82 percent. The highest tree infestation was recorded in Sitamarhi at 89.82%, while the lowest was recorded in Darbhanga at 65.00%.

**Hameed et al. (1999)** identifies litchi fruit borer or cacao moth (*Conopomorpha cramerella* Snellen) and leaf roller (*Platyepelus aprobola* Meyer) as major pests and others minor or sporadic pest were fruit borer (*Carpophilus* species), nut borer (*Blastobasis* species), aphid (*Toxoptera aurantii*), litchi mealy bugs (*Drosicha mangiferae* and *D. Dalbergia*), white flies (*Aleurocanthus husaini* and *Dialeurolonga elongata*), litchi bug (*Chrysocoris stollii* Wolff) and leaf cutting weevil (*Myloccerus* species).

**Singh et al. (2001)** described 54 insect and mite pests commonly associated with litchi trees and their fruit.

**Waite (2005)** reported several species of fruit flies as a source of damage to litchi fruits, including *Bactrocera dorsalis* Hendel, *Bactrocera cucurbitae* (Coquillett), as well as *B. tryoni*, which has been detected in Queensland damaging litchi fruits. *Aristobia testudo* (Voet) and *Dasyneura* were also reported as serious pests in Guangdong province.

**Schulte (2007)** reported that litchi stink bug, *Tessaratoma papillosa* (Drury) and phytophagous mite, *Aceria litchi* (Keifer) are the major pests of litchi in Asia. Mites generally suck the cells of young leaves and cause punctiform lesions.

Surveys of insects and other pests on litchi were carried out from 2002 to 2007 in southern Taiwan. A total of 22 species of insects, one species of mite and one species of snail were found. Among them, the mango aphid *Greenidea mangiferae*, litchi fruit borer, *Conopomorpha sinensis*, leaf borer *C litchiella*, cottony mealybug *Chloropulvinaria psidu*, leaf roller, *Ehola celligera* and oriental fruit fly. *Bactrocera dorsalis* were considered of economic importance (**Wen-Hung and Liou-Tsung, 2008**)

**Anonymous (2009)** found that Litchi mites (*Aceria litchii* Keifer), *Conopomorpha cramerella* Snellen (litchi fruit borer) and *Platypus aprobola* Meyer (litchi leaf roller) were identified as major pests and the *Mylocerous* species (leaf cutting weevil) are minor pests of litchi, whereas the *Indarbella* species (bark eating caterpillar) are major pests. during the survey conducted in major litchi growing districts.

**Kumar et al. (2011)** reported that insect species previously unnoticed or of minor importance were reported to be present in severe forms. The weevils were *Apoderous* sp., while the borer was *Conopomorpha cramerella*. It was brownish red in color, approximately 5-7 mm long, and had a strong rostrum, inflicting heavy damage on the new flush. There was a devastating impact on young, growing trees under five years of age.

**Kumar et al. (2014)** identified and assessed four pests that pose a threat: *Apoderus blandus* (red weevil), *Perixera illepidaria* (loopers), *Dudua aprobola* (leaf roller) and *Eumeta crameri* (bagworm) at the National Research Centre for Litchi (NRCL). *A. blandus* outbreak could be detected throughout the year, except during extreme hot and cold weather, whereas *P. illepidaria* occurred between September and November, and *E. crameri* occurred between November and February. Peak infestation of *D. aprobola* was during July-February.

#### **Bark eating caterpillars, *Indarbela quadrinotata* (Walker)**

Bark-eating caterpillar was found to be the most economically important pest, which showed significant variation in infestation on the stem of old and young litchi varieties. The incidence of bark eating caterpillar on old plant varied from 0.75 to 2.25 fecal garlands per plant. A bark-eating caterpillar species is known (*Indarbela tetraonis*

Moore and *Indarbela quadrinotata* Walker), and they feed on a wide variety of plants, including , mangoes, rambutans, mulberries, berries, citrus, phalsa guavas, jackfruits, jamuns, loquats, pomegranates and roses (**Verma and Khurana, 1974; Khurana and Gupta, 1972**). The incidence was started from the month of September with distinct fecal garland in the month of February (**Anonymous, 1999**).

**Sharma and Kumar (1986)** reported that bark eating caterpillars are widespread throughout the Indian subcontinent and are primarily found in Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, Haryana, Orissa, Andhra Pradesh, Tamil Nadu, and Maharashtra. Bihar was particularly hard hit by the pest *Indarbela tetraonis* Moore because it was notorious for destroying litchi, guava, mango and ber. After nibbling at the bark, the newly emerged caterpillars covered the damaged area with silken webs made of excreta and chewed wood. After 2 -3 days, the larvae bore into the trunk or branches of the tree and created tunnels downward from there.

**Hameed et al. (1999)** recorded moderate to severe infestations of bark-eating caterpillars that damaged stems and shoots. There was a high infestation between August and October, and a moderate infestation in other months.

In a recent study, it was reported that bark-eating caterpillars bore into trunks, main stems and thick branches of litchi trees and destroyed the tissues of the xylum resulting in weak growth and fruiting of the tree. Caterpillars remain within the tunnel inside the stem during day, come out in night and feed upon the bark. Older and uncared trees were more affected by the pest. Infestation may be noticed by the presence of ribbons of wood chips, frass and silken thread over the bark surface. After hatching in June caterpillar feeds up to March-April and completes only one generation in a year (**Hameed et al., 2001**).

It has been reported that in low hills of Himachal Pradesh there was an increase in the incidence and intensity of bark eating caterpillar *Indarbela sp.* Citrus, litchi, mango, and guava orchards had an incidence ranging from 91.5 to 98.0 percent, with litchi being the most preferred host (with a 3.95 caterpillar incidence index) (**Gupta et al., 2014**).

**Litchi shoot and fruit borer, *Conopomorpha sinensis* (Bradley)**

In the past, *Conopomorpha sinensis* (Lepidoptera: Gracillariidae) has been a destructive pest of litchi plant, which has caused significant economic losses. At Pusa, Bihar, it has been reported that the first litchi leaves and fruits were destroyed by *Acrocercops cramerella* Snellen (**Fletcher, 1919**) In the field of forecasting and prevention, many studies have been conducted for *C. sinensis* (**Chen et al., 2011; Tsang and Liang, 2007; and Li et al., 2013**).

According to **Lall and Sharma (1976)**, cacao moths (*Acrocercops cramerella* Snellen) pose a serious threat to litchi foliage and fruits. These pest larvae mine the young leaves and shoots of litchi trees and bore into the fruit that can be found on the trees. Pest activity caused leaf infestations ranging from 7.1 to 72.5 percent, while tree infestations ranged from 47.7 to 88.9 percent during the months of August and February. Bihar and Uttar Pradesh had now established the pest as a major pest of litchi.

**Lall and Sharma (1978)** recorded that cacao moths (*Conopomorpha cramerella* Snellen) appear to be active on litchi trees as leaf miners during August to February, it relies mostly on alternate hosts from March through April during off-season (March to April). In litchi orchards, Kath jamun (*Zyzigium jambolana*) and Chhota amaltas (*Cassia tora*) were alternate hosts. May is the time when litchis become mature, and the moths migrate to litchi orchards to lay their eggs. The newly emerged larvae bored into mature fruits and fed on its pulp. September had the highest population density (0.92 larvae / leaf), while December had the lowest (0.45 larvae / leaf).

**Sharma (1985)** discovered that fruit borer activity occurs between April and May on inflorescences, and once the fruit has set the moths lay eggs near the pedicel of the plant, and when they hatch the larvae enter through it.

The litchi fruit borer and the litchi stem borer are also known as *Conopomorpha sinensis* in China and Thailand. Formerly known as *Acrocercops cramerella* this pest is now described as *Conopomorpha cramerella* Snellen (**Bradley, 1986**)

**Sharma and Agarwal (1988)** documented the life cycle of *C. Cramerella* and reported that in its life cycle, *C. Cramerella* passes through five larval instars and in Bihar and Uttar Pradesh, India, *L Cramerella* was a major pest. In young leaves, larvae tunnel into the midrib and build mines. The pest thrives on inflorescences and fruits from April to May.

**Hwang and Hsieh (1989)** have studied bionomics of the gracillariid *Conopomorpha cramerella* Sn. an important pest of litchi trees in Taiwan. *C. cramerella* was active in litchi during fruit developing season (April to September).

**Yao and Liu (1990)** reported two gracillariids *Conopomorpha sinensis* and *C. litchiefla* for the first time in China infesting litchi in Guangdong and Fujian. These two closely related species have long been considered as a single species. *C. sinensis* damages the fruits and shoots of litchi while *C. litchiella* damages shoots only.

A survey has been taken in the orchard of litchi to study the Lepidopterous pests on shoots, spikes of flowers, and fruits in Taiwan Results showed that 13 species of lepidopterous pests were found from litchi shoots which included two species of the *Grazillariidae*, *Conopomorpha sinensis* Bradley and *Citchiella* Bradley; six species of the *Tortricidae*. *Statherotis leucaspis* Meyrick, *Dudua aprobola* Meyrick, *Eboda celligeru* Meyrick, *Adoxophes prestana* Walker, *Lobesia* sp., and *Cryptophlebic ombrodelta* Lower, two species of the *Pyalidae*, *Diaphania indica* Saunders and *Camogethes evaxalls* Walker; two species of the Noctuidae, *Sympts rufibasis* Quenee and *Oxyodes scrobiculata* Fabricius: and one species of the *Geometridae*, *Thalassodes immissaris* Walker.

**Yao and Liu (1990a)** reported two species, *C. sinensis* and *C. litchiella* first time infesting litchi, *Litchi chinensis* in Guangdong and Fujian regions in China.

**Yao and Liu (1990b)** reported *Conopomorpa sinensis* and *Conopomorpha litchiella* Bradley first time in Taiwan attacking litchi fruit trees.

**Newton and Crause (1990)** conducted an experiment on litchi fruit borer in South Africa in 1986 and reported low rate of oviposition by the moth early in the seasons at 0.02 eggs/fruit, but increased rapidly to 0.21 eggs/fruit after ripening began.

**Gill (1992)** indicated that there was a serious pest of litchi in Punjab known as litchi nut borer, *Blastobasis*.

**Hameed et al. (1992)** observed that *Conopomorpha sinensis* caused most damage to fruits during May and July, and its population was highest in August. The population was not observed in the orchards from October to March, but was observed again in April.

**Sulistyowati et al. (1995)** found that cocoa pod borer, *C. cramerella*, was one of the most significant pests of cocoa crops in Indonesia, Malaysia, and the Philippines.

**Bhatia et al. (2000)** observed that in the two years studied, borer incidence ranged between 13.6% and 64.9%.

**He deng (2001)** identified *C. sinensis* as a major pest of litchis in Guangdong, China.

**Waite and Hwang (2002)** also recorded litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae) as one of the major pests of litchi in China and Thailand.

**Bhatia and Gupta (2003)** found that *C. cramerella* caused 10 to 50 per cent damage to litchi trees in six districts of Himachal Pradesh during the nine-year survey between 1991-1999.

According to **Menzel and Waite (2005)**, *Conopomorpha sinensis* Bradley was commonly known in China as the litchi stem end borer and in Thailand as the litchi fruit borer. The pest was earlier known as *Acrocercops cramerella* Snellen.

**Anupunt and Sukhvibul (2005)** cited litchi fruit borer, *C. sinensis*, and longan stink bug, *Tessarotoma papillosa*, as the major constraints in litchi production in addition to physiological factors such as alternate bearing and fruit cracking.

Five species of lepidopterous pests were observed on the spikes of flowers and fruits of litchi (**Hung et al., 2006**).

Similarly, **Nair and Sahoo (2006b)** found that the fruit borer, *C. cramerella*, infests litchi fruit (from March to May) and leaves (from July to November). Further,

they reported that raw and ripened fruits dropped between 26.0 and 89.0% because of this pest.

**Wen and Liou (2008)** investigated six insect pests associated with Yuh-Heh-Bau litchi, including fruit borer, *C. sinensis*, and leaf borer, *C. litchiella*.

**Yin et al. (2009)** studied how litchi stem borer, *C. sinensis*, can be controlled in southern China as a means of controlling this pest. As a result, the workers came to the conclusion that this pest mainly infested fruits in the area.

**Rosmana et al. (2010)** found *C. cramerella* to be the most serious pest of litchi plantations in China.

**Kumar et al. (2011)** surveyed litchi growing areas in Bihar in 2009-10 for emerging pests and diseases. During the study, two insect species were identified: the weevil *Apoderous* sp. and borer, *C. cramerella* on fruits which were causing severe damage.

#### **Litchi leaf roller, *Argyroplote leucaspis*.**

In Hawaii, South Africa, Australia, and China the Leaf roller, *Platyepplus aprobola* (Meyer), had been reported in various fruit crops. In Bihar and its surrounding areas, leaf rollers were a serious litchi pest. In Litchi trees, leaf rollers are observed throughout the year, though a higher proportion of the population was observed from July to February than other times of the year. In accordance with **Singh (1971a)**, the larvae injured tender leaves by rolling them and feeding within them. The percentage of leaves injured by the leaf roller varied from 16.70 to 71.60 percent, and the percentage of trees infested by the leaf roller varied from 12.88 to 53.54 percent. Leaf folders mate and oviposit at night. In July-August, the life cycle of the insect takes 21.6-31.0 days while in September-October, it takes 46.0-51.0 days. The number of days in February-March is 46.5 (**Kulkarni et al., 1967; Maiti and Sahoo, 1991**).

**Lall and Mallik (1976)** reported that Leaf rollers breed between August and February on litchi leaves as soon as new flush is available and breeding is restricted to off season between from March to April which occurs on an alternate host such as *Eugenia jambolana* (Kath jamun) and *Cassia tora* (Chhota amaltash) grows in orchards

of litchi between March to July. During November, moth populations reached their peak (0.71 / leaf) while in January they reached their lowest (0.20 / leaf). In China and Australia, *Platyepplus aprobola* Meyrick has also been reported as a minor pest of litchi leaves.

**Waite (1992)** described leaf roller species *Olethreutes praeceadens* Wals as a minor pest that attacks litchi crops in Australia while *Olethreutes perdulata* Meyr is considered an occasional pest in Queensland.

**Hameed et al. (1999)** discovered that the leaf roller was particularly destructive during the onset of new flush and also saw the infesting of leaves during August and November, but the leaf roller was not seen during the rest of the year.

**Chakraborty and Samanta (2005)** reported the highest incidence (48.00%) of *Platyepplus aprobola* Meyer (litchi leaf roller) in West Bengal in October.

#### **Litchi mite. *Aceria litchi***

**Hazarika (1951)** found that mites multiply quickly in warm weather as opposed to the winter, when they remain dormant.

**Alam (1959)** reported that the litchi erineum mite had the potential to destroy almost all of the litchi plants in almost every country that grows litchi. Throughout the year, litchi leaves in Pakistan were infested by the pest. April to May and September and October were the most prolific months for the pest population and during the moderately hot and dry period, mites multiplied most rapidly, the weather conditions were very unfavorable, with humid conditions, continuous rain, and extreme temperatures.

It was observed that the mite population reached its peak in April to May, and again in September and October according to **Alam (1962)**. In June and July, when humidity is high and continuous rain occurs, the pest population decreases significantly. If the temperature exceeded 98 degrees Fahrenheit, the mite failed to thrive.

**Alam and Wadud (1963)** reported that in young orchards, leaf injury due to litchi mites ranged from 5 to 45 percent, while in old orchards, it ranged from 5 to 25

percent. Upon finding infested leaves, they observed that they dried up prematurely and fell off. However, flower bud injuries ranged 39 to 75 per cent. In some cases, the mite caused severe damage to 100% of buds while premature fruits caused severe damage to young plants. 19 to 37% of panicles were damaged on middle-aged plants.

**Krishnamurthi (1967)** reported that the mite's breeding season began in March, and its biological activity peaked in July. There was a noticeable increase in the number of adult insects during the period from March to July. Erineum mites are typically spread by wind from one orchard to another through old, infected litchi leaves. Young leaves, inflorescences, and developing fruits are damaged by both nymphs and adults. Their stout rostrum punctures and lacerates the leaves' tissues, sucking out the sap. A hair-like growth called 'Erineum' appears on the underside of the leaves as a result of its infestation.

**Lall and Rahman (1975)** reported that the *Erineum mites* were active on litchi trees between January and October, according to their observations and during the adult stage (*Erineum*), hibernated beneath the hairy and velvety growth. The peak of the population occurs on the undersurface of the leaf from November to December. March had the highest population (18.1 per cm<sup>2</sup>), while December had the lowest (1.40 per cm<sup>2</sup>).

It was reported by **Mishra (1980)** that the litchi *erineum mite* population declined from November to February in Bihar as a result of severe infestation between March and September. November and December were the months with the lowest litchi mite populations.

**Sharma et al. (1986)** observed that the peak period of infestation coincided with the availability of tender plant tissues. The maximum temperature had a significant positive correlation and the relative humidity had significant negative correlation with the mite population.

**Singh et al. (1987)** noted that West Bengal and Bihar had the most mite damage, with 10.75 per cent and 39.50 per cent respectively.

**Sharma and Agarwal (1988)** found that leaf infestation in north Bihar ranged from 46.84 to 99.44 percent.

**Somchoudhary et al. (1989)** In a recent study, it was found that Litchi trees were infested with *Aceria litchi* Keifer, a mite originating from West Bengal.

**Huang et al. (1990)** reported that the litchi erinose mite, *Aceria litchi* Keifer, in China.

**Thakur and Sharma (1990)** found that mites prefer warm weather and are most numerous during summer. They disappear during winter. In June-July, the number of these birds was higher, but with the onset of monsoon, in late September, they declined and remained low until December, after which they became almost extinct. Among the pests analyzed, 31.10 to 93.10 were detected per 2.5 cm<sup>2</sup> leaf surface. In December, pest populations were lowest and in May, they were highest.

**Hameed et al. (1992)** revealed that Litchi *erineum mite* destroyed leaves, inflorescences, and young fruits all year round and the highest population was during April-May, while the lowest population was observed during November - December.

**Menzel (2002)** claims that the litchi *erinose mite*, *Aceria litchii* (Keifer), is a significant pest of litchi (*Litchi chinensis* Sonn) grown in semi-humid tropical regions at higher elevations, often in Asia.

**Singh et al. (1997)** found that temperatures, relative humidity, wind speed, and precipitation are all correlated with mite populations as well as abiotic factors, and the optimal temperature range for mite populations is 29.7°C to 31.20°C.

In the Raygada district, Orrissa, India, **Singh et al. (2002)** conducted an extensive survey of litchi orchards infested with *Aceria litchi* and found that almost all litchi orchards were infested. As a whole, leaves and branches averaged 54.19% infestation, 61.71 for whole plants, 61.79 for branches, and 61.71 for whole plants, respectively.

## 2.2 Effect of climatic factors on the abundance of major insect pests of litchi

**Boavida and Neuenschwander (1995)** reported the population dynamics of *Phenacoccus solenopsis* in relation to abiotic and biotic factors. Mealybug population in cotton and okra was found to be higher in the month of October. Whereas, mealybug population was maximum in the month of February on tomato and potato plants.

Furthermore, there was positive correlation of mealy bug population with higher temperature. Whereas, there was negative correlation of natural enemies with lower temperature and humidity.

**Kumar et al. (2008)** studied population dynamics and seasonal occurrence of litchi bug, *Tessaratomya javanica*. Observations showed a significant positive correlation between litchi bug population and maximum temperature, while a significant negative correlation was found with maximum humidity. Moreover, rainfall and maximum temperature were significantly positively correlated with insect population, while relative humidity was significantly negative correlated with relative humidity. Litchi bugs emerged in late April and disappeared after the beginning of August, after which they hibernated in adulthood.

The population dynamics of litchi pest during 2006-07 and 2007-08 was studied by **Ranjan and Mukherjee (2008)**. Leaf infestation maximum in August with 69.8 and 62.60% infestation in 2006-07 and 2007-08 respectively whereas leaf infestation was found to be minimum in the month November during the both years. Minimum temperature ( $r=0.558$ ) and relative humidity ( $r=0.663$ ) were found to be significantly correlated with the leaf infestation. Furthermore, the pest appeared in the month of April to June both the years where maximum fruit infestation (53.40%) was recorded in June, 2007. Hence, similar results were observed in June, 2006 (52.6%). The biotic factors were significantly correlated with the fruit infestation.

**Wang et al. (2010)** surveyed and recorded *Tessaratomya papillosa* (Drury) populations and their spatial distribution. A peak in oviposition occurs between April and February. Nymph abundance peaked in March, and adult abundance in April and July. All *T. Papillosa* developmental stages had a mutually exclusive distribution, and adult individuals had an aggregated distribution.

**Boopathi et al. (2011)** studied the population dynamics of stink bug, *Tessaratomya papillosa* during summer, monsoon and winter season on litchi. The highest population of bugs was recorded in summer (92.13), moderate during monsoon season (81.34) and lowest in winter (73.55). The monthly incidence of *T. papillosa* was found to be positively correlated with maximum temperature ( $r = 0.533$ ), minimum temperature ( $r = 0.181$ ), relative humidity ( $r = 0.205$ ) and rainfall ( $r = 0.071$ ).

**Ray and Mukherjee (2012)** observed the effect of abiotic factors on infestation of litchi leaf roller, *Dudua aprobola* in both years i.e., 2010-11 and 2011-12. In the month of April and May, its activity was not observed on the litchi during both the years. The maximum leaf infestation was recorded during the month of October i.e., 50.90 and 53.20 per cent during the years 2010-11 and 2012. In the month of January leaf infestation found to be minimum in both the years. Moreover, all the abiotic factors viz, relative humidity 0700 hrs, 1400 hrs ( $r = 0.696$  and  $0.640$ , respectively) and rainfall ( $r = 0.407$ ) were significantly correlated with the leaf infestation individually.

A field experiment was conducted by **De Azevedo et al. (2014)** to estimate the population dynamics of *Aceria litchii* and its associated natural enemies. The highest population of *A. litchii* was observed during the month of November and June and lowest population was found between January and March. The natural enemy reported was predatory mite, *phytoseiid Phytoseius intermedius*.

**Li et al. (2014)** studied the effect of temperature on emergence of *Conopomorpha sinensis* at 5 different temperatures viz, 15, 20, 25, 30, and 35 °C, 80% RH and 14:10 h L:D. Results have shown that temperature has significantly affected the emergence duration and emergence rate but there was no change in sex ratio and pattern of emergence. Furthermore, with decrease in temperature the duration of emergence was increased. Moreover, at temperature 20, 25, and 30°C the emergence rate was significantly higher as compare to 15 and 35 °C. There was no change in sex ratio of *C. sinensis* under different temperature and remained approximately (1:1) whereas pattern of emergence of female was similar to males.

**Boopathi et al. (2015)** studied the population dynamics of litchi stink bug, *Tessaratoma papillosa* and observed an increase in population of *T. papillosa* with increasing temperature and decreasing relative humidity from April to July. Furthermore, a forecasting model namely the autoregressive integrated moving average (ARIMA) was developed to predict the incidence of *T. papillosa*

**Ranjan and Ray (2015)** reported the population dynamics of litchi mite in relation to the different abiotic factors. Results have shown that the maximum leaf infestation was recorded during the month of May i.e., 56.20 and 60.40 per cent during

the years 2012 and 2013, respectively. The leaf infestation was minimum in the month of January in both the years. However, all the abiotic factors together had the significant effect on the leaf infestation by the pest and the coefficient of determination ( $R^2$ ) was 89.00 per cent.

**Amaral et al. (2020)** conducted 25-months study on the population dynamics of this mite in different varieties of lychee. There were five varieties: Bengal, Americana, Brewster, Groff, and WB4 to study and there was an increased incidence of *Aceria litchii* on lychee plants in October and November over the years. It was the Bengal variety, which was widely commercialized, and the most likely to be attacked by mites, Although Americana exhibited mite resistance. While the pest was recorded in this variety, it reduced the number of individuals and, as a result, reduced the *erinose*.

**Charak et al. (2020)** reported regarding the effects of weather factors on the population dynamics of the litchi leaf roller, *Platyepplus aprobola*. According to the results, leaf roller activity peaked during the first fortnight of September (50.74%) to the second fortnight of October (54.97%). Correlation and regression studies found positive relationships between leaf roller incidence and average temperatures, relative humidity, sunshine hours, and rainfall, as well as negative relationships with average wind velocity.

The effect of local climate conditions on the dynamics of *Conomomorpha cramerella* Snellen pest populations has been studied, especially the relation between temperature, humidity, and altitude. In April 2014, 2015, and 2016, 15.30% of *Conomomorpha cramerella* pests showed mild attacks. Since February 2015, 88.09% of all *Conomomorpha cramerella* pest infestations have been severe. In order to control *Conomomorpha cramerella* pests, clones that are resistant to Cocoa Fruit Borer can be used along with improved plant maintenance practices **Zul (2020)**.

**Dalui and Sarkar (2021)** studied seasonal incidence and damage potential of litchi fruit borer (*Conopomorpha sinensis* Bradley) in relation to major abiotic factors in the environment. Infestation of the borer (3.3%) began after 21 days, and it grew steadily until 60 days of fruit set when it reached its peak (42.66%). There was a significant decrease after that. Statistically, it was found that rainfall does not

significantly affect the activity of the pest species, while temperature is of significant importance, especially for larval activity.

### **2.3 Volatiles compounds from different litchi plant parts of litchi plant, including tender shoots, flowers, immature fruit and mature fruits**

**Ong and Acree (1998)** using GC/O analysis, detected at least 60 volatiles that possessed odor-active properties in the fruit extract. It was found that ethyl acetate extract contains more volatiles than nonpolar Freon extract. A number of compounds were found to have significant odor activity, including damascenone, guaiacol, 2-acetyl-2-thiazoline, (Z)-2-nonenal,  $\beta$ -, 1-octen-3-ol, geraniol, Furaneol, 2-phenylethanol, unknown (58), vanillin, and linalool were found to be the most odor-active. Isobutyl acetate, guaiacol, cis-rose oxide, 2-acetyl-2-thiazoline,  $\beta$ -damascenone, Furaneol, linalool, (E)-2-nonenal, geraniol, and isovaleric acid were determined to significantly contribute to the aroma of this fruit. GC/O analysis confirmed that geraniol is responsible for the citrus-fruity aroma, while 2-phenylethanol likely contributes the floral flavor. Lychee's aroma was determined to be the result of interactions between floral, nutty, citrus, and fruity compounds.

**Guangquan et al. (1999)** used GC-MS to analyze the chemical composition of litchi (*Litchi chinensis* Sonn.) pericarps. A total of 22 compounds were analyzed, these include esters, fat acids, bridged rings, cyclic ethers, and cyclic olefines. It was discussed how the structure of litchi pericarps correlates with the denaturation of the components.

**Chyau et al. (2003)** isolated and separated free and glycosidically-bound volatile compounds from fresh clear lychee juice using an Amberlite XAD-2 column. In a subsequent process, almond  $\beta$ -glucosidase hydrolyzed the bound fraction to release the volatile compounds. Volatile components of both free and bound fractions were then determined by GC and GC-MS, and they showed similar volatile profiles. Two terpenes, two ketone esters, fourteen alcohols, two aldehydes, four acids and two alcohols were identified in both fractions. According to aroma evaluation, the bound fraction had an odourless fragrance, whereas the free volatile fraction was fresh-fruity and lychee-like in taste. As a result of enzymatic hydrolysis, the bound fraction

exhibited the characteristic lychee fragrance. A strongly fruity, lychee-like aroma was observed when the free and hydrolysed bound fractions were combined.

According to **Wu et al. (2009)**, gas chromatography-mass spectrometry was utilized in conjunction with headspace solid phase extraction to investigate the volatile components of nine litchi cultivars with high commercial value. In total, 96 volatiles were detected in the sample, of which 43 were identified. Cis-rose oxide, trans-rose oxide, 1-octen-3-ol, and geraniol had the highest OAVs in most cultivars, followed by the trans-rose oxide. A cluster analysis based on major volatile component amounts revealed similar volatile profiles between two Huaizhi samples from two different producing areas.

**Li et al. (2012)** isolated and characterized litchi pericarp (*Litchi chinensis*) procyanidin oligomers. Lastly, epicatechin from litchi pericarp, A-type procyanidin dimers (A2) and trimers, epicatechin-(48, 207)-epicatechin-epicatechin from litchi pericarp were studied for their role in free radical scavenging. As a new plant source of A-type procyanidins and natural antioxidants, litchi appears to be a good source of the A-type procyanidin dimer and trimer.

**Feng et al. (2015)** applied 5-ALA solution to the fruit peel of Feizixiao litchi 45 days after full bloom at concentrations 80, 100, 120, 140, and 160 mg for 'Feizixiao' litchi, 5-ALA could enhance the color of the skin through the accumulation of anthocyanin but not chlorophyll degradation during harvest. Further the study shown that there was significant improvement in skin colour by application of 5-ALA during harvesting time and simultaneously promoting fruit growth, promote delay in soluble solid degradation, and edible rate increases.

L-cystein was investigated and studied to determine its efficacy on Gola litchi fruits by **Ali et al. (2016)**. Treatment with L-cysteine 0.25% proved to be the most effective among the used concentrations. Compared to control fruit, fruits treated with L-cysteine (0.25%) showed significant reductions in loss in weight, incidence of diseases and severity, index of browning, leakage of membrane, and malondialdehyde (MDA) contents. Consequently, pre-storage l-cysteine (0.25%) application to litchi fruit preserved antioxidative properties for 28 days while reducing pericarp browning.

**Feng et al. (2017)** conducted a GC-MS experiment to find out the volatile's compounds present in a 'sweetheart' lychee and to identify active aromatic compounds in lychee. Solvent assisted flavor evaporation (SAFE) technique was used. Furthermore, aroma extract dilution analysis (AEDA) was done to find out odorants in lychee and to identify 31 key active aroma odorants were identified using flavor dilution (FD). Moreover, methanol and geraniol shown the highest flavor dilution followed by fureneol, nerol, dimethyl trisulfide, linalool, nerolidol etc., Furthermore, the flavor profile of 'Sweetheart' lychee was described by sensory analysis.

The browning index of four litchi cultivars was studied and compared by **Chen et al. (2019)** in which comparative metabolomics was conducted on the pericarps of four varieties of litchi during browning. Litchi pericarp exhibited 119 kinds of metabolites, including 30 types of primary metabolites, 44 types of volatile compounds, 29 types of free amino acids, and 16 types of hydrolytic amino acids. The ANOVA result and the OPLS-DA result showed 52 types of metabolites with a predictive VIP > 1 and  $p < 0.05$  as the most important ones. The yellow-green pericarp of FZX has a significant increase in amino acids resulting in a delay in browning. Three red pericarp cultivars were negatively correlated with browning speed of their pericarps as a result of increased soluble sugars and free amino acids during browning. As a result of the browning, FZX, NMC, and HZ exhibited positive correlations with sesquiterpene levels in their pericarps. A correlation analysis also revealed a negative relationship between amino acids and volatile compounds, perhaps suggesting pericarp browning induces amino acid metabolism to terpene conversion.

**Lal et al. (2019)** estimated the leaf phenol and flavonoids from 20 different genotypes of litchi trees, including those that flower and those that do not. There was a range of 22.86 - 53.59 mg/g of phenol content in flowering trees in 2017, while there was a range of 10.03 - 33.7 mg/g in non-flowering genotypes. Similar to that, phenol content ranged from 6.54 - 31.17 mg/g in non-flowering trees in the year 2018. There were 3.27 - 71.46% differences in phenol contents between flowering and non-flowering trees in 2018. There was a difference in phenol content between flowering and non-flowering litchi trees from year to year, but more phenol content was found in flowering trees.

#### 2.4 Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant

There are few examples of such metabolites reviewed by **Bennett and Wallsgrove (1994)** Secondary metabolites have deterrent/anti-feedant effects, to be toxic, or to be precursors to the formation of physical defence systems. Phytopathogenic organisms and specialist herbivores do not merely circumvent secondary metabolite deterrents or poisons, but rather use them as recognition cues and nutrients. A cyanogenic glucoside and a glucosinolate are examples of defensive compounds. Shikimic acid and aromatic amino acids are sources of a large number of secondary metabolites, many of which play a key role in defence mechanisms. As a result of infection, wounding, or herbivory, several classes of secondary products are produced, and examples of these are given. Although their precise roles and interactions in signalling and development have not been fully elucidated, salicylates and jasmonates have been implicated as physiological signals in such responses.

**Takabayashi et al. (1994)** reviewed several literatures where he clubbed how plants can defend themselves when attacked by herbivores by intensifying the effectiveness of natural enemies of insect pests and named it as a “indirect defence. In this literature, emphasis on the role of terpenoids in the induced indirect defense of plants against herbivorous mites was done where the “herbivore-induced synomone” (HIS) are emitted from both damaged and undamaged areas of infested plants, and the composition of “herbivore-induced synomone” (HIS) varies among different plant species. predatory mites cope with this variation of his by innate recognition as well as temporary specialization to a certain HIS via learning.

**Geervliet et al. (1997)** studied difference in the volatile emission by herbivores infested plants that differs from those emitted by un infested plants. Parasitoids of *Pieris* species, *Cotesia glomerata* and *C. rubecula*, responded differently towards different herbivore- infested food plants. Whereas differences in responses to plants infested by other herbivore species were less clear. In addition, the characterization of compounds derived from red cabbage, white cabbage, and nasturtium plants that had been infested with larvae of *P. brassicae* or *P. rapae* was done and eighty-eight

compounds including alcohols, ketones, aldehydes, esters, nitriles, terpenoids, sulfides, (iso)thiocyanates, carboxylic acids, and others were identified. Furthermore, herbivore-infested plants emitted the greatest number of compounds.

Using leaf, root, and bulb tissues at different stages of development, **War *et al.* (2013)** analyzed changes in primary and secondary metabolites. Stress induced by caterpillars promoted bulb mass and differing glucosinolate regulation in leaves. In response to mild insect stress, aphids enhanced the growth of leaves and increased the concentration of glucosinolates in the bulb, the principal storage organ of rats *B. rapa*. Plant growth parameters did not change when either herbivore had mild effects on older plants or concentrations of the metabolites analyzed. The Brassica plants continued to grow and displayed enhanced defense patterns under mild herbivore stress, varying significantly by herbivore type and development stage. In conclusion, these findings provide new insights into how plants respond to herbivores and how to manage *Brassica rapa* in agroecosystems

**Agut *et al.* (2018)** proposed the role of plant compounds such as flavonoids, glucosinolates, or acyl sugars as acaricides against a polyphagous mite, *Tetranychus urticae* Koch. Here in plants can be induced to produce stimuli to increase the resistance against spider mites. Plant volatiles compounds were found to have a repellent activity. Furthermore, integration of VOCs into current management practices will prove to be a sustainable crop management tool.

According to **Eisenring *et al.* (2018)**, phloem-feeding aphids and whiteflies and leaf-chewing caterpillars significantly alter secondary metabolomes of young, undamaged cotton leaves. Additionally, various herbivore-infested plants were subjected to bioassays with caterpillars to assess their performance. ABA and jasmonoyl-L-isoleucine levels were increased by caterpillar damage, while spider mite infestations did not affect them. There were no systemic effects of aphid and whitefly infestations on secondary metabolites. The salicylic acid content of plants infested with aphids decreased, while ABA levels increased in plants infested with whiteflies. Aphid infestations and whitefly infestations had no effect on caterpillar performance. In light

of the results, it is imperative that further research be conducted into how resource sequestration could be viewed as a potential systemic defensive reaction following herbivory by chewers and cell-content predators.

In their study on *Phenacoccus manihoti*-infested and non-infested cassava plants were investigated by **Gazola et al. (2019)** further identified and quantified secondary metabolites. Using three cassava cultivars, Baianinha, Santa Helena, and IAC-12, as well as two layers of canopy (apical and basal) and two levels of *P. manihoti* infestation (infested and non-infested), examined the biomass of these three cultivars. Detection and quantitation of compounds were conducted using aliquots of extracts analyzed by HPLC. Caffeic acid, p-coumaric acid, ferulic acid, rutin, and trace amounts of gallic acid were detected in bark and leaf extracts of Baianinha, Santa Helena, and IAC 12 cassava cultivars. All evaluated cultivars contained primarily caffeine in the basal leaves. Moreover, Baianinha and Santa Helena basal leaves had relatively high levels of ferulic acid. In addition, rutin concentrations were higher at the apex of apical leaves than at the base of apical leaves for all three cultivars, regardless of infestation with *P. manihoti*. Plants with 'Baianinha' apical leaves produced more rutin when *P. manihoti* was present.

**Faiola and Taipale (2020)** reviewed that herbivore show difference in the volatile emission in response to the infestation by the insects. When active herbivores feed on plants, stress volatiles dominate. The review gives a detailed-on plant volatile compound. As a conclusion, the review provided a synthesis of volatile emissions provided by trees during insect herbivory.

**Perez et al. (2021)** concluded that tomato plants which were induced with (Z)-3-hexenyl propanoate [(Z)-3-HP] were found to be less susceptible to the attack of major insect pest of tomato. Further, Transcriptomic and metabolomic analyses of plants induced with (Z)-3-HP confirmed that genes involved in specialized anti-herbivore defense were up-regulated, resulting in an increased production of fatty acid-derived compounds, activation of the lipoxygenase pathway and accumulation of specific defense compounds. Results depicted that under commercial greenhouse conditions how does the release of HIPVs as elicitors of plant defenses via designed

polymeric dispensers can be successfully integrated as a new biorational and sustainable tool for pest control.

**Rahman and Babu (2021)** performed an experiment using GC-MS studies to reveal variation in qualitative and quantitative volatile profiles of in both infested and uninfested leaf by red spider mite (*Oligonychus coffeae*). Furthermore, 'Y'-tube olfactometer experiment was performed to test whether the the odours of *O. coffeae* induced plant volatiles from tea leaves are detectable cues for the attraction of the predatory mite, *Neoseiulus longispinosus* preying on red spider mite. Results shown that *O. coffeae* induced plant volatiles from tea leaves are detectable cues for the attraction of the predatory mite, *Neoseiulus longispinosus* preying on red spider mite. But predatory mites were significantly attracted to infested leaves when more numbers of prey mites were presented. There was no significant variation in attraction when mechanically damaged or previously infested tea leaves were presented against normal leaves. Preference was most significant to four leaves each with 100 prey mites when supplied against clean air. Results of this study deserve importance as data base for further determination of the feasibility of manipulating volatile info-chemicals as attractants for *N. longispinosus* in tea plantation.

**Gunpal and Patni (2022)** conducted a GC-MS study to find out difference in the compounds present in a mite infested galled leaves and normal leaves. Results shown that leaves were rich in sugars, sesquiterpenes, terpenes, linoleic acid esters, vitamins, antioxidants, glycerol and steroids. Amount of Alpha methyl mannofuranoside reduced in the galled leaves to 60.82% from 72.49% in the normal leaves. Amount of Vitamin E reduced from 1.80% in normal leaves to 0.40% in galled leaves. Caryophellene increased in galled leaves (2.04%) when compared to normal leaves (0.38%). Betulinaldehyde and gamma-Sitosterol were absent in galled leaves but present in normal leaves (4.95% and 2.12% respectively). Lupeol and beta-Longipinene were present only in galled leaf (1.98% and 4.54% respectively) and absent in the normal leaf. The results obtained from this study show that the metabolic processes of the leaf cells have been altered by the *Aceria* mite, leads to changes in the chemical composition of the leaves.

## 2.5 Olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits

**Schuster and Starks (1974)** examined the olfactory responses to a greenbug host, a non-host insect (*Heiothis zea* Boddie), and a peanut cactus rarely colonized by aphids (*Chamaecereus silvestrii*), all of which contained host insects.

**Ramachandran et al. (1990)** conducted an electroantennogram study of 91 volatile chemicals of plant origin was conducted on male and female leaf Folder species. When aliphatic aldehydes were saturated and unsaturated, males and females displayed significant differences in EAG responses, further in both species' compounds of the green leaf odor complex evoked high EAG responses in both species and sexes.

**Jang et al. (1997)** performed a laboratory test on fresh leaves and solvent-water leaf extracts of the hedgerow shrub panax, *Polyscias guilfoylei* (Bull) in laboratory flight tunnel and cage olfactometer bioassays to assess their attraction to oriental fruit flies, *Bactrocera dorsalis*. A flight tunnel experiment showed that mated female oriental fruit flies were attracted to fresh mature whole panax leaves. Virgin females and males showed a low response compared to controls. In a rotating olfactorometer, methylene chloride and water layers competed with one another and the methylene chloride layer was more attractive. Methylene chloride showed the greatest activity in olfactory assays with outdoor cages compared to water fraction. The results of the study suggested that mated female oriental fruit flies are attracted to volatile semiochemicals from this nonhost plant.

**Reddy et al. (2002)** investigated the interaction between bioagents and volatiles associated with the host using the Y olfactometer. The pheromone blends that were used to attract *Trichogramma chilonis* were synthetic pheromone blends. *C. plutellae* showed a response to the blend. A 1:1 blend of the major components of the pheromone evoked a response in males and females, although no response was elicited by single compounds. *T. chilonis*, *C. plutellae*, and *C. carnea*, responded to only Z3-6:Ac among the cabbage green leaf volatiles. *C. carnea* males had an increased response to these volatiles blended with the pheromone, but all other males displayed similar responses. It appears that these natural enemies locate their diamondback moth hosts by

detecting sex pheromones and larval frass volatiles from the diamondback moth and cabbage volatiles.

**Turlings *et al.* (2004)** observed the reactions of the solitary host-induced odour-producing endoparasite, *Cotesia marginiventris* (Cresson) to the six-arm olfactometer.

There was no difference in the behaviour of female wasps when they were exposed to a single source of odour and when they were exposed to multiple choices. Males preferred arms in which females had been released, but females did not seem to attract or repel each other when released in groups as well as individually.

An attracticide using synthetic plant volatiles has been developed for noctuid moths by **Del Socorror *et al.* (2010)** used in two-choice olfactometer settings to assess the attractiveness of a number of known hosts and non-hosts (for larval development) using this system. According to the results of the test, 33 plants proved to be highly attractive to both sexes. Males and females found plants to be attracted to each other in high numbers. To identify potential compounds that might be useful in developing moth attractants, especially for females, collections of volatiles were made from plants that were attractive to moths in the olfactometer. Aromatic compounds, hydrocarbons, monoterpenes, and sesquiterpenes were found. Synthetic attractants can be developed using a method, known as 'super-blending', that combines compounds from all these classes that are found in plants that are attractive in general in blends that aren't directly modelled after specific plants.

Based on a study, **Revadi *et al.* (2015)** discovered that mated females were attracted to volatiles released by intact fruits. A volatile electroantennographically (EAG) active, isoamyl acetate, significantly attracts mated females in olfactorometer bioassays. As a result, this study indicates that *Drosophila suzukii* follows olfactory cues when selecting oviposition sites. The identification of volatiles emitted by host fruits that attract *D. suzukii* may aid in the development of a selective and efficient synthetic lure for monitoring this pest. This species offers an opportunity to study the physiological mechanisms that contribute to the shift from rotten to ripe fruit oviposition in *Drosophila melanogaster*.

**Abounbakar et al. (2019)** studied the olfactometer response of *Therophilus javanus* towards the odours emitted by four *M. vitrata* damaged host plants i.e., cowpea *Vigna unguiculata*, *Lonchocarpus sericeus*, *Sesbania rostrata*, and *Tephrosia platycarpa* were female *T. javanus* shown more attraction to infested flower of *T. platycarpa* as compare to uninfested flowers of the same plant. Moreover, another study shown that *T. javanus* females were oriented towards the odours emitted by infested cowpea flowers and infested pods. Moreover, parasitoid was more attracted to caterpillar infested pods than caterpillar infested flowers which depicts that odour released by cowpea pods was more detectable to female parasitoids.

A field experiment was conducted by **Cao et al. (2019)** in 18 different flower host plants of *F. occidentalis*. Both male and female showed different preference for different plant odor where female *F. occidentalis* shown significantly different preference for different plant odor, whereas no preference was shown by male *F. occidentalis*.

**Yang et al. (2019)** performed an experiment on kudzu bug, *Megacopta cribraria* using chromatography with electroantennographic detection (GC-EAD) & electroantennogram (EAG) assays to study electrophysiological and behavioural responses of insect towards volatiles emitted by kudzu and soybean. Furthermore, the volatile compounds quantified were examined to identify the semiochemicals which can be used for host selections. The resulted into finding of compounds which is used by *M. cribraria* to locate its host plant. Therefore, these results may be evaluated in future field tests and ultimately useful to develop a semiochemical-based monitoring technique and integrated pest management program for *M. cribraria*.

**Karmakar et al. (2020)** conducted a laboratory experiment to study the olfactory responses of female *Aulacophora foveicollis* towards volatiles emitted from undamaged, insect- damaged, and mechanically damaged fruits. Furthermore, identification of volatile compounds which is used to locate host by insects is quantified using GC-MS and GC-FID analyses. Hence, quantification and identification of volatile compounds which effects or alter the behaviour of insect pest can be implemented for eco-friendly management of insect pest.

**Nusra et al. (2021)** observed the response of virgin female, gravid female, and male insects towards the volatile emission from host plant fruits, leaves and shoot and flowers were studied using y-shaped olfactometer. Results shown that virgin female, gravid female and male insects responded positively towards the host plant fruits, leaves, and shoots but no response towards flowers was shown.

**Song et al. (2022)** conducted an experiment to find out chemicals present in damaged geranium responsible to repel the diamondback moth (DBM), *Plutella xylostella* female. Study showed that damaged geranium has strongly repelled DBM. Furthermore, bioactive compounds from geranium were identified using gas chromatography–electroantennographic detection and gas chromatography–mass spectrometry. Hence, five bioactive compounds namely components myrcene,  $\gamma$ -terpinene, linalool, camphor, and terpinen-4-ol were found to be effective in repelling DBM mated females. These five substances are promising behavioural regulators of the destructive moths and could be potential candidates for “push” components in plant-based “push–pull” strategies.

## **2.6 Impact of Plant and animal based natural formulations on the olfactory response of litchi fruit borer adults**

**Pazhanisamy and Krishnan (2019)** conducted in vitro experiment to study the effectiveness of panchgavya in combination with different botanical extracts on shoot and fruit borer, *Earias vittella* (Fab.) insect pest of Bhendi. Observation on antifeedant activity and per cent mortality of these combinations was observed. The results indicated that all binary mixtures recorded visibly the highest per cent of antifeedant activity in NLE (5%) + panchagavya (3%) (65.11%) on par with NSKE (5%) (64.84%) and the highest mortality was recorded in panchagavya (3%) + NSKE (5%) (83.33%), followed by pungam oil (3%) + panchagavya 3 per cent (66.67%) and NLE (5%) + panchagavya (3%) (53.33%). The results indicated that these botanicals extract mixture with panchagavya give good results for the management of *E. vittella*.

**Karimzadeh and Rabiei (2020)** examined the effectiveness of extracts from flower, seeds, roots, leaf, and stem of *Datura stramonium* L., on *P. xylostella* larvae and adults. Bioassay study showed that higher toxicity was shown by flower, seed, and

roots as compare to leaf and stem. Furthermore, greater toxicity was exhibited by flower as compare to seed, root, leaf and stem extract. Moreover, using sublethal doses flower extract was found to be most effective in deterring oviposition by *P. xylostella* adults in comparison to roots, seeds, stem and leaf extracts. Results indicated that jimsonweed extracts could be used as an effective pesticide and oviposition deterrent against *P. xylostella*. Possibilities for application of *D. stramonium* extracts in pest management and for developing a botanical insecticide or an oviposition deterrent in context of sustainable pest management are discussed.

**Krishnan et al. (2020)** performed an in vitro experiment to study the effectiveness of different botanicals as a mixture with panchagavya to suppress the population of on *Spodoptera litura* (Fab.) in black gram. The extracts combinations used were *Cleistanthus collinue* leaf extract (5%) combination with panchagavya @ 5%, neem oil 3% + panchagavya 5%, pungam oil 3%+ panchagavya 5%, *Ocimum sanctum* extract 5% + panchagavya 5%, *Calotrophis gigantea* extract 5%+ panchagavya 5% has been studied for the pest management. Using leaf disc method experiment was performed. The results indicated that all binary mixtures recorded visibly the highest per cent mortality in Neem oil 3% + panchagavya 3% followed by *Cleistanthus collinue* Extract 5%+ panchagavya 5%, Pungam oil 3% + panchagavya 5% and *Ocimum* 5% extract + panchagavya 5%. The botanicals extract mixture with panchagavya was found to show the maximum percentage mortality against *S. litura*.

**Ingber et al. (2021)** studied the behavioural change of gravid female of fall armyworm for oviposition preference and fitness of its larvae which is altered by conspecific larval feeding, two choice tests for oviposition, feeding trails for larvae, metabolomics target, and analyses of VOC were performed. Results depicted that female does not prefer larval damaged plant for oviposition. Furthermore, increase in metabolites and VOC concentration was found in larval feeding plants. Several VOCs with significantly increased concentrations in damaged corn plants were known oviposition deterrents that warrant further investigation in an integrated pest management context.

## 2.7 Evaluation of different Plant and animal based natural based formulations against the of major pest associated with litchi

**Schulte et al. (2006)** reported the efficacy of azadirachtin at a concentration of 0.17 g active ingredient per centimeter trunk diameter) against litchi stink bug by injecting the dissolved product (NeemAzalU) into the trunks of four caged litchi trees. Four untreated caged trees served as control. Mean weekly mortality rates of individuals released on the treatment date (initially 55 nymphs per cage) were significantly higher in the treatment cages (55%) than in the control cages (10%) between the second and the fourth week of the experiment. Azadirachtin concentration in ripe fruits was less than 5 mg/kg fruit pulp 18 days after tree injection.

**Gupta (2007)** studied the efficacy of different indigenous products viz. neem leaf and seed kernel extract, neem oil, cow urine, cow and buffalo milk, garlic and red pepper extract in different concentration and in different combinations against gram pod borer *Helicoverpa armigera* in comparison with bio pesticide *Bacillus thuringiensis*, and chemical insecticides (quinalphos 0.05%, cypermethrin 0.01%) on chickpea. Amongst all the treatment combinations, garlic+red pepper (0.5%, 1%), cow butter milk (4-8%) and buffalo butter milk (8%) were found statistically at par with the chemical insecticides in reducing the larval population and pod damage.

**Yankanchi and Patil (2009)** evaluated the field efficacy of four plant extracts such as *Vitex negundo*, *Clerodendrum inerme*, *Lantana camara* and *Eupatorium odoratum* against the, *H. armigera* larvae on cultivated cabbage. Among the plant extracts, *E. odoratum* (1%) treatment had more impact on *H. armigera* followed by *L. camara* (10.00%), *V. negundo* and *C. inerme* (1.33%). Treatment with *L. camara* (1%) tended to result in a lower percentage of intensity of cabbage damage (4%) caused by *H. armigera* than control and other plant extract treatments.

**Morya et al. (2010)** evaluated the powdered leaves of *Lantana camara*, *Clerodendron inerme* and *Citrus limon* for their efficacy against the *Corcyra cephalonica* at seven different doses ranging from 0.05 to 2.0 g per 20.0 g of Rice to evaluate their effect on its life cycle and mortality. *L. camara* and *C. inerme* exhibited biopesticidal activity as evidenced by the high mortality rate in treated insects while *C. limon* was ineffective against *C. cephalonica* in the tested conditions.

**Shivaraju et al. (2011)** recorded the efficacy of natural products viz. NSKE 5%, garlic chilli extract (GCK) 5%, garlic extract (GE) and panchagavya against *M. testulalis* on blackgram. NSKE reported high larval reduction followed by GCK, panchagavya, and GE with 36.26, 21.43, 18.35 and 11.50 per cent larval reduction during 1<sup>st</sup> spray and 55.34, 54.08, 55.34 and 49.13 per cent larval reduction during 2<sup>nd</sup> spray, respectively. Efficacy of panchagavya was higher than GCK during the 2<sup>nd</sup> spray.

**Baidoo and Adam (2012)** studied the effects of ethanolic extract of *Azadirachta indica* seeds and petroleum ether extract of *Lantana camara* leaves on the populations of three cabbage pests, *Plutella xylostella*, *Brevicoryne brassicae* and *Hellula undalis*. The mean weight of cabbage heads on the sprayed plots was significantly heavier than that of the control unsprayed plots. The use of *A. indica* seeds and *L. camara* leaf extracts increased yield by 37.05 per cent and 25.80 per cent, respectively.

**Byrappa et al. (2012)** investigated the impact of biopesticide viz. NSKE (5%), HaNPV (250 LE/ha), Bt (1kg/ha), neem oil (2%), panchagavya (3%), Clerodendron+ cow urine extract (10%), and sequential spray of HaNPV- NSKE, Bt-NSKE-HaNPV and NSKE- HaNPV-Bt against pod borer complex in organically grown field bean. Amongst the cow urine based formulations, panchagavya (3%) and clerodendron extract+ cow urine (10%) recorded mean larval population/m<sup>2</sup> of 2.55 and 2.66 of *E. atmosa*, 2.11 and 2.91 of *E. Zinckenella*, 14.69 and 16.20 of *H. armigera*, 2.31 and 2.75 of *M. testulalis*, 2.09 and 3.03 of *S. caffer*, 1.63 and 2.11 of *L. boeticus* respectively.

**Chandrashekharaiyah et al. (2013)** studied the insecticidal activity of panchagavya, cow urine, dasagavya, chilli + garlic extract, neem fruit + red chilli + custard apple leaf extract and neem seed kernel + Aloe vera + Calotropis + Clerodendron leaf extract against diamondback moth (DBM) and cowpea aphid in laboratory. Highest mortality in DBM and aphids was recorded in neem seed kernel + Aloe vera + Calotropis + Clerodendron leaf extract and neem fruit + red chilli+ custard apple leaf extract. The mortality was considerably high in DBM compared to aphids. Panchagavya, cow urine and chilli + garlic extract was comparatively less toxic to

aphids and DBM. However, Dasagavya shown moderate toxicity to DBM. Laboratory studies indicated that the products containing neem i.e., neem seed kernel + Aloe vera + Calotropis + Clerodendron leaf extract and neem fruit + red chilli + custard apple leaf extract were more effective in causing mortality to DBM.

**Karkar et al. (2014)** conducted a field experiment to evaluate the effect of verimwash and liquid manure with 20%, 30%, 40%, 50% concentration to suppress pest population of brinjal. Moreover, the results have shown that at concentration 50% it was successful in suppressing the sucking pests as well as shoot and fruit borer incidence **Chauhan and Singh (2015)** conducted a field experiment to study potential of vermiwash and neem parts on *Earias vittela* incidence. Moreover, reduction in pest infestation of pod borer was observed after spraying vermiwash and Neem.

**Ravisankar and Gangish (2016)** reported increase in natural enemies of crop pests such as Coccinellids, syrphids, and spiders, *Micromus*, *Chrysopa* and *Campoletis*. Higher number of natural enemies was observed under organic management as compared to integrated and inorganic management. Whereas, Coccinellids was found to be two to three times higher under organic management in cotton, groundnut, soybean, potato and maize crop fields. Similarly, spiders are found to be twice higher under organic management compared to inorganic management. Meanwhile, the diversity of arthropod population in soil viz., Collembola, dipluran, pseudo scorpions, *crypto stigmatids* and other mite's population was also found to be higher under organic management compared to integrated and chemical management.

**Bijewar et al. (2018)** evaluated the field efficacy of plant leaf extracts, cow urine and their combinations against pigeon pea pod borer complex. The treatments madar + cow urine @ 5% (w/v) followed by lantana + cow urine @ 5% (w/v) proved to be the most effective treatments, not only in reducing the damage due to pod borer complex, but also recorded higher grain yield (979.57 and 883.60 kg/ha, respectively). However, cow urine @ 5% (v/v) reduced the larval population to the tune of 3.93 larvae per five plants, pod damage to 22.08 per cent and increased grain yield 749.60 kg/ha as against inferior untreated control with highest larval population (5.00 larvae/5 plants), pod damage (32.06%) by *H. armigera* and lowest grain yield (542.45 ka/ha) in Pigeon pea crop.

**Das et al. (2018)** conducted a field experiment to study the efficacy of various combination viz, panchagavya (3%) and cow urine (10%) whereas, maximum fruit yield of tomato was recorded with panchagavya (3%) + lantana leaf extract (10%) + vermiwash (10%) on insect pest population and yield. Moreover, derisom (3 ml/lit) alone or in combination with panchagavya (3%) , lantana leaf extract (10%) and vermiwash (10%) was found effective in minimizing the per cent disease index (PDI) and per cent insect damage in maize, soybean and tomato. Application of neem oil (3 ml/lit) and derisom (3 ml/lit) was found effective in controlling stem borer, *Monolepta* and *Epilenchna* in maize and leaf folder, flea beetle and *mylloceros* in soybean.

**Pazhanisamy et al. (2019)** studied the efficacy of different bio intensive pest management modules against shoot and fruit borer on bhendi and their impact on natural enemies. Amongst all the modules, module III proved to be most effective treatment with lowest fruit and shoot infestation (12.90 & 16.66%, 11.08 & 12.54%) followed by module IV (13.76 & 18.67%, 12.69 & 13.46%). Hence, moderate fruit and shoot damage was observed in module II and module I as compared to control. Meanwhile, maximum yield and highest cost benefit ratio was observed in module III followed by module IV. Moreover, module III counts for maximum mean number of natural enemies.

**Thakur and Sood (2019)** studied lethal and inhibitory activities of natural products and biopesticide formulations viz. Darekastra, fermented buttermilk, Jeevamrit, Panchgavya, Tamarlassi, vermiwash, cow urine, and biopesticide formulations; Eupatorium 5EC, Melia 5EC and Neem baan to evaluated for toxic, ovicidal activity, repellence, feeding, and oviposition deterrence using leaf dip method of bioassay against *Tetranychus urticae* Koch. All natural products exhibited moderate level of repellence and oviposition deterrence but Neem baan 0.15EC was ranked highest for both the properties. Feeding deterrence was at low levels for the natural products while Neem baan 0.15EC exhibited 100% of feeding deterrence. An exception was observed for leaf treatment with Panchgavya which acted as an oviposition inducer for the red spider mites. Based on arbitrary rank score, fermented buttermilk, Tamarlassi, and Neem baan 0.15EC possessed high toxic properties to spider mites.

**Bhullar et al. (2021)** studied the effect of natural formulations and biorationals on mite population. Lowest pest population was observed in neemastra and brahmastra. treated populations with upto 90% reduction in mite populations. Similarly, PAU neem extracts reduced pest population by 74.61%. The natural enemies *Blaptostethus pallescens* and *Chryosperla zastrowi* resulted in reduction of pest by 82- 84%. Whereas, *Neoseiulus longispinosus* reduced pest population by 87%. Hence, all the natural enemies have effectively reduced the mite population. Therefore, incorporation of natural products and biorational management practices in brinjal will show better and eco-friendly approaches.



*Materials  
and  
Methods*



The investigation on the following aspects of “**Studies on plant volatile mediating orientation behaviour of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulations for its management**” Was carried out at Horticulture Research Centre (*HRC*), Patharchatta, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Distt. U.S. Nagar (Uttarakhand) in year 2018 and 2019. The materials used, technique adopted and methods for observation are presented in this chapter.

#### **Geography of study area:**

Pantnagar is situated at the foothills of Himalayas at an altitude of 243.84 meter above the mean sea level (MSL), 29°N latitude and 79.3°E longitude. The annual rainfall is about 145cm, which has a lot of variation throughout the year. The temperature variation is very large, as summer holding temperature maxima of around 42-45°C while in winter season it falls heavily to 0-9°C.

The experimental methods used and procedures followed during the course of investigation are described below under the following heads and subheads:

### **3.1 Diversity of insect fauna and population dynamics of major insect pests associated with litchi ecosystem**

To assess the diversity of insect pest population in litchi orchard at H.R.C Patharchatta, during January to December 2018 and January to December 2019. Survey has taken on weekly intervals. For this, selected six trees with uniform cultural practices were selected randomly

#### **3.1.1 Diversity of litchi mite**

A survey was conducted on the density of litchi mite in Pantnagar region of Uttarakhand. For recording the data, mite infested leaves were observed during the year. The litchi plants were surveyed (unsprayed) for collection of mite infested leaves. Four branches were selected from each tree (one branch in each direction). Randomly 100 leaves from four branch in each direction were collected and analysed for the data

recoding (**Ranjan and Kumar 2018**). The observations so recorded were pooled for mean mite infestation which was calculated with the help of following formula:

$$\text{Per cent mite infestation} = \frac{\text{No.of infested leaves}}{\text{Total no.of leaves collected}} \times 100$$

### 3.1.2 Diversity of litchi fruit borer

Data on the population of litchi fruit borer (pupae and larval infested fruits) were recorded at weekly interval in six randomly selected trees. The observations on the population of litchi fruit borers were recorded in each tree, 40 panicles/tree. We counted the number of litchi fruits that had fruit borer infestation from each tree by visually observing the symptoms of infestation, i.e., the presence of little yellowish-brown excreta coming from the holes in the fruit and number of pupal cages in 40 panicles/ tree.

### 3.1.3 Diversity of litchi leaf roller

Data on the population of leaf roller were recorded at weekly interval in six randomly selected trees. The observations on the population of leaf roller were recorded in each tree, 40 panicles/tree.

### 3.1.4 Diversity of mealy bug

Data on mealybug incidence was recorded at weekly intervals from 6 randomly selected trees in four directions of the litchi tree. Mealybug incidence was taken by visual counting of number of mealybugs on 10 cm long shoot or panicle (**Kumar *et al.*, 2009**).

### 3.1.5 Diversity of barkeating caterpillar

$$\text{Barkeating caterpillar infestation} = \frac{\text{No. frass galleries}}{\text{Total no. of infested tree}}$$

## 3.2 Effect of climatic factors on the abundance of major insect pests of litchi

Data on the population of litchi fruit borer (pupae and larval infested fruits) were recorded at weekly interval in six randomly selected trees. The observations on the population of litchi fruit borers were recorded in each tree, 10 panicles/tree. We counted the number of litchi fruits that had fruit borer infestation from each tree by

visually observing the symptoms of infestation, i.e., the presence of little yellowish-brown excreta coming from the holes in the fruit and number of pupal cages in 40 panicles/ tree. Meteorological data regarding mean daily temperature, relative humidity and rainfall were acquired from the meteorological observatory of Meteorological Department GBPUA &T, Pantnagar, Uttarakhand.

### **3.2.1 Data analysis**

The data collected were subjected to statistical analysis using State regression and correlation. SPSS Associations between insect pest populations and weather factors were estimated. The results are graphically depicted to determine the effect of different weather parameters on the incidence and development of insect pests.

### **3.3 Volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit.**

#### **3.3.1 Extraction of Phytochemicals**

Litchi plant parts i.e., mature and immature fruits, tender shoots, and flowers were collected from Horticulture Research Centre, Patharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. For the preparation of extract, the freshly collected litchi plant parts viz., mature and immature fruits, tender shoots, and flowers of litchi plant were washed under tap water to eliminate soil particles and other debris and then air-dried by keeping within the newspaper for 2-3 weeks under (12/12) the fan. The air-dried samples were pulverized by using an electric grinder (Crompton Greaves HD 550) and processed for extract preparation. Following steps were adopted for the extraction of phytochemicals:

1. First in 250 ml of the conical flask, dried powder (10 g) of each plant sample was macerated in 80 % aqua acetone and aqua methanol solvent (s) (20: 80) and airtight with parafilm and aluminium foil.
2. The conical flasks were kept in an orbital shaker at 120 rpm for 10 days incubation.
3. After the incubation, the mixture of extracts were seep through filter paper (Whatman no. 1) in Petri plates (labelled and weighed) and was kept for evaporation of the solvent under room temperature for 2-3 days.

4. After evaporation of respective solvents, Petri plates along with extract were again, weighed for the evaluation of extraction yield, and then extract was scratched out, kept in Eppendorf, and stored at 4 degree C for further experimentation.

### 3.3.2 Biochemical analysis.

Varying plant volatiles phytoconstituents against innumerable insect pest were analyzed by Biochemical analysis. The syringe-filtered aqua-methanol plant extracts (1  $\mu$ l) were loaded to Gas Chromatography-Mass Spectrometry assembly and for the authentication of bioactive compounds, NIST (National Institute of Standards Technology) library, charged with 62,000 plus patterns and New York's Wiley mass spectral databases, was considered.

**Table 3.1: Machine conditions.**

|                         |                 |
|-------------------------|-----------------|
| Column oven temp.       | 60.0 °C         |
| Injection temp.         | 260.00 °C       |
| Injection mode          | Splitless       |
| Sampling time           | 1.00 min        |
| Flow control mode       | Linear Velocity |
| Pressure                | 73.3 kPa        |
| Total flow              | 16.3 ml/min     |
| Column flow             | 1.21 ml/min     |
| Linear velocity         | 40.1 cm/sec     |
| Purge flow              | 3.0 ml/min      |
| Split ratio             | 10.0            |
| High-pressure injection | Off             |
| Carrier gas saver       | Off             |
| Splitter hold           | Off             |

**Table 3.2: chromatography program.**

|              |           |
|--------------|-----------|
| Start Time   | 4.00 min  |
| End Time     | 49.98 min |
| ACQ Mode     | Scan      |
| Scan Speed   | 3333      |
| Start m/z    | 40.00     |
| End m/z      | 650.00    |
| Sample Inlet | UnitGC    |

**Table 3.3: spectrometry table.**

| Rate  | Temperature (°C) | Hold Time (min) |
|-------|------------------|-----------------|
|       | - 60.0           | 3.00            |
| 10.00 | 250.0            | 5.00            |
| 15.00 | 280.0            | 21.00           |

**Table 3.4: Oven temperature program:**

|                  |               |
|------------------|---------------|
| Ion Source Temp. | 230.00 °C     |
| Interface Temp.  | 270.00 °C     |
| Solvent Cut Time | 3.50 min      |
| Detector Gain    | Mode Relative |
| Detector Gain    | +0.00 kV      |
| Threshold        | 1000          |

### 3.4 Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant

#### 3.4.1 Plant Extract Preparation

The mite infected leaves and healthy leaves of litchi were collected from Horticulture Research Centre, Patharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The leaves were shade dried separately at room temperature and powdered using a grinder. 10gms powder, each of normal and galled leaves weighed and then extraction in 80% methanol using Soxhlet apparatus for almost 24 hours was performed. Furthermore, among the several chemicals which are used for extraction of volatile compounds present from leaves, methanol is an effective one (Kilari and Putta, 2016). The extract obtained was be filtered and used for Gas chromatography analysis.

**Table 3.5: Machine conditions.**

|                         |                 |
|-------------------------|-----------------|
| Column oven temp.       | 60.0 °C         |
| Injection temp.         | 260.00 °C       |
| Injection mode          | Splitless       |
| Sampling time           | 1.00 min        |
| Flow control mode       | Linear Velocity |
| Pressure                | 73.3 kPa        |
| Total flow              | 16.3 ml/min     |
| Column flow             | 1.21 ml/min     |
| Linear velocity         | 40.1 cm/sec     |
| Purge flow              | 3.0 ml/min      |
| Split ratio             | 10.0            |
| High-pressure injection | Off             |
| Carrier gas saver       | Off             |
| Splitter hold           | Off             |

**Table 3.6: Program.**

|              |           |
|--------------|-----------|
| Start Time   | 4.00 min  |
| End Time     | 49.98 min |
| ACQ Mode     | Scan      |
| Scan Speed   | 3333      |
| Start m/z    | 40.00     |
| End m/z      | 650.00    |
| Sample Inlet | Unit GC   |

**Table 3.7: spectrometry table.**

| Rate  | Temperature (°C) | Hold Time (min) |
|-------|------------------|-----------------|
|       | - 60.0           | 3.00            |
| 10.00 | 250.0            | 5.00            |
| 15.00 | 280.0            | 21.00           |

**Table 3.8: Oven temperature program:**

|                  |               |
|------------------|---------------|
| Ion Source Temp. | 230.00 °C     |
| Interface Temp.  | 270.00 °C     |
| Solvent Cut Time | 3.50 min      |
| Detector Gain    | Mode Relative |
| Detector Gain    | +0.00 kV      |
| Threshold        | 1000          |

### 3.5 Olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flower, mature and immature fruits.

1. The adult male and female moth of litchi fruit borer was subjected to an olfactometer to study the olfactory preference towards different host volatiles using five arm olfactometer (**Ranjith, 2007 and Hao *et al.*, 2012**).
2. In five arm olfactometer four host plant tissues solutions namely litchi flower, litchi tender shoot, litchi mature fruit, and litchi immature fruit and water was subjected.
3. The mean orientation of the male and female towards different host tissue solution was observed in 1hr, 2hr and 3hr intervals. Each litchi tissues solutions were kept in 4 different arms which was firmly closed with a lid.
4. The inlet of the olfactometer on the top centre place was connected to an aquarium pump (220–240-volt AC) to release the pressure.
5. Out of five arms, one arm was connected to water solution. fifty litchi fruit borers were released for observations.
6. The medical air was passed from aquarium pump at the rate of 4 lit/ min in to the olfactometer.
7. After five minutes of saturation of different host odour in the olfactometer, fifty numbers of male and female adult litchi fruit borer were released in the olfactometer through a central hole, which will also serve as odour exit hole.
8. Observation was made on number litchi fruit borer settled on each arm at 1hr, 2hr, and 3hr HAR (hours after release) for their host preference. This experiment was replicated three times.

#### 3.5.1 Statistical analysis

Boxplot was presented to show the mean orientation of litchi fruit borer moth combining all the time interval readings for different sex. In order to test whether the differences were statistically significant, initially we conducted one-way ANOVA for male, female, and different time intervals separately keeping different treatments as the

independent factor. Duncan Multiple Range Test (DMRT) was used for post-hoc analysis. Tukey HSD post hoc analysis to conduct pair wise comparisons will be implemented.

### **3.6 Impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults.**

1. In order to study the preference of litchi fruit borer to natural formulations viz., panchgavya, vermiwash, NSKE, dashparni, neemastra, lantana leaf extract, and an insecticide chlorantraniliprole 18.5 SC.
2. Thirty adults of litchi fruit borer were placed in the centre of olfactometer chamber. Five ml of attractant solution impregnated in cotton wick was be placed in distal end of each arm of eight arm olfactometer.
3. The response was studied by visual observations for total three hours and observation recorded at one hour interval was depended upon the response of adult moths to the natural formulations and an insecticide.
4. The entire olfactometer was covered with black cloth.
5. The number of moths entering into eight different arms were counted at one hour interval.
6. The whole experiment was carried out for three hours and replicated four times. The treatments of natural formulations and an insecticide will be interchanged among the different arms for each replication to eliminate any photo tactic/directional influence.
7. A heavy-duty plastic air compressor of DC 12V was installed at each of the eight distal openings of the arms to provide uniform airflow. This setup allowed the insects to receive airflow at speeds ranging from 0.2 to 0.8 m/sec was passed in the tunnel and the suitable air speed (0.4 m/sec) of the tunnel and running time for 3 hours was standardized for conducting experiment (**Jagdish, 2014**).

#### **3.6.1 Statistical analysis.**

A one-way analysis of variance (ANOVA) will be conducted for litchi fruit borer larvae in different time intervals with different treatments as the independent

factor. A post-hoc analysis will be performed using the Duncan Multiple Range Test (DMRT) followed by Tukey HSD post- hoc test which will be used to compare differences between the treatments.

### 3.7 Efficacy of plant and animal based natural based formulations against the major pest associated with litchi.

The field experiment will be carried out at Horticulture Research Centre, Patharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar during the year 2018-19 and 2019-20. Pantnagar is located in the Tarai region of Uttarakhand at 290 N latitude and 79.30E longitude, 243.8m above the mean sea level.

#### 3.7.1 Treatment details

A randomized block design (RBD) with three replications and eight treatments will laid out for the experiment. A total number of 24 litchi trees (*Litchi chinensis*) will be selected, and each of them will be sprayed with different treatments during the study. Rocker sprayers will be used for the application of natural formulations and insecticide. The details of treatments is given below.

**Table 3.9: Details of treatments used in the experiment**

| Treatment Number | Treatment Name       | Concentration/Dosage |
|------------------|----------------------|----------------------|
| T1               | Panchgavya           | 3%                   |
| T2               | Vermiwash            | 50%                  |
| T3               | NSKE                 | 5%                   |
| T4               | Dashparni            | 3%                   |
| T5               | Neemastra            | 3%                   |
| T6               | Chlorantraniliprole  | 18.5% SC             |
| T7               | Lantana leaf Extract | 5%                   |
| T8               | Control              | --                   |

### 3.7.2 Method of preparation of different natural formulations

#### Preparation of Panchgavya

Initially, cow dung (5 kg) and cow ghee (0.5 kg) will be added to a wide mouthed 50-liter drum and kept for 48 hours under shade by covering with a muslin cloth. The remaining ingredients i.e., cow urine 3 lit, cow milk 2 lit, curd 2 lit with 1 dozen rotten banana will be added after two days by mixing thoroughly and kept under shade. The coction will be stirred twice a day for about 20 minutes, both in the morning and evening to facilitate aerobic microbial activity. After fifteen days, the contents will be filtered through a clean cloth to get the clear stock solution of panchagavya (**Sarkar et al., 2014**).

#### Preparation of NSKE

Neem seeds of 3-8 months old will be collected during the bearing season to prepare the neem seed kernel extract. The collected seeds will be washed and shade dried, and grinded to prepare neem seed powder. 50 g of powdered neem seed kernels will be taken and soaked in one litre of water for 8 hours and stirred often. The soaked materials will be squeezed repeatedly for better extraction of the azadirachtin in the aqueous suspension. The contents will be filtered through muslin cloth, and one lit of the filtrate was prepared. Soap water (2%) will added before spraying.

#### Preparation of Dashparni

Five liters of water will be taken in a bucket, and crushed leaves of karanj, custard apple, dhatura, tulsi, papaya, marigold, neem, bael, castor, and calotropis were added to it. Cow urine (2L) and cow dung (500g) will be mixed together and will be allowed to ferment for 24 hours. The next day, we add 1g each of chopped tobacco, ginger, garlic, and turmeric and will mix them thoroughly with a stick. For one month, the bucket will be kept covered with muslin and will be kept in a shady place, stirring the mixture in the mornings and evenings (**Gonjari et al., 2016**).

#### Preparation of Neemastra

Initially, 5lits of water will be taken in a container. Then 250gm of neem leaves, 250 ml of cow urine and 50 gm of fresh cow dung will be added into it. The prepared

formulation will be stirred properly and kept for 24 hours. The prepared formulation will be strained with the help of muslin cloth and will be further used as a spray material (Bullar *et al.*, 2021)

### **Preparation of lantana extract**

Lantana leaves will be collected during the morning hours from the university campus and will be washed properly to remove dust particles. 100g of cleaned leaves will be grinded to make a fine paste. 100 grams of the ground paste will be soaked in 2 l of water overnight to produce 5 percent plant extracts. Next day, the solution will be filtered through muslin cloth, and two pinches of detergent powder will be added to it (Mamun *et al.*, 2011). Vermiwash was collected from the Vermicomposting unit present in the University campus.

### **3.7.3 Method of observation**

Observations on the mean population of major insect pest of litchi after application of different treatments will be taken one day prior to spray and after 1,3, 5,7, 10, and 14 days of spraying. The experiment will be set up in RBD, involving eight treatments replicated three times. The observations on the population of major insect pest of litchi will be recorded in each treatment, 10 panicles/tree.

### **3.7.4 Statistical analysis**

The data were analyzed using software R software for RBD analysis of variance after appropriate transformations. By adding a factor of 0.5, the mean values were transformed into square roots and used for further analysis.

**PLATE : 1 List of different major insect pests on litchi at HRC, Patharchatta, Pantnagar**



**Litchi fruit borer**



**Litchi bug**



**Litchi leaf roller**



**Litchi mite infestation**



**Data collection**



**Bark eating caterpillar infestation**

**PLATE 2: List of different natural enemies on litchi at HRC, Patharchatta, Pantnagar**



**PLATE 3: Sample Preparation litchi plant parts i.e., immature fruits and mature, tender shoots and flowers were collected from Horticulture Research Centre, Patharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand**



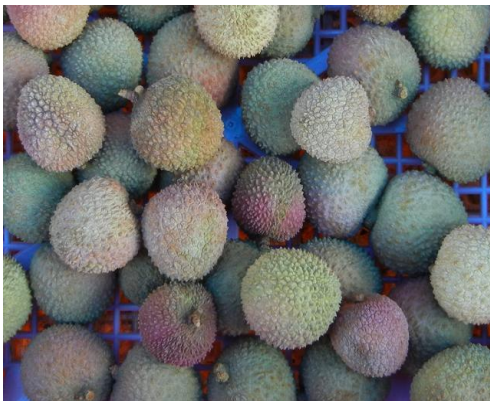
**Sample collection from field**



**Tender shoots**



**Flowers**

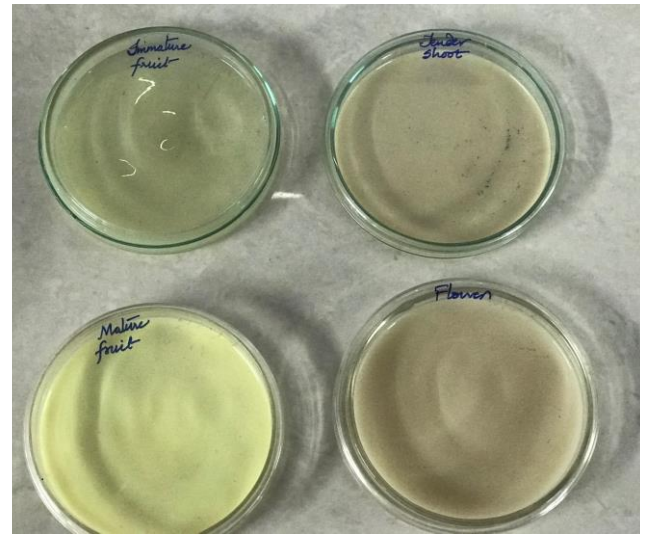
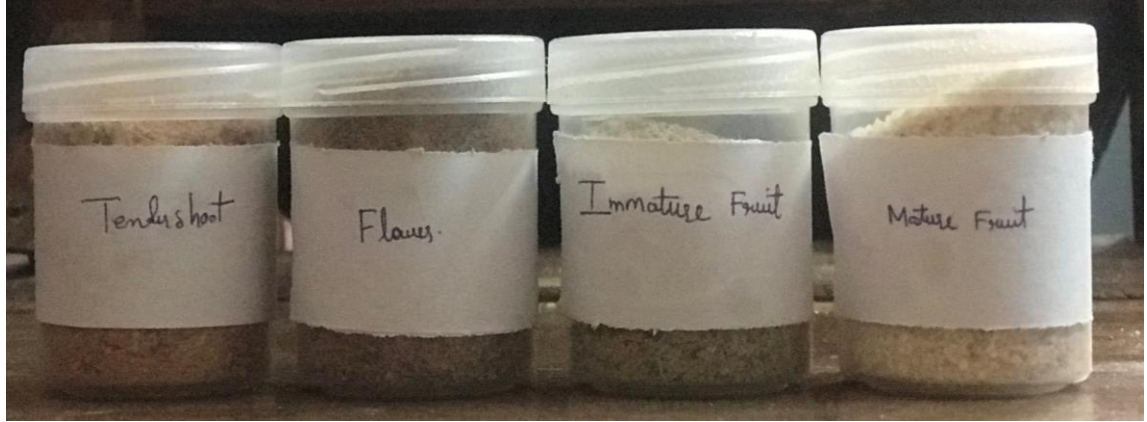


**Immature fruit**



**Mature fruit**

*Plate 3 : Contd....*



**PLATE 4 : Olfactometer set up**



## PLATE 5: Collection and preparation of spray material

### Dashparni preparation



### Panchgavya preparation



### NSKE preparation





*Results  
and  
Discussion*



#### 4.1 Diversity of insect fauna and their associated natural enemies on litchi at Pantnagar, Uttarakhand.

The present study emphasizes on understanding the diversity of different insect pest and natural enemies associated with litchi ecosystem at Horticulture Research Centre, Patharchatta, GBPUA&T, Pantnagar. Regular surveying of litchi orchard was carried out at weekly interval for two years *i.e.*, 2018 and 2019 to record the diversity of insect pest, natural enemies on litchi. Moreover, the population of different insect pest and natural enemies with respect to different Meteorological standard weeks (MSW) were also recorded throughout the two years of study.

A total number of 16 insect pest and 1 mite; infesting different plant parts of litchi during various developmental stages of the plant were recorded during the present study. Whereas, 13 different natural enemies associated with different insect pest of litchi were recorded. Amongst the insect pest reported during the present study, eight insects belonged to the order Hemiptera, 5 to Lepidoptera, 2 to Coleoptera, 1 to Thysanoptera and litchi mite to the order acarina. However, 5 natural enemies belonged the order Hymenoptera, two each from Diptera and Hemiptera order and one each from Coleoptera, Neuroptera and Araneae were present. The insect pests recorded were categorized as major and minor on the basis of their incidence and extent of damage caused by them to the plant. The list of different insect-pest and their associated natural enemies fauna on litchi crop recorded during the present study has been enlisted in **Table 4.1 and Table 4.2.**

The findings of present experiment are in accordance with some previous literature. **Wen-Hung and Liou-Tsung (2008)** reported a total of 22 species of insects in litchi ecosystem, one species of mite and one species of snail. **Waite and Hwang (2002)** reported that the fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae), is one of the major pests of litchi, *Litchi chinensis* Sonn. **Storey and Rogers (1980)** reported 34 lepidoptera species on litchi with their symptoms of damage and peak months of activity in northern Queensland, Australia. **Sen et al. (1965)**

**Table 4.1: List of different insect pests on litchi at HRC, Patharchatta, Pantnagar.**

| Sl.no | Common name             | Scientific name                              | Order        | Family         | Stage Attacked                   | Status | Peak activity period |
|-------|-------------------------|--|--------------|----------------|----------------------------------|--------|----------------------|
| 1     | Litchi fruit borer      | <i>Conopomorpha sinensis</i> Bradley         | Lepidoptera  | Gracillariidae | Fruits                           | Major  | May- June            |
| 2     | Litchi bug              | <i>Tessaratomya javanica</i> (Thun.)         | Hemiptera    | Pentatomidae   | Leaves, twigs, flower and fruits | Major  | April-June           |
| 3     | Leaf roller             | <i>Tortrix epicyrta</i> (Meyrick)            | Lepidoptera  | Tortricidae    | leaves                           | Major  | July                 |
| 4     | Mealy bug               | <i>Drosicha mangifera</i> (Green)            | Hemiptera    | Margarodidae   | Tender shoots and flowers        | Minor  | February-April       |
| 5     | Bark Eating Caterpillar | <i>Indarbela quadrinotata</i> (walker)       | Coleoptera   | Metarbelidae   | Bark                             | Minor  | April                |
| 6     | Grey weevil             | <i>Mylocherus undecimpustulatus</i> Marshall | Coleoptera   | Curculionidae  | leaves, shoot and flower         | Minor  | February – March     |
| 7     | Litchi leaf curl mite   | <i>Eriophyes litchi</i> (Keifer)             | Acarina      | Eriophyidae    | Leaves                           | Major  | May- July            |
| 8     | Semilooper              | <i>Trichoplusia spp.</i>                     | Lepidoptera  | Noctuidae      | Tender twigs                     | Minor  | February - March     |
| 9     | Mango leaf hopper       | <i>Amritodus atkinsoni</i> (Lethierry),      | Hemiptera    | Cicadellidae   | Flowering and fruiting stages    | Minor  | February-April       |
| 10    | Citrus black fly        | <i>Aleurocanthus woglumi</i> Ashby           | Hemiptera    | Aleyrodidae    | Leaves                           | Minor  | March – April        |
| 11    | Citrus aphid            | <i>Toxoptera spp.</i>                        | Hemiptera    | Aphididae      | Leaves and Twigs                 | Minor  | February-March       |
| 12    | Jewel bug               | <i>Chrysocoris stollii</i> (Wolff.)          | Hemiptera    | Pentatomidae   | leaves                           | Minor  | April-May            |
| 13    | Bagworm                 | <i>Eumeta crameri</i> (Westwood)             | Lepidoptera  | Psychidae      | Older leaves and bark            | Minor  | September-October    |
| 14    | Gundhi bug              | <i>Leptocoris acuta</i> Thunberg             | Hemiptera    | Alydidae       | No damaging symptoms             | Minor  | October              |
| 15    | Thrips                  | <i>Scirtothrips dorsalis</i> Morg            | Thysanoptera | Thripidae      | New shoot emergence              | Minor  | Dec-May              |
| 16    | Tiger moth              | <i>Arctia caja</i> (Linnaeus)                | Lepidoptera  | Arctiidae      | No damaging symptoms             | Minor  | June                 |
| 17    | Green stink bug         | <i>Nazara viridula</i> L.                    | Hemiptera    | Pentatomidae   | Leaves, petioles and shoots      | Minor  | November             |

**Table 4.2: List of different natural enemies on litchi at HRC, Patharchatta, Pantnagar.**

| SI. no | Common Name             | Scientific Name                                | Family        | Order         | Host Range  |
|--------|-------------------------|--|---------------|---------------|---|
| 1      | Red ant                 | <i>Oecophylla smaragdina</i><br>Fabricius      | Formicidae    | Hymenoptera   | Litchi fruit borer                                    |
| 2      | Lady bird beetle        | <i>Coccinella septumpunctata</i><br>(Linnaeus) | Coccinellidae | Coleoptera    | Litchi leaf curl mites, Litchi fruit borer, mealybugs |
| 3      | Cotesia wasp            | <i>Cotesia spp.</i>                            | Braconidae    | Hymenoptera   | Litchi fruit borer                                    |
| 4      | Green Lacewing          | <i>Chrysoperla zastrowii</i><br>Sillemi        | Chrysopidae   | Neuroptera    | Litchi leaf curl mites, Litchi fruit borer            |
| 5      | Black ant               | <i>Componotus spp</i> Mayr                     | Formicidae    | Hymenoptera   | Litchi fruit borer                                    |
| 6      | Ichneumonid wasp        | unidentified                                   | Ichneumonidae | Hymenoptera   | Litchi bug  |
| 7      | Assasian Bug            | <i>Rhynocoris spp.</i> Hahn                    | Reduviidae    | Hemiptera     | Litchi bug  |
| 8      | <i>Eocanthecona</i> bug | <i>Eocanthecona spp.</i> Hahn                  | Pentatomidae  | Hemiptera     | Litchi Bug, Mango leaf hopper                         |
| 9      | Hover Fly               | <i>Syrphus spp.</i> Linnaeus                   | Syrphidae     | Diptera       | Litchi fruit borer                                    |
| 10     | Braconid wasp           | <i>Bracon spp.</i> Fabricius                   | Braconidae    | Hymenoptera   | Litchi bug  |
| 11     | Tachinid Fly            | unidentified                                   | Tachinidae    | Diptera       | Litchi fruit borer                                    |
| 12     | Spider                  | Unidentified                                   | Arachnid      | Araneae       | Litchi fruit borer, mealybugs, litchi bug             |
| 13     | Rove beetle             | <i>Staphylinidae Latreille</i>                 | Coleoptera    | Staphylinidae | Litchi fruit borer,                                   |

observed that the *T. javanica* causes 25 per cent of the damage to litchi trees. **Prasad and Singh (1981)** reported that *Aceria litchi* is one of the most significant pests of litchi in Bihar. **Waite et al. (1992)** described leaf roller species *Olethreutes praeceadens* Wals as a minor pest that attacks litchi crops in Australia while *Olethreutes perdulata* Meyr is considered as an occasional pest in Queensland. **Kumar et al. (2011)** reported one weevil *Apoderous* sp. and one borer, *C. cramerella* on litchi which were causing severe damage. Similar findings were also reported by **Rosmana et al. (2010)**. **Wen and Liou (2008)** investigated six insect pests associated with Yuh-Heh-Bau litchi, including fruit borer, *C. sinensis*, and leaf borer, *C. litchiella*. **Anupunt and Sukhvibul (2005)** cited litchi fruit borer, *C. sinensis*, and longan stink bug, *Tessaratomia papillosa*, as the major constraints in litchi production in addition to physiological factors such as alternate bearing and fruit cracking. According to **Menzel and Waite (2005)** *Conopomorpha sinensis* Bradley was commonly known in China as the litchi stem end borer and in Thailand as the litchi fruit borer. The pest was earlier

known as *Acrocercops cramerella* Snellen. **Waite and Hwang (2002)** also recorded litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae) as one of the major pests of litchi in China and Thailand. **He deng (2001)** identified *C. sinensis* as a major pest of litchi in Guangdong, China. **Yao and Liu (1990b)** reported *Conopomorpha sinensis* and *Conopomorpha litchiella* Bradley first time in Taiwan attacking litchi fruit trees. **Yao and Liu (1990a)** reported two species, *C. sinensis* and *C. litchiella* first time infesting litchi, *Litchi chinensis* in Guangdong and Fujian regions in China. **Yao and Liu (1990)** reported two gracillariids *Conopomorpha sinensis* and *C. litchiella* for the first time in China infesting litchi in Guangdong and Fujian. These two closely related species have long been considered as a single species.

*C. sinensis* damages the fruits and shoots of litchi while *C. litchiella* damages shoots only. **Sharma and Kumar (1986)** reported that bark eating caterpillars are widespread throughout the Indian subcontinent and are primarily found in Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, Haryana, Orissa, Andhra Pradesh, Tamil Nadu, and Maharashtra. The incidence of bark eating caterpillar on old plant varied from 0.75 to 2.25 fecal garlands per plant. The incidence was started from the month of September with distinct fecal garland in the month of February (**Anonymous, 1999**). **Anonymous (2009)** found that Litchi mites (*Aceria litchii* Keifer), *Conopomorpha cramerella* Snellen (litchi fruit borer) and *Platytypus aprobola* Meyer (litchi leaf roller) were identified as major pests and the *Myloccerous* species (leaf cutting weevil) are minor pests of litchi, whereas the *Indarbella* species (bark eating caterpillar) are major pests. during the survey conducted in major litchi growing districts. **Schulte (2007)** reported that litchi stink bug, *Tessaratomia papillosa* (Drury) and phytophagous mite. *Aceria litchi* (Keifer) are the major pests of litchi in Asia. Mites generally suck the cells of young leaves and cause punctiform lesions. **Singh et al. (2001)** described 54 insect and mite pests commonly associated with litchi trees and their fruit. A survey was conducted in a litchi orchard in Taiwan to study the Lepidopterous pests on litchi shoots, spikes of flowers, and fruits. 13 species of lepidopterous pests were found on litchi shoots, including 2 species of Gracillariidae, 6 species of Tortricidae, 2 species of Pyralidae, 2 species of Noctuidae, and 1 species of Geometridae. **Kumar and Lall (1984)** surveyed several districts in Bihar where litchi was grown and measured pest incidences viz. fruit borer (*Carpophilus* species, leaf roller (*Platytypus aprobola*

Meyrick) and fruit fly (*Dacus dorsalis* Hendel) of litchi. According to Singh (1971) *Myllocerus discolor* Boh and *M. undecimpustulatus* Faust were found for the first time attacking litchi in India.

#### **4.1.1. Population dynamics of major insect pests and their associated natural enemies on litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

The population dynamics of major insect- pests and their associated natural enemies on litchi were studied in the litchi orchard, Horticulture Research Centre (HRC), Patharchatta, Pantnagar. The observations were recorded at weekly interval throughout the year during the course of study (January 2018- December 2018). The mean population of insect pest and natural enemies with respect to the mean standard weeks (MSW) were recorded and presented in **Figure 4.1a, Figure 4.1b, and Figure 4.2** along with **Table 4.3 and Table 4.4**, respectively.

The infestation of litchi mite was recorded indirectly through the infested leaves. Due to continuous sucking of sap by the nymphs and adults of litchi mite, leaf tissues become aggravated and formed erineum. Mite infested leaves on the plant were present throughout the year. The percent leaf infestation was calculated for the same. The leaf infestation percentage by litchi mite ranged from 2.21- 76.80 percent. Least infestation on leaves (2.21 percent) was recorded during 49<sup>th</sup> MSW. Whereas, maximum percent leaf infestation (76.80%) was recorded during 23<sup>rd</sup> MSW. The incidence of mango mealy bug on litchi tree during our present study was reported from 1<sup>st</sup> MSW to 17<sup>th</sup> MSW. The highest and lowest population of mealy bug ranged from 9.17-51.00 mealybugs/Panicle. Both the nymphs and adults were seen damaging to the plant. Maximum and minimum population of mealybug was reported during 9<sup>th</sup> and 1<sup>st</sup> MSW respectively. Litchi fruit borer was found as one among the major pests attacking to the litchi crop during the fruiting stage of the plant. The observations on litchi fruit borer population were calculated indirectly by counting the number of infested fruits with excreta on it. First appearance of litchi fruit borer damage was recorded during 10<sup>th</sup> MSW and continued till 28<sup>th</sup> MSW. Peak infestation of fruit borer (25.0 infested fruits/panicle) was recorded during 23<sup>rd</sup> MSW and least infestation (4.50 infested fruits/plant) was recorded during 27<sup>th</sup> MSW. The presence of litchi leaf roller was observed throughout the year on the litchi plant. The highest and least population of

litchi fruit borer was recorded during 1<sup>st</sup> and 44<sup>th</sup> MSW with 5.00 and 38.12 rolled leaves/Panicle respectively.

The attack of bark eating caterpillars on litchi plant was recorded by counting the number of active holes per plant. The infestation was recorded in two phases during the year. First active hole on the plant was observed during 1<sup>st</sup> MSW and continued till 12<sup>th</sup> MSW. Maximum and minimum number of active holes during that period was 2.66/plant and 1.00/plant respectively. However, 2<sup>nd</sup> phase of infestation was reported during 36<sup>th</sup> to 52<sup>nd</sup> MSW. The least and highest population of active holes due to bark eating caterpillar was 0.52/plant and 2.83/plant during 52<sup>nd</sup> and 38<sup>th</sup> MSW respectively. Gundhi bug infestation on the plant was observed from 39<sup>th</sup> to 47<sup>th</sup> MSW with maximum and minimum population of 0.47 bugs/panicle and 0.12 bugs/p during 43<sup>rd</sup> and 47<sup>th</sup> week respectively. Attack of mango leaf hopper on litchi plant was recorded on the plant during 5<sup>th</sup> to 20<sup>th</sup> MSW. The pest remained absent on the plant from 21<sup>st</sup> to 36<sup>th</sup> MSW and continued after 37<sup>th</sup> MSW to 45<sup>th</sup> MSW. The number of hoppers attacking the plant during the first phase was relatively more in number than the second phase. The highest and lowest population of hoppers during first phase was 10.39 and 0.34 hoppers/plant during 12<sup>th</sup> and 20<sup>th</sup> MSW respectively. However, during the second phase, lowest and highest population of hoppers were recorded during 52<sup>nd</sup> and 43<sup>rd</sup> MSW with 0.41 and 20.88 hoppers/panicle respectively.

Grey weevil were reported on the plant from 4<sup>th</sup> and 14<sup>th</sup> MSW with highest and lowest population of weevil *i.e.* 2.26 and 17.30 weevils/plant during 4<sup>th</sup> and 12<sup>th</sup> MSW respectively. The pest remained absent on the crop from 15<sup>th</sup> to 28<sup>th</sup> MSW and continued after the very next week to 52<sup>nd</sup> MSW. During the second phase maximum and minimum population of weevils were recorded during 43<sup>rd</sup> and 52<sup>nd</sup> MSW with 20.88 and 0.41 weevils/panicle respectively. Scale insects were present throughout the year and the observation on scale insect was taken by counting the insect number per 1 cm<sup>2</sup> leaf area. Maximum population of scale insects (24.24/cm<sup>2</sup>) were recorded during 9<sup>th</sup> MSW. Whereas, minimum population (3.33/cm<sup>2</sup>) was recorded during 12<sup>th</sup> and 28<sup>th</sup> MSW respectively.

Green stink bug population on litchi plant was recorded from 1<sup>st</sup> to 5<sup>th</sup> MSW and 43<sup>rd</sup> MSW to 52<sup>nd</sup> MSW of the year. During the initial part of the year, minimum

and maximum population of stink bugs were reported during 5<sup>th</sup> and 2<sup>nd</sup> MSW with 0.04 and 0.10 bugs/panicle. Whereas, during the 2<sup>nd</sup> phase lowest and highest number of bugs *i.e.* 0.11 and 1.46 bugs/ panicle was recorded during 52<sup>nd</sup> and 43<sup>rd</sup> MSW respectively. Tiger moths were reported on the litchi plant from 18<sup>th</sup> MSW to 26<sup>th</sup> MSW. Highest and least population of tiger moths were reported during 21<sup>st</sup> and 26<sup>th</sup> MSW with 0.25 and 0.04 moths/panicle respectively. Infestation of citrus aphids on the litchi plant was reported from 3<sup>rd</sup> and continued till 11<sup>th</sup> MSW. Peak population of aphids (2.08 aphids/cm<sup>2</sup> twig) was reported during 7<sup>th</sup> MSW and least population (0.44 aphids/cm<sup>2</sup> twig) was reported during 11<sup>th</sup> MSW. The incidence of jewel bug on litchi plant was reported during 36<sup>th</sup> to 42<sup>nd</sup> MSW. Highest and least population of bugs were reported during 39<sup>th</sup> and 42<sup>nd</sup> week with a mean population of 0.24 and 0.04 bugs/panicle respectively.

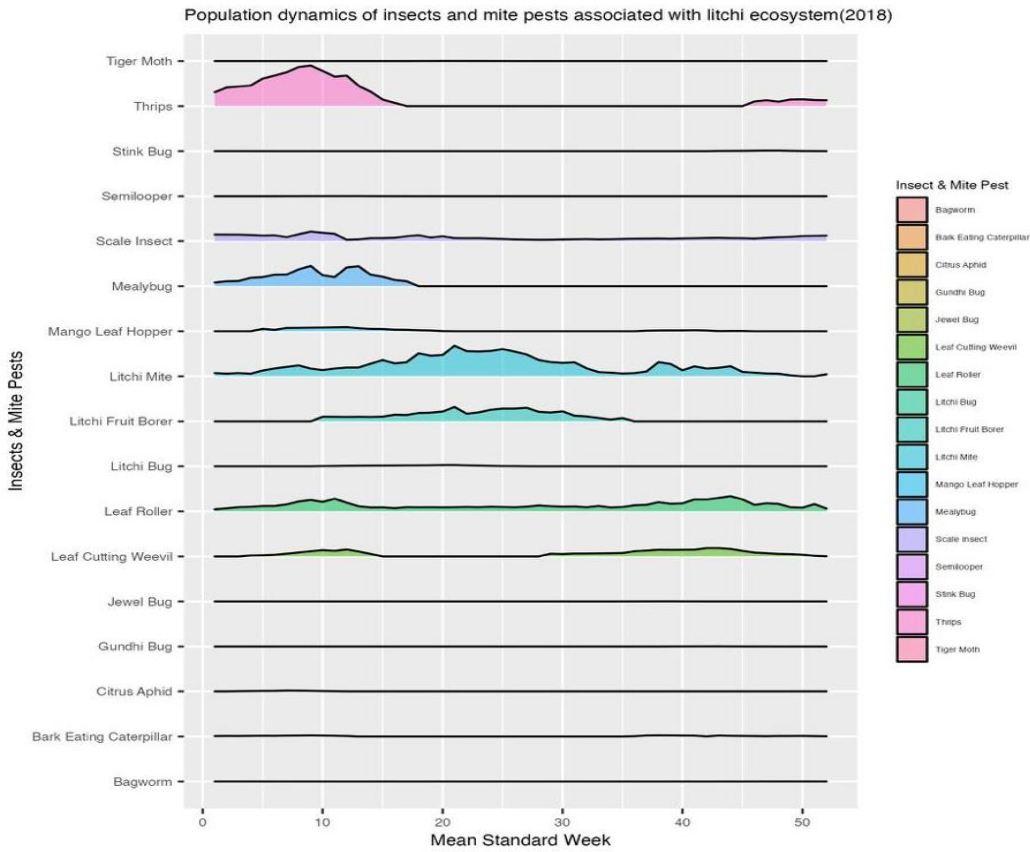
Bag worms were reported at the starting *i.e.* 1<sup>st</sup> -9<sup>th</sup> week as well as end *i.e.* 44<sup>th</sup> to 52<sup>nd</sup> week of the year. The population of bag worms were very less throughout. During the initial phase, the population ranged from 0.01-0.10 bags/panicle with lowest and highest population during 9<sup>th</sup> and 3<sup>rd</sup> MSW respectively. However, during the last weeks of the year, population ranged from 0.02-0.12 bags/panicle with highest and lowest population during 44<sup>th</sup> and 47<sup>th</sup> MSW respectively. Similarly, attack of thrips to the litchi plant were reported two times throughout the year. The first phase of attack to the plant was reported from 1<sup>st</sup> to 17<sup>th</sup> week with highest and lowest mean population of aphids *i.e.*, 101.67aphids/cm<sup>2</sup> twig during 9<sup>th</sup> MSW and 8.17 during 16<sup>th</sup> MSW respectively. Reappearance of aphids on the plant were reported during 46<sup>th</sup> MSW and continued till 52<sup>nd</sup> MSW with highest population (17.00 aphids/cm<sup>2</sup>) during 50<sup>th</sup> MSW and least population (11.17 aphids/cm<sup>2</sup>) during 48<sup>th</sup> MSW. Litchi bug; one among the major pest seen infesting to the crop was reported during 10<sup>th</sup> to 27<sup>th</sup> MSW. The lowest population of litchi bug *i.e.*, 0.08 bugs/panicle was reported during 27<sup>th</sup> MSW. However, highest population *i.e.*, 3.00 bugs/plant was reported during 21<sup>st</sup> MSW. The semilooper larvae were reported on the litchi plant from 7<sup>th</sup> to 19<sup>th</sup> MSW. The mean population of semiloopers ranged from 0.02-0.40 larvae/plant with least and highest population during 19<sup>th</sup> and 13<sup>th</sup> MSW respectively.

**Table 4.3: Population dynamics of major insect pests on litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

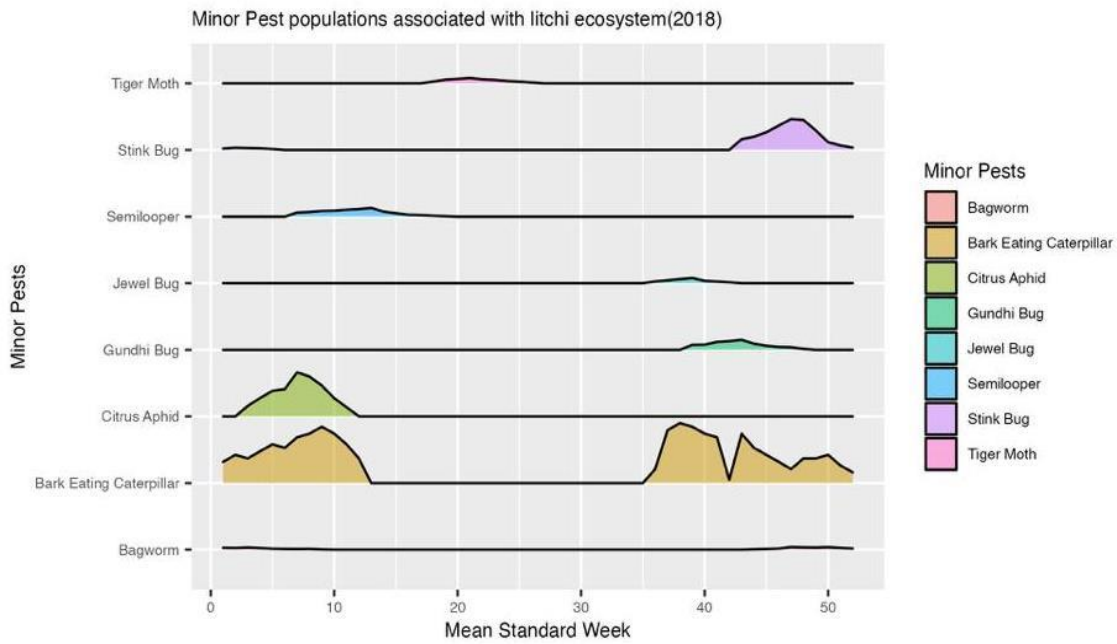
| MSW | Date  | Month       | Litchi Mite | Mealy bug | Litch fruit borer | Litchi leaf roller | Bark eating caterpillar | Mango leaf hopper | Grey weevil | Scale insects | Gundhi bug | Green stink bug | Tiger moth | Citrus aphids | Jewel bug | Bag worm | Thrips | Litchi bug | Semilooper |
|-----|-------|-------------|-------------|-----------|-------------------|--------------------|-------------------------|-------------------|-------------|---------------|------------|-----------------|------------|---------------|-----------|----------|--------|------------|------------|
| 1   | 01-07 | Jan         | 8.00        | 9.17      | 0.00              | 5.00               | 1.00                    | 0.00              | 0.00        | 16.83         | 0.00       | 0.06            | 0.00       | 0.00          | 0.00      | 0.09     | 34.83  | 0.00       | 0.00       |
| 2   | 08-14 | Jan         | 6.50        | 12.33     | 0.00              | 7.67               | 1.33                    | 0.00              | 0.00        | 16.68         | 0.00       | 0.10            | 0.00       | 0.00          | 0.00      | 0.08     | 46.67  | 0.00       | 0.00       |
| 3   | 15-21 | Jan         | 8.00        | 13.17     | 0.00              | 10.50              | 1.16                    | 0.00              | 0.00        | 16.58         | 0.00       | 0.09            | 0.00       | 0.50          | 0.00      | 0.10     | 49.17  | 0.00       | 0.00       |
| 4   | 22-28 | Jan- Feb    | 6.30        | 21.00     | 0.00              | 11.33              | 1.50                    | 0.00              | 2.26        | 15.68         | 0.00       | 0.08            | 0.00       | 0.87          | 0.00      | 0.07     | 51.67  | 0.00       | 0.00       |
| 5   | 29-04 | Feb         | 14.50       | 22.83     | 0.00              | 13.33              | 1.83                    | 5.93              | 2.75        | 14.08         | 0.00       | 0.04            | 0.00       | 1.20          | 0.00      | 0.05     | 69.17  | 0.00       | 0.00       |
| 6   | 05-11 | Feb         | 19.60       | 28.67     | 0.00              | 13.50              | 1.66                    | 3.51              | 3.97        | 14.76         | 0.00       | 0.00            | 0.00       | 1.29          | 0.00      | 0.03     | 76.67  | 0.00       | 0.00       |
| 7   | 12-18 | Feb         | 23.60       | 29.17     | 0.00              | 17.50              | 2.16                    | 8.35              | 6.66        | 10.19         | 0.00       | 0.00            | 0.00       | 2.08          | 0.00      | 0.03     | 85.00  | 0.00       | 0.19       |
| 8   | 19-25 | Feb         | 27.30       | 42.33     | 0.00              | 24.67              | 2.33                    | 8.65              | 9.80        | 17.50         | 0.00       | 0.00            | 0.00       | 1.88          | 0.00      | 0.04     | 98.00  | 0.00       | 0.22       |
| 9   | 26-04 | Feb-March   | 19.30       | 51.00     | 0.00              | 28.67              | 2.66                    | 9.08              | 12.89       | 24.24         | 0.00       | 0.00            | 0.00       | 1.46          | 0.00      | 0.01     | 101.67 | 0.00       | 0.26       |
| 10  | 05-11 | March       | 15.50       | 27.50     | 11.50             | 23.67              | 2.33                    | 9.32              | 15.64       | 21.25         | 0.00       | 0.00            | 0.00       | 0.86          | 0.00      | 0.00     | 88.33  | 0.48       | 0.28       |
| 11  | 12-18 | March       | 19.50       | 22.83     | 11.33             | 31.83              | 1.83                    | 9.85              | 13.97       | 18.62         | 0.00       | 0.00            | 0.00       | 0.44          | 0.00      | 0.00     | 74.00  | 0.65       | 0.32       |
| 12  | 19-25 | March       | 21.80       | 47.20     | 11.00             | 21.83              | 1.16                    | 10.39             | 17.30       | 3.33          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 76.67  | 1.18       | 0.35       |
| 13  | 26-01 | March-April | 22.00       | 50.33     | 11.33             | 12.67              | 0.00                    | 7.67              | 12.30       | 4.36          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 50.67  | 1.34       | 0.40       |
| 14  | 02-08 | April       | 31.66       | 28.83     | 11.00             | 9.83               | 0.00                    | 5.82              | 6.05        | 7.39          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 36.33  | 1.54       | 0.23       |
| 15  | 09-15 | April       | 40.66       | 23.67     | 11.67             | 10.00              | 0.00                    | 5.59              | 0.00        | 7.50          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 16.50  | 1.67       | 0.15       |
| 16  | 16-22 | April       | 32.50       | 15.67     | 16.50             | 8.00               | 0.00                    | 3.88              | 0.00        | 8.50          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 8.17   | 1.85       | 0.09       |
| 17  | 23-29 | April-May   | 35.16       | 12.50     | 15.83             | 10.50              | 0.00                    | 3.54              | 0.00        | 12.50         | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 2.08       | 0.07       |
| 18  | 30-06 | May         | 57.50       | 0.00      | 20.83             | 10.17              | 0.00                    | 2.37              | 0.00        | 15.00         | 0.00       | 0.00            | 0.08       | 0.00          | 0.00      | 0.00     | 0.00   | 2.17       | 0.04       |
| 19  | 07-13 | May         | 51.50       | 0.00      | 21.67             | 10.33              | 0.00                    | 1.74              | 0.00        | 9.17          | 0.00       | 0.00            | 0.17       | 0.00          | 0.00      | 0.00     | 0.00   | 2.45       | 0.02       |
| 20  | 14-20 | May         | 53.30       | 0.00      | 24.50             | 10.00              | 0.00                    | 0.34              | 0.00        | 12.50         | 0.00       | 0.00            | 0.21       | 0.00          | 0.00      | 0.00     | 0.00   | 2.98       | 0.00       |
| 21  | 21-27 | May         | 76.80       | 0.00      | 23.83             | 10.33              | 0.00                    | 0.00              | 0.00        | 7.50          | 0.00       | 0.00            | 0.25       | 0.00          | 0.00      | 0.00     | 0.00   | 3.00       | 0.00       |
| 22  | 28-03 | May- June   | 62.83       | 0.00      | 22.00             | 11.00              | 0.00                    | 0.00              | 0.00        | 7.28          | 0.00       | 0.00            | 0.19       | 0.00          | 0.00      | 0.00     | 0.00   | 2.21       | 0.00       |
| 23  | 04-10 | June        | 62.00       | 0.00      | 25.00             | 10.33              | 0.00                    | 0.00              | 0.00        | 7.42          | 0.00       | 0.00            | 0.16       | 0.00          | 0.00      | 0.00     | 0.00   | 1.62       | 0.00       |
| 24  | 11-17 | June        | 63.33       | 0.00      | 14.00             | 11.50              | 0.00                    | 0.00              | 0.00        | 6.42          | 0.00       | 0.00            | 0.11       | 0.00          | 0.00      | 0.00     | 0.00   | 1.04       | 0.00       |
| 25  | 18-24 | June        | 68.33       | 0.00      | 12.33             | 10.83              | 0.00                    | 0.00              | 0.00        | 5.42          | 0.00       | 0.00            | 0.08       | 0.00          | 0.00      | 0.00     | 0.00   | 0.46       | 0.00       |
| 26  | 25-01 | June-July   | 61.83       | 0.00      | 8.50              | 10.17              | 0.00                    | 0.00              | 0.00        | 4.17          | 0.00       | 0.00            | 0.04       | 0.00          | 0.00      | 0.00     | 0.00   | 0.38       | 0.00       |

**Table 4.3: Contd...**

| MSW | Date  | Month    | Litchi Mite | Mealy bug | Litch fruit borer | Litchi leaf roller | Bark eating caterpillar | Mango leaf hopper | Grey weevil | Scale insects | Gundhi bug | Green stink bug | Tiger moth | Citrus aphids | Jewel bug | Bag worm | Thrips | Litchi bug | Semilooper |
|-----|-------|----------|-------------|-----------|-------------------|--------------------|-------------------------|-------------------|-------------|---------------|------------|-----------------|------------|---------------|-----------|----------|--------|------------|------------|
| 27  | 02-08 | July     | 54.66       | 0.00      | 4.50              | 11.67              | 0.00                    | 0.00              | 0.00        | 3.75          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.08       | 0.00       |
| 28  | 09-15 | July     | 40.83       | 0.00      | 8.17              | 14.67              | 0.00                    | 0.00              | 0.00        | 3.33          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 29  | 16-22 | July     | 35.66       | 0.00      | 0.00              | 12.83              | 0.00                    | 0.00              | 6.48        | 3.46          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 30  | 23-29 | July-Aug | 33.66       | 0.00      | 0.00              | 11.67              | 0.00                    | 0.00              | 5.84        | 4.17          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 31  | 30-05 | Aug      | 35.00       | 0.00      | 0.00              | 12.17              | 0.00                    | 0.00              | 6.95        | 4.58          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 32  | 06-12 | Aug      | 20.00       | 0.00      | 0.00              | 10.17              | 0.00                    | 0.00              | 7.08        | 5.00          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 33  | 13-19 | Aug      | 10.50       | 0.00      | 0.00              | 13.50              | 0.00                    | 0.00              | 7.45        | 4.38          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 34  | 20-26 | Aug      | 9.00        | 0.00      | 0.00              | 9.67               | 0.00                    | 0.00              | 7.84        | 4.66          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 35  | 27-02 | Aug-Sep  | 6.83        | 0.00      | 0.00              | 10.83              | 0.00                    | 0.00              | 8.43        | 5.42          | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 36  | 03-09 | Sep      | 7.87        | 0.00      | 0.00              | 15.15              | 0.66                    | 0.00              | 12.92       | 5.98          | 0.00       | 0.00            | 0.00       | 0.00          | 0.08      | 0.00     | 0.00   | 0.00       | 0.00       |
| 37  | 10-16 | Sep      | 12.00       | 0.00      | 0.00              | 16.33              | 2.50                    | 1.32              | 14.58       | 6.12          | 0.00       | 0.00            | 0.00       | 0.00          | 0.13      | 0.00     | 0.00   | 0.00       | 0.00       |
| 38  | 17-23 | Sep      | 35.55       | 0.00      | 0.00              | 23.00              | 2.83                    | 1.79              | 16.67       | 6.49          | 0.00       | 0.00            | 0.00       | 0.00          | 0.19      | 0.00     | 0.00   | 0.00       | 0.00       |
| 39  | 24-30 | Sep-Oct  | 30.90       | 0.00      | 0.00              | 19.00              | 2.66                    | 1.89              | 16.26       | 5.83          | 0.23       | 0.00            | 0.00       | 0.00          | 0.24      | 0.00     | 0.00   | 0.00       | 0.00       |
| 40  | 01-07 | Oct      | 15.00       | 0.00      | 0.00              | 20.00              | 2.33                    | 1.97              | 16.58       | 6.77          | 0.24       | 0.00            | 0.00       | 0.00          | 0.11      | 0.00     | 0.00   | 0.00       | 0.00       |
| 41  | 08-14 | Oct      | 25.00       | 0.00      | 0.00              | 30.00              | 2.16                    | 2.38              | 16.87       | 7.13          | 0.37       | 0.00            | 0.00       | 0.00          | 0.08      | 0.00     | 0.00   | 0.00       | 0.00       |
| 42  | 15-21 | Oct      | 19.34       | 0.00      | 0.00              | 29.89              | 0.16                    | 1.71              | 20.83       | 7.88          | 0.41       | 0.00            | 0.00       | 0.00          | 0.04      | 0.00     | 0.00   | 0.00       | 0.00       |
| 43  | 22-28 | Oct      | 21.20       | 0.00      | 0.00              | 33.67              | 2.33                    | 0.38              | 20.88       | 8.33          | 0.47       | 0.51            | 0.00       | 0.00          | 0.00      | 0.00     | 0.00   | 0.00       | 0.00       |
| 44  | 29-04 | Nov      | 25.30       | 0.00      | 0.00              | 38.12              | 1.66                    | 0.60              | 18.75       | 7.50          | 0.29       | 0.63            | 0.00       | 0.00          | 0.00      | 0.02     | 0.00   | 0.00       | 0.00       |
| 45  | 05-11 | Nov      | 10.98       | 0.00      | 0.00              | 30.00              | 1.33                    | 0.60              | 13.88       | 7.30          | 0.19       | 0.83            | 0.00       | 0.00          | 0.00      | 0.03     | 0.00   | 0.00       | 0.00       |
| 46  | 12-18 | Nov      | 9.00        | 0.00      | 0.00              | 16.21              | 1.00                    | 0.00              | 9.58        | 6.41          | 0.13       | 1.15            | 0.00       | 0.00          | 0.00      | 0.05     | 11.67  | 0.00       | 0.00       |
| 47  | 19-25 | Nov      | 7.00        | 0.00      | 0.00              | 20.28              | 0.66                    | 0.00              | 7.92        | 8.33          | 0.12       | 1.46            | 0.00       | 0.00          | 0.00      | 0.12     | 14.67  | 0.00       | 0.00       |
| 48  | 26-02 | Nov- Dec | 6.41        | 0.00      | 0.00              | 18.71              | 1.16                    | 0.00              | 6.07        | 10.00         | 0.05       | 1.42            | 0.00       | 0.00          | 0.00      | 0.10     | 11.17  | 0.00       | 0.00       |
| 49  | 03-09 | Dec      | 2.21        | 0.00      | 0.00              | 10.19              | 1.16                    | 0.00              | 5.58        | 11.03         | 0.00       | 0.92            | 0.00       | 0.00          | 0.00      | 0.10     | 16.50  | 0.00       | 0.00       |
| 50  | 10-16 | Dec      | 0.00        | 0.00      | 0.00              | 9.21               | 1.33                    | 0.00              | 4.17        | 12.95         | 0.00       | 0.37            | 0.00       | 0.00          | 0.00      | 0.11     | 17.00  | 0.00       | 0.00       |
| 51  | 17-23 | Dec      | 0.00        | 0.00      | 0.00              | 18.28              | 0.83                    | 0.00              | 1.38        | 13.33         | 0.00       | 0.21            | 0.00       | 0.00          | 0.00      | 0.08     | 15.17  | 0.00       | 0.00       |
| 52  | 24-31 | Dec- Jan | 5.00        | 0.00      | 0.00              | 7.00               | 0.50                    | 0.00              | 0.41        | 13.97         | 0.00       | 0.11            | 0.00       | 0.00          | 0.00      | 0.05     | 14.67  | 0.00       | 0.00       |



**Figure 4.1a: Population dynamics of insects and mite pests associated with litchi ecosystem during 2018**



**Figure 4.1b: Population dynamics of minor pests population associated with litchi ecosystem during 2018**

Amongst the natural enemies, Spiders were found associated with different insect pest throughout the year. Maximum and minimum population of spiders *i.e.*, 2.75/panicle and 0.22/panicle were reported during 22<sup>nd</sup> and 49<sup>th</sup> MSW respectively. Lady bird beetles were also reported in two phases on the crop. The beetle population was absent from 19<sup>th</sup> to 41<sup>st</sup> MSW. Highest and lowest population of lady bird beetles were observed on the crop during 10<sup>th</sup> and 18<sup>th</sup> MSW with a mean population of 2.67 beetles/panicle and 0.28 beetles/panicle respectively. Green lace wing bugs were found absent on the crop from 21<sup>st</sup> to 34<sup>th</sup> MSW. Highest mean population (1.62 bugs/panicle) of lace wing bugs were reported during 1<sup>st</sup> MSW. Whereas, lowest mean population of 0.18 bugs/panicle was reported on 20<sup>th</sup> MSW. Assasian bug was present throughout the year except from 27<sup>th</sup> to 34<sup>th</sup> MSW. Peak population of assasian bugs *i.e.*, 1.25 bugs/panicle were reported during 12<sup>th</sup> MSW and least population of bugs, 0.03 bugs/panicle was reported during 35<sup>th</sup> MSW. Similarly, black ants were also observed on the litchi panicle throughout the year except 33<sup>rd</sup> to 46<sup>th</sup> MSW. The maximum and minimum population of black ants were reported during 22<sup>nd</sup> and 32<sup>nd</sup> MSW with 3.37 and 0.19 ants/panicle respectively. However, presence of red ants on the litchi panicle were reported from 7<sup>th</sup> to 26<sup>th</sup> MSW. Lowest mean population of red ants *i.e.*, 0.21/panicle were reported on 26<sup>th</sup> MSW. Whereas, the highest mean population of red ants, 2.08/panicle were recorded during 23<sup>rd</sup> and 12<sup>th</sup> MSW.

The observations on the population of natural enemies viz. braconid wasp, cotesia wasp and ichneumonid wasp were taken by using yellow sticky trap. Braconid wasps were absent from 26<sup>th</sup> to 36<sup>th</sup> MSW. The maximum and minimum population of braconid wasps, 2.33 and 0.5 wasps/trap were reported during 41<sup>st</sup> and 1<sup>st</sup> MSW respectively. Ichneumonid wasps were present from 1<sup>st</sup> MSW to 23<sup>rd</sup> MSW. The highest mean number of ichneumon wasp (1.83 wasps/trap) were recorded on 12<sup>th</sup> MSW. Whereas, lowest number of wasps (0.33/trap) were recorded on 1<sup>st</sup> and 19<sup>th</sup> MSW. Cotesia wasps were observed on the trap from 8<sup>th</sup> to 21<sup>st</sup> MSW and 37<sup>th</sup>- 43<sup>rd</sup> MSW. The highest and least population of cotesia wasps were reported during 39<sup>th</sup> and 43<sup>rd</sup> MSW with 4.33 and 1.00 wasps/trap respectively. Rove beetles were present from 10<sup>th</sup> to 27<sup>th</sup> MSW. The maximum and minimum population of rove beetles were reported during 21<sup>st</sup> and 27<sup>th</sup> MSW with 1.83 and 0.33 beetles/panicle.

**Table 4.4: Population dynamics of natural enemies associated with litchi during 2018 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

| Week No. | Date  | Month       | Green lacewing | Spider | Lady bird beetle | Tachinid fly | Braconid wasp | Syrphid fly | Eocanthecona bug | Assasian bug | Black ant | Cotesia wasp | Red ant | Ichneumonid wasp | Rove beetle |
|----------|-------|-------------|----------------|--------|------------------|--------------|---------------|-------------|------------------|--------------|-----------|--------------|---------|------------------|-------------|
| 1        | 01-07 | Jan         | 1.62           | 0.36   | 1.75             | 0.84         | 0.50          | 0.15        | 0.27             | 0.57         | 1.68      | 0.00         | 0.00    | 0.33             | 0.00        |
| 2        | 08-14 | Jan         | 1.58           | 0.39   | 2.03             | 1.01         | 1.00          | 0.19        | 0.30             | 0.59         | 1.77      | 0.00         | 0.00    | 0.67             | 0.00        |
| 3        | 15-21 | Jan         | 1.49           | 0.44   | 2.09             | 1.19         | 0.83          | 0.21        | 0.37             | 0.58         | 1.98      | 0.00         | 0.00    | 0.50             | 0.00        |
| 4        | 22-28 | Jan- Feb    | 1.30           | 0.52   | 2.31             | 1.25         | 0.67          | 0.25        | 0.39             | 0.64         | 1.88      | 0.00         | 0.00    | 0.50             | 0.00        |
| 5        | 29-04 | Feb         | 1.16           | 0.74   | 2.40             | 1.27         | 1.67          | 0.37        | 0.42             | 0.70         | 2.09      | 0.00         | 0.00    | 1.17             | 0.00        |
| 6        | 05-11 | Feb         | 1.08           | 0.92   | 2.04             | 1.39         | 1.33          | 0.46        | 0.46             | 0.71         | 2.23      | 0.00         | 0.00    | 1.00             | 0.00        |
| 7        | 12-18 | Feb         | 1.17           | 1.17   | 2.29             | 1.42         | 1.00          | 0.63        | 0.50             | 0.83         | 2.68      | 0.00         | 0.83    | 1.00             | 0.00        |
| 8        | 19-25 | Feb         | 1.04           | 1.21   | 2.50             | 1.30         | 1.17          | 0.79        | 0.54             | 0.85         | 2.50      | 1.83         | 1.43    | 1.17             | 0.00        |
| 9        | 26-04 | Feb-March   | 0.90           | 1.24   | 2.55             | 1.49         | 1.17          | 0.92        | 0.55             | 0.95         | 2.63      | 2.50         | 1.65    | 0.83             | 0.00        |
| 10       | 05-11 | March       | 0.83           | 1.38   | 2.67             | 1.44         | 1.83          | 1.07        | 0.55             | 1.11         | 2.74      | 1.67         | 1.85    | 1.50             | 0.67        |
| 11       | 12-18 | March       | 0.79           | 1.37   | 2.08             | 1.48         | 2.00          | 1.24        | 0.63             | 1.20         | 3.23      | 2.50         | 1.95    | 0.83             | 1.33        |
| 12       | 19-25 | March       | 0.65           | 1.62   | 1.72             | 1.50         | 2.17          | 1.25        | 0.70             | 1.25         | 3.33      | 3.50         | 2.08    | 1.83             | 1.17        |
| 13       | 26-01 | March-April | 0.83           | 1.65   | 1.67             | 1.58         | 1.67          | 1.29        | 0.71             | 1.17         | 2.39      | 2.33         | 0.98    | 1.50             | 0.83        |
| 14       | 02-08 | April       | 0.92           | 1.73   | 1.53             | 1.63         | 1.50          | 1.15        | 0.79             | 0.90         | 2.04      | 3.83         | 0.82    | 1.17             | 1.00        |
| 15       | 09-15 | April       | 0.93           | 1.85   | 1.25             | 1.67         | 0.83          | 0.92        | 0.79             | 0.82         | 1.65      | 3.17         | 0.63    | 1.00             | 1.50        |
| 16       | 16-22 | April       | 1.07           | 2.13   | 1.24             | 1.68         | 1.67          | 0.79        | 0.82             | 0.71         | 1.43      | 2.83         | 0.87    | 1.50             | 1.33        |
| 17       | 23-29 | April-May   | 0.75           | 2.27   | 0.42             | 1.46         | 0.50          | 0.47        | 0.83             | 0.77         | 1.28      | 4.00         | 0.98    | 0.83             | 1.00        |
| 18       | 30-06 | May         | 0.41           | 2.31   | 0.28             | 1.24         | 0.00          | 0.40        | 0.85             | 0.49         | 2.08      | 3.33         | 1.04    | 0.50             | 0.50        |
| 19       | 07-13 | May         | 0.33           | 2.45   | 0.00             | 0.83         | 0.83          | 0.34        | 0.88             | 0.50         | 2.49      | 1.83         | 1.09    | 0.33             | 0.67        |
| 20       | 14-20 | May         | 0.18           | 2.51   | 0.00             | 0.63         | 1.17          | 0.17        | 0.97             | 0.41         | 2.88      | 1.33         | 1.17    | 0.17             | 0.83        |
| 21       | 21-27 | May         | 0.00           | 2.59   | 0.00             | 0.47         | 1.50          | 0.10        | 1.00             | 0.24         | 3.23      | 1.17         | 1.67    | 1.00             | 1.83        |
| 22       | 28-03 | May- June   | 0.00           | 2.75   | 0.00             | 0.25         | 2.17          | 0.04        | 1.07             | 0.20         | 3.37      | 0.00         | 1.95    | 1.33             | 1.00        |
| 23       | 04-10 | June        | 0.00           | 2.10   | 0.00             | 0.00         | 1.33          | 0.00        | 0.79             | 0.13         | 1.77      | 0.00         | 2.08    | 0.67             | 1.33        |
| 24       | 11-17 | June        | 0.00           | 1.90   | 0.00             | 0.00         | 0.83          | 0.00        | 0.76             | 0.12         | 1.19      | 0.00         | 0.81    | 0.00             | 0.50        |
| 25       | 18-24 | June        | 0.00           | 1.61   | 0.00             | 0.00         | 0.67          | 0.00        | 0.67             | 0.07         | 0.85      | 0.00         | 0.73    | 0.00             | 1.17        |

**Table 4.4: Contd...**

| Week No. | Date  | Month     | Green lacewing | Spider | Lady bird beetle | Tachinid fly | Braconid wasp | Syrphid fly | Eocanthecona bug | Assasian bug | Black ant | Cotesia wasp | Red ant | Ichneumonid wasp | Rove beetle |
|----------|-------|-----------|----------------|--------|------------------|--------------|---------------|-------------|------------------|--------------|-----------|--------------|---------|------------------|-------------|
| 26       | 25-01 | June-July | 0.00           | 1.83   | 0.00             | 0.00         | 0.00          | 0.00        | 0.67             | 0.04         | 0.82      | 0.00         | 0.21    | 0.00             | 0.50        |
| 27       | 02-08 | July      | 0.00           | 1.07   | 0.00             | 0.00         | 0.00          | 0.00        | 0.63             | 0.00         | 0.23      | 0.00         | 0.00    | 0.00             | 0.33        |
| 28       | 09-15 | July      | 0.00           | 0.83   | 0.00             | 0.00         | 0.00          | 0.00        | 0.49             | 0.00         | 0.42      | 0.00         | 0.00    | 0.00             | 0.00        |
| 29       | 16-22 | July      | 0.00           | 0.78   | 0.00             | 0.00         | 0.00          | 0.00        | 0.38             | 0.00         | 1.59      | 0.00         | 0.00    | 0.00             | 0.00        |
| 30       | 23-29 | July-Aug  | 0.00           | 0.79   | 0.00             | 0.00         | 0.00          | 0.00        | 0.37             | 0.00         | 1.67      | 0.00         | 0.00    | 0.00             | 0.00        |
| 31       | 30-05 | Aug       | 0.00           | 0.65   | 0.00             | 0.00         | 0.00          | 0.00        | 0.30             | 0.00         | 0.48      | 0.00         | 0.00    | 0.00             | 0.00        |
| 32       | 06-12 | Aug       | 0.00           | 0.72   | 0.00             | 0.00         | 0.00          | 0.00        | 0.25             | 0.00         | 0.19      | 0.00         | 0.00    | 0.00             | 0.00        |
| 33       | 13-19 | Aug       | 0.00           | 0.47   | 0.00             | 0.00         | 0.00          | 0.00        | 0.28             | 0.00         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 34       | 20-26 | Aug       | 0.00           | 0.42   | 0.00             | 0.00         | 0.00          | 0.00        | 0.24             | 0.00         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 35       | 27-02 | Aug-Sep   | 0.36           | 0.49   | 0.00             | 0.00         | 0.00          | 0.00        | 0.20             | 0.03         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 36       | 03-09 | Sep       | 0.41           | 0.92   | 0.00             | 0.00         | 0.00          | 0.00        | 0.14             | 0.06         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 37       | 10-16 | Sep       | 0.42           | 0.52   | 0.00             | 0.00         | 1.00          | 0.00        | 0.11             | 0.28         | 0.00      | 2.50         | 0.00    | 0.00             | 0.00        |
| 38       | 17-23 | Sep       | 0.48           | 0.50   | 0.00             | 0.00         | 1.33          | 0.00        | 0.08             | 0.30         | 0.00      | 3.17         | 0.00    | 0.00             | 0.00        |
| 39       | 24-30 | Sep-Oct   | 0.55           | 0.50   | 0.00             | 0.00         | 2.00          | 0.00        | 0.04             | 0.35         | 0.00      | 4.33         | 0.00    | 0.00             | 0.00        |
| 40       | 01-07 | Oct       | 0.60           | 0.64   | 0.00             | 0.18         | 1.83          | 0.00        | 0.03             | 0.41         | 0.00      | 3.50         | 0.00    | 0.00             | 0.00        |
| 41       | 08-14 | Oct       | 0.63           | 0.60   | 0.00             | 0.29         | 2.33          | 0.00        | 0.03             | 0.42         | 0.00      | 2.50         | 0.00    | 0.00             | 0.00        |
| 42       | 15-21 | Oct       | 0.69           | 0.50   | 0.42             | 0.41         | 1.50          | 0.00        | 0.04             | 0.49         | 0.00      | 1.33         | 0.00    | 0.00             | 0.00        |
| 43       | 22-28 | Oct       | 0.71           | 0.41   | 0.63             | 0.50         | 1.67          | 0.00        | 0.00             | 0.52         | 0.00      | 1.00         | 0.00    | 0.00             | 0.00        |
| 44       | 29-04 | Nov       | 0.79           | 0.37   | 0.79             | 0.47         | 0.83          | 0.00        | 0.00             | 0.54         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 45       | 05-11 | Nov       | 0.84           | 0.31   | 0.83             | 0.63         | 1.33          | 0.00        | 0.00             | 0.47         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 46       | 12-18 | Nov       | 0.93           | 0.28   | 0.92             | 0.67         | 1.83          | 0.00        | 0.00             | 0.41         | 0.00      | 0.00         | 0.00    | 0.00             | 0.00        |
| 47       | 19-25 | Nov       | 1.04           | 0.29   | 1.21             | 0.70         | 1.50          | 0.00        | 0.00             | 0.26         | 0.79      | 0.00         | 0.00    | 0.00             | 0.00        |
| 48       | 26-02 | Nov- Dec  | 1.20           | 0.27   | 1.20             | 0.71         | 1.33          | 0.00        | 0.08             | 0.24         | 0.85      | 0.00         | 0.00    | 0.00             | 0.00        |
| 49       | 03-09 | Dec       | 1.25           | 0.22   | 1.30             | 0.78         | 1.17          | 0.06        | 0.12             | 0.18         | 1.28      | 0.00         | 0.00    | 0.00             | 0.00        |
| 50       | 10-16 | Dec       | 1.42           | 0.29   | 1.39             | 0.81         | 2.17          | 0.09        | 0.13             | 0.40         | 1.43      | 0.00         | 0.00    | 0.00             | 0.00        |
| 51       | 17-23 | Dec       | 1.57           | 0.33   | 1.53             | 0.83         | 1.00          | 0.11        | 0.16             | 0.42         | 1.53      | 0.00         | 0.00    | 0.00             | 0.00        |
| 52       | 24-31 | Dec- Jan  | 1.60           | 0.34   | 1.66             | 0.87         | 0.67          | 0.14        | 0.20             | 0.49         | 1.66      | 0.00         | 0.00    | 0.00             | 0.00        |

Population dynamics of natural enemies associated with litchi ecosystem(2018)

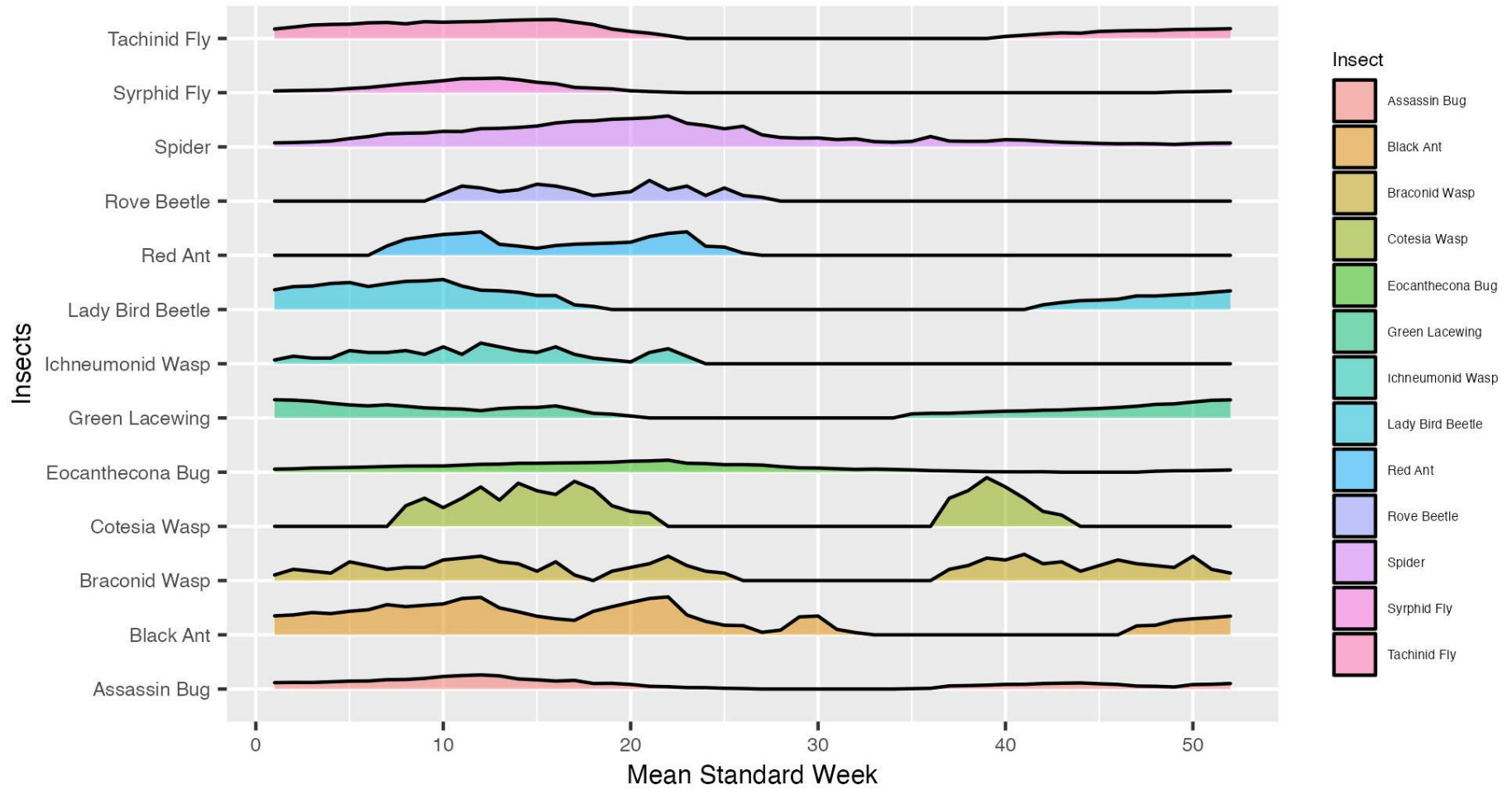


Figure 4.2 population dynamics of natural enemies associated with litchi ecosystem during 2018

Tachnid flies and syrphid flies were also observed throughout the period of study except 23<sup>rd</sup>-39<sup>th</sup> MSW and 23<sup>rd</sup> to 48<sup>th</sup> MSW respectively. Peak population of both the flies were recorded during 16<sup>th</sup> and 13<sup>th</sup> MSW with a mean population of 1.68/panicle and 1.29/panicle for tachinid flies and syrphid flies respectively. Whereas, lowest mean population *i.e.*, 0.18 and 0.06/panicle were reported during 40<sup>th</sup> and 49<sup>th</sup> MSW for tachinid flies and syrphid flies respectively. Eocanthecona bugs were present almost throughout the year except 43<sup>rd</sup> to 46<sup>th</sup> MSW. The mean population of eocanthecona bug was on peak *i.e.*, 1.07/panicle during 22<sup>nd</sup> MSW. Whereas, lowest mean population of 0.03 bugs/panicle were reported during 41<sup>st</sup> and 42<sup>nd</sup> MSW.

#### **4.1.2. Population dynamics of major insect pests and their associated natural enemies on litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

The observations were recorded at weekly interval throughout the year during the course of study (January 2019- December 2019) and the mean population of insect pest and natural enemies with respect to the mean standard weeks (MSW) were recorded and presented in **Figure 4.3a**, **Figure 4.3b**, and **Figure 4.4** along with **Table 4.5** and **Table 4.6** respectively

Litchi mite infestation was observed throughout the year. Its peak population was 59.45% which was recorded during 24<sup>th</sup> MSW and the lowest population recorded was 5% which was observed during both 1<sup>st</sup> and 51<sup>st</sup> MSW. Mealy bug infestation was first recorded first during 1<sup>st</sup> MSW and its last infestation was recorded during 22<sup>nd</sup> MSW. Its highest (48.78) and lowest (1.0) population was recorded during 9<sup>th</sup> and 22<sup>nd</sup> MSW respectively. Litchi fruit borer damage to the fruits were recorded from 13<sup>th</sup> MSW to 26<sup>th</sup> MSW. Maximum no of infested fruits, 41.00/panicle were reported during 21<sup>st</sup> MSW. However, lowest number of infested fruits (3.00/panicle) were reported during 26<sup>th</sup> MSW. Leaf roller infestation was measured indirectly through number of rolled leaves/panicle. Rolled leaves were observed throughout the year. The lowest number of rolled leaves was during 3<sup>rd</sup> MSW while maximum leaf rolled was during 44<sup>th</sup> MSW. Bark eating caterpillar was measured indirectly by number of active holes/plants. It was observed in two phases. First phase was observed from 1<sup>st</sup> MSW to 16<sup>th</sup> MSW while second phase was recorded from 31<sup>st</sup> MSW to end of the year. Highest

number of active holes per panicle was recorded during 5<sup>th</sup> MSW while the lowest was observed during 16<sup>th</sup> and 34<sup>th</sup> MSW.

Infestation of mango leaf hopper was commenced during (9 -33) MSW and it re- emerged during 35<sup>th</sup> MSW and continued till 46<sup>th</sup> MSW. Its peak population was recorded during 22<sup>nd</sup> MSW (6.46hoppers/panicle) while minimum was during 35<sup>th</sup> MSW (0.37 hoppers/panicle). Grey weevil was observed during (6-22) and (29-47) MSW. Maximum number of infestations was during 6<sup>th</sup> MSW (16.66) while the lowest number of infestations was recorded during 47<sup>th</sup> MSW (0.36). Scale insect population was measured indirectly through number of scale insect/cm<sup>2</sup>leaf. Its infestation was observed throughout the year but its highest and lowest population was recorded during 15<sup>th</sup> and 46<sup>th</sup> MSW respectively. Gundhi bug was observed during (14-24) MSW in the start of the year and again in the end of the year, it re-emerged again during (36-50) MSW. Highest and lowest population was recorded during 45<sup>th</sup> and 24<sup>th</sup> MSW respectively which was 0.50 bugs/panicle and 0.06 bugs/panicle respectively.

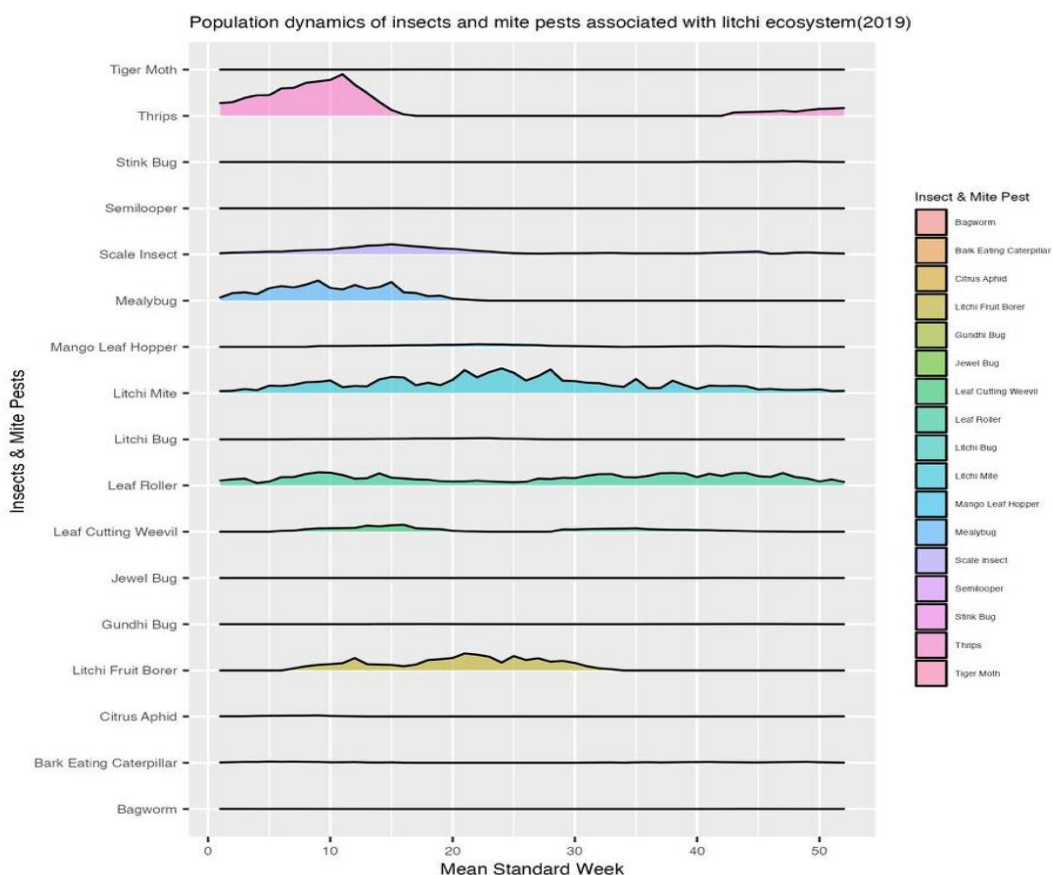
Green sting bug infestation was measured indirectly by number of bugs per panicle. Green stink bug commenced its infestation in first week of the year and it continued upto 11<sup>th</sup> MSW. Again, it re-emerged in 41<sup>st</sup> MSW and it continued its infestation till the end of the year. Highest (1.53) and lowest (0.03) number of bugs per panicle was observed during 48<sup>th</sup> and 11<sup>th</sup> MSW respectively. Tiger moth population was reported from 15<sup>th</sup> MSW to 27<sup>th</sup> MSW. Highest and least population of tiger moth were reported during 18<sup>th</sup> (0.27 moths per panicle) and 27<sup>th</sup> (0.03 moths per panicle) MSW respectively. The infestation of citrus aphid was recorded during (1-12) in first phase and (51-52) MSW in second phase. Peak population of citrus aphid was recorded during 9<sup>th</sup> MSW and lowest population during 51<sup>st</sup> MSW which was 2.6 and 0.32 aphids per cm<sup>2</sup> respectively. The incidence of bagworm was recorded during 1<sup>st</sup> to 12<sup>th</sup> MSW. Again, its infestation was recorded 40<sup>th</sup> MSW and continued till end of the year. Jewel bug infestation was recorded during (39-50) MSW. Its lowest population was recorded in 50 MSW and highest population was recorded during 43<sup>rd</sup> MSW which was 0.03 and 0.25 insect bugs/panicle respectively. Thrips population was reported at the starting of the year i.e. (1-16) MSW and at the end part of the year i.e. (43-52) MSW as well.

**Table 4.5: Population dynamics of major insect pests on litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

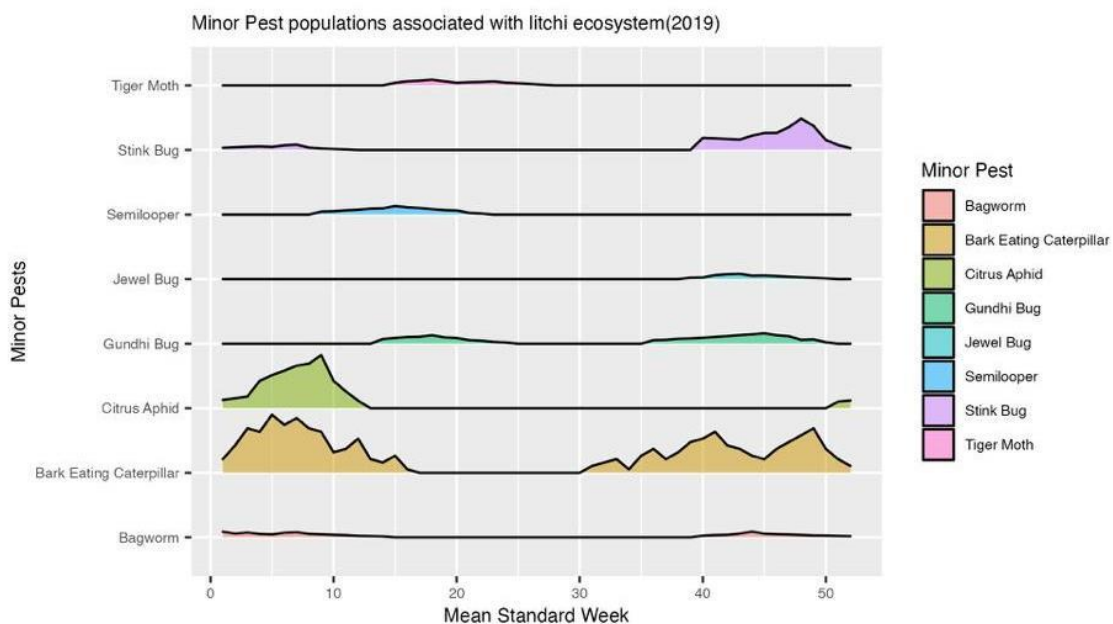
| MSW | Months | Litchi mite | Mealy bug | Litchi Fruit borer | Litchi Leaf roller | Bark eating caterpillar | Mango leaf hopper | Grey weevil | Scale insects | Gundhi bug | Green Stink bug | Tiger moth | Citrus aphids | Jewel bug | Bagworm | Thrips | Litchi bug | Semilooper |
|-----|--------|-------------|-----------|--------------------|--------------------|-------------------------|-------------------|-------------|---------------|------------|-----------------|------------|---------------|-----------|---------|--------|------------|------------|
| 1   | 04-Jan | 5.00        | 7.79      | 0.00               | 12.00              | 0.67                    | 0.00              | 0.00        | 2.81          | 0.00       | 0.10            | 0.00       | 0.41          | 0.00      | 0.28    | 30.83  | 0.00       | 0.00       |
| 2   | 11 Jan | 5.60        | 18.09     | 0.00               | 15.12              | 1.33                    | 0.00              | 0.00        | 4.05          | 0.00       | 0.13            | 0.00       | 0.49          | 0.00      | 0.19    | 32.83  | 0.00       | 0.00       |
| 3   | 18 Jan | 9.90        | 20.05     | 0.00               | 17.00              | 2.17                    | 0.00              | 0.00        | 4.82          | 0.00       | 0.15            | 0.00       | 0.57          | 0.00      | 0.24    | 43.17  | 0.00       | 0.00       |
| 4   | 25 Jan | 7.00        | 15.90     | 0.00               | 5.67               | 2.00                    | 0.00              | 0.00        | 5.53          | 0.00       | 0.17            | 0.00       | 1.34          | 0.00      | 0.17    | 49.67  | 0.00       | 0.00       |
| 5   | 01 Feb | 18.00       | 30.12     | 0.00               | 9.63               | 2.83                    | 0.00              | 0.00        | 6.66          | 0.00       | 0.15            | 0.00       | 1.61          | 0.00      | 0.15    | 50.17  | 0.00       | 0.00       |
| 6   | 08 Feb | 17.10       | 35.45     | 0.00               | 20.45              | 2.33                    | 0.00              | 2.08        | 6.74          | 0.00       | 0.23            | 0.00       | 1.83          | 0.00      | 0.23    | 66.33  | 0.00       | 0.00       |
| 7   | 15 Feb | 20.00       | 32.00     | 0.00               | 20.67              | 2.67                    | 0.00              | 2.59        | 8.75          | 0.00       | 0.25            | 0.00       | 2.08          | 0.00      | 0.25    | 67.67  | 0.40       | 0.00       |
| 8   | 22 Feb | 26.34       | 38.92     | 0.00               | 28.00              | 2.17                    | 0.00              | 5.97        | 10.28         | 0.00       | 0.11            | 0.00       | 2.17          | 0.00      | 0.18    | 79.67  | 0.50       | 0.00       |
| 9   | 29 Feb | 27.20       | 48.78     | 0.00               | 32.00              | 2.00                    | 1.85              | 7.91        | 11.23         | 0.00       | 0.07            | 0.00       | 2.60          | 0.00      | 0.15    | 83.17  | 0.60       | 0.14       |
| 10  | 07Mar  | 30.50       | 31.00     | 0.00               | 31.17              | 1.00                    | 2.08              | 8.33        | 11.93         | 0.00       | 0.05            | 0.00       | 1.34          | 0.00      | 0.12    | 86.83  | 0.63       | 0.16       |
| 11  | 14Mar  | 14.23       | 27.00     | 0.00               | 25.54              | 1.17                    | 1.99              | 8.74        | 15.83         | 0.00       | 0.03            | 0.00       | 0.82          | 0.00      | 0.10    | 100.50 | 0.70       | 0.20       |
| 12  | 21Mar  | 17.21       | 38.00     | 0.00               | 16.89              | 1.67                    | 2.45              | 9.16        | 17.50         | 0.00       | 0.00            | 0.00       | 0.37          | 0.00      | 0.07    | 75.17  | 0.84       | 0.23       |
| 13  | 28Mar  | 16.21       | 29.00     | 5.00               | 17.86              | 0.67                    | 2.60              | 14.60       | 21.58         | 0.00       | 0.00            | 0.00       | 0.00          | 0.00      | 0.06    | 55.50  | 0.93       | 0.29       |
| 14  | 04 Apr | 33.00       | 33.00     | 10.00              | 29.54              | 0.50                    | 2.86              | 12.92       | 22.36         | 0.23       | 0.00            | 0.00       | 0.00          | 0.00      | 0.05    | 33.50  | 1.24       | 0.30       |
| 15  | 11 Apr | 39.04       | 45.20     | 13.45              | 19.18              | 0.83                    | 3.15              | 15.37       | 24.91         | 0.28       | 0.00            | 0.13       | 0.00          | 0.00      | 0.00    | 14.17  | 1.45       | 0.41       |
| 16  | 18 Apr | 37.90       | 19.96     | 15.11              | 17.45              | 0.17                    | 3.92              | 16.66       | 22.29         | 0.33       | 0.00            | 0.20       | 0.00          | 0.00      | 0.00    | 3.50   | 1.56       | 0.35       |
| 17  | 25Apr  | 18.91       | 18.50     | 17.34              | 15.00              | 0.00                    | 4.13              | 8.42        | 19.62         | 0.34       | 0.00            | 0.23       | 0.00          | 0.00      | 0.00    | 0.00   | 2.08       | 0.32       |
| 18  | 02May  | 25.12       | 10.67     | 29.65              | 14.00              | 0.00                    | 4.21              | 6.94        | 17.53         | 0.41       | 0.00            | 0.28       | 0.00          | 0.00      | 0.00    | 0.00   | 2.08       | 0.26       |
| 19  | 09May  | 19.09       | 12.00     | 15.00              | 10.45              | 0.00                    | 5.00              | 6.07        | 14.76         | 0.31       | 0.00            | 0.20       | 0.00          | 0.00      | 0.00    | 0.00   | 2.23       | 0.22       |
| 20  | 16May  | 32.17       | 5.00      | 14.00              | 9.67               | 0.00                    | 5.09              | 2.21        | 13.60         | 0.28       | 0.00            | 0.13       | 0.00          | 0.00      | 0.00    | 0.00   | 2.17       | 0.20       |
| 21  | 23May  | 55.50       | 3.00      | 41.00              | 10.00              | 0.00                    | 5.47              | 1.00        | 11.34         | 0.18       | 0.00            | 0.15       | 0.00          | 0.00      | 0.00    | 0.00   | 2.52       | 0.08       |
| 22  | 30May  | 38.04       | 1.00      | 38.00              | 11.87              | 0.00                    | 6.46              | 0.63        | 8.50          | 0.14       | 0.00            | 0.17       | 0.00          | 0.00      | 0.00    | 0.00   | 2.91       | 0.05       |
| 23  | 06June | 50.55       | 0.00      | 33.00              | 10.00              | 0.00                    | 5.89              | 0.00        | 6.82          | 0.09       | 0.00            | 0.20       | 0.00          | 0.00      | 0.00    | 0.00   | 2.94       | 0.00       |
| 24  | 13June | 59.45       | 0.00      | 19.00              | 8.65               | 0.00                    | 5.70              | 0.00        | 4.45          | 0.06       | 0.00            | 0.13       | 0.00          | 0.00      | 0.00    | 0.00   | 1.80       | 0.00       |
| 25  | 20June | 49.23       | 0.00      | 5.00               | 7.78               | 0.00                    | 5.05              | 0.00        | 2.88          | 0.00       | 0.00            | 0.11       | 0.00          | 0.00      | 0.00    | 0.00   | 1.65       | 0.00       |
| 26  | 27June | 30.30       | 0.00      | 3.00               | 8.87               | 0.00                    | 4.70              | 0.00        | 2.13          | 0.00       | 0.00            | 0.07       | 0.00          | 0.00      | 0.00    | 0.00   | 1.20       | 0.00       |

Table 4.5: Contd...

| MSW | Months  | Litchi mite | Mealy bug | Fruit borer | Leaf roller | Bark eating caterpillar | Mango leaf hopper | Grey weevil | Scale insect | Gundhi bug | Stink bug | Tiger moth | Citrus aphids | Jewel bug | Bagworm | Thrips | Litchi bug | Semilo oper |
|-----|---------|-------------|-----------|-------------|-------------|-------------------------|-------------------|-------------|--------------|------------|-----------|------------|---------------|-----------|---------|--------|------------|-------------|
| 27  | 04 July | 41.00       | 0.00      | 0.00        | 17.00       | 0.00                    | 4.19              | 0.00        | 1.84         | 0.00       | 0.00      | 0.03       | 0.00          | 0.00      | 0.00    | 0.00   | 0.48       | 0.00        |
| 28  | 11 July | 57.00       | 0.00      | 0.00        | 16.00       | 0.00                    | 2.51              | 0.00        | 2.04         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.12       | 0.00        |
| 29  | 18 July | 30.03       | 0.00      | 0.00        | 19.00       | 0.00                    | 2.21              | 5.42        | 2.69         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.05       | 0.00        |
| 30  | 25 July | 28.90       | 0.00      | 0.00        | 18.34       | 0.00                    | 1.69              | 5.21        | 2.63         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 31  | 01 Aug  | 25.05       | 0.00      | 0.00        | 23.92       | 0.33                    | 1.36              | 6.43        | 2.88         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 32  | 08 Aug  | 24.03       | 0.00      | 0.00        | 27.72       | 0.50                    | 0.95              | 6.97        | 3.32         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 33  | 15 Aug  | 18.18       | 0.00      | 0.00        | 27.89       | 0.67                    | 0.40              | 7.36        | 3.53         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 34  | 22 Aug  | 15.09       | 0.00      | 0.00        | 20.67       | 0.17                    | 0.00              | 7.64        | 2.88         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 35  | 29 Aug  | 34.02       | 0.00      | 0.00        | 19.89       | 0.83                    | 0.37              | 8.14        | 2.53         | 0.00       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 36  | 05 Sep  | 12.02       | 0.00      | 0.00        | 23.45       | 1.17                    | 0.46              | 6.02        | 2.48         | 0.17       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 37  | 12 Sep  | 12.09       | 0.00      | 0.00        | 29.80       | 0.67                    | 0.61              | 5.14        | 2.50         | 0.19       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 38  | 19 Sep  | 30.05       | 0.00      | 0.00        | 30.43       | 1.00                    | 1.04              | 4.63        | 2.49         | 0.24       | 0.00      | 0.00       | 0.00          | 0.00      | 0.00    | 0.00   | 0.00       | 0.00        |
| 39  | 26 Sep  | 18.90       | 0.00      | 0.00        | 29.56       | 1.50                    | 1.25              | 4.58        | 2.33         | 0.25       | 0.00      | 0.00       | 0.00          | 0.07      | 0.00    | 0.00   | 0.00       | 0.00        |
| 40  | 03 Oct  | 10.09       | 0.00      | 0.00        | 20.54       | 1.67                    | 1.34              | 3.89        | 2.61         | 0.29       | 0.59      | 0.00       | 0.00          | 0.08      | 0.08    | 0.00   | 0.00       | 0.00        |
| 41  | 10 Oct  | 18.00       | 0.00      | 0.00        | 28.54       | 2.00                    | 1.66              | 3.71        | 3.43         | 0.33       | 0.57      | 0.00       | 0.00          | 0.19      | 0.10    | 0.00   | 0.00       | 0.00        |
| 42  | 17 Oct  | 17.00       | 0.00      | 0.00        | 23.32       | 1.33                    | 1.74              | 2.50        | 4.36         | 0.37       | 0.54      | 0.00       | 0.00          | 0.23      | 0.12    | 0.00   | 0.00       | 0.00        |
| 43  | 24 Oct  | 17.50       | 0.00      | 0.00        | 30.00       | 1.17                    | 1.26              | 2.22        | 5.10         | 0.42       | 0.50      | 0.00       | 0.00          | 0.25      | 0.19    | 8.00   | 0.00       | 0.00        |
| 44  | 31 Oct  | 16.50       | 0.00      | 0.00        | 30.54       | 0.83                    | 0.84              | 1.40        | 5.98         | 0.45       | 0.70      | 0.00       | 0.00          | 0.16      | 0.28    | 9.00   | 0.00       | 0.00        |
| 45  | 07 Nov  | 9.00        | 0.00      | 0.00        | 22.76       | 0.67                    | 0.78              | 0.84        | 6.82         | 0.50       | 0.83      | 0.00       | 0.00          | 0.17      | 0.18    | 9.67   | 0.00       | 0.00        |
| 46  | 14 Nov  | 10.00       | 0.00      | 0.00        | 21.00       | 1.17                    | 0.59              | 0.63        | 1.75         | 0.41       | 0.83      | 0.00       | 0.00          | 0.14      | 0.16    | 10.50  | 0.00       | 0.00        |
| 47  | 21 Nov  | 8.00        | 0.00      | 0.00        | 30.30       | 1.50                    | 0.00              | 0.36        | 1.94         | 0.36       | 1.11      | 0.00       | 0.00          | 0.11      | 0.14    | 12.33  | 0.00       | 0.00        |
| 48  | 28 Nov  | 7.70        | 0.00      | 0.00        | 20.89       | 1.83                    | 0.00              | 0.00        | 4.17         | 0.19       | 1.53      | 0.00       | 0.00          | 0.09      | 0.11    | 9.83   | 0.00       | 0.00        |
| 49  | 05 Dec  | 8.08        | 0.00      | 0.00        | 17.29       | 2.17                    | 0.00              | 0.00        | 4.63         | 0.21       | 1.17      | 0.00       | 0.00          | 0.06      | 0.09    | 13.67  | 0.00       | 0.00        |
| 50  | 12 Dec  | 9.00        | 0.00      | 0.00        | 9.81        | 1.17                    | 0.00              | 0.00        | 3.53         | 0.07       | 0.49      | 0.00       | 0.00          | 0.03      | 0.08    | 16.50  | 0.00       | 0.00        |
| 51  | 19 Dec  | 5.00        | 0.00      | 0.00        | 14.87       | 0.67                    | 0.00              | 0.00        | 2.69         | 0.00       | 0.24      | 0.00       | 0.32          | 0.00      | 0.07    | 17.50  | 0.00       | 0.00        |
| 52  | 26 Dec  | 5.56        | 0.00      | 0.00        | 8.56        | 0.33                    | 0.00              | 0.00        | 2.12         | 0.00       | 0.09      | 0.00       | 0.38          | 0.00      | 0.05    | 18.83  | 0.00       | 0.00        |



**Figure 4.3a: Population dynamics of insects and mite pests associated with litchi ecosystem during 2019**



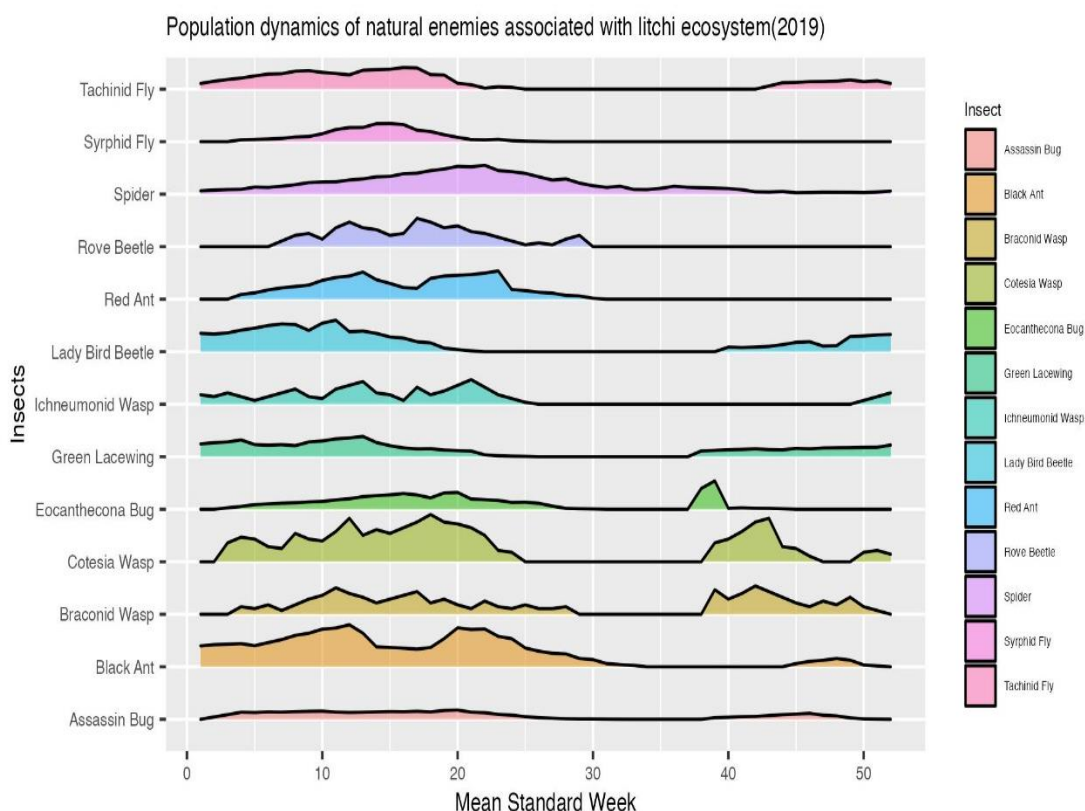
**Figure 4.3b: Population dynamics of minor pests population associated with litchi ecosystem during 2019**

Highest population was observed during 11 MSW (100.5 thrips/cm<sup>2</sup> twig) and lowest was recorded during 16 MSW (3.5 thrips/cm<sup>2</sup>). Litchi bug infestation was reported from 7<sup>th</sup> to 29<sup>th</sup> MSW. Highest and lowest population was recorded in 23<sup>rd</sup> (2.94) and 29<sup>th</sup> (0.05) MSW respectively. The infestation of semilooper was commenced at 9<sup>th</sup> MSW and continued till 22<sup>nd</sup> MSW. It recorded highest population in 15<sup>th</sup> MSW and the lowest population was recorded in 22<sup>nd</sup> MSW.

Among the natural enemies, Assasian bug population recorded in two phases. First phase was from 2<sup>nd</sup> MSW to 31<sup>st</sup> MSW and the second phase lasted from 39<sup>th</sup> to 51<sup>st</sup> MSW. The highest and lowest population was recorded on 20<sup>th</sup> (0.82) and 31<sup>st</sup> MSW (0.01) respectively. Black ant infestation was recorded during (1-33) and (45-51) MSW. The peak population was recorded in 12<sup>th</sup> MSW and lowest was during 33<sup>rd</sup> MSW. The infestation of braconid wasp observed in two phases. The first phase of attack was reported from 4<sup>th</sup> MSW to 28<sup>th</sup> MSW. Reappearance of braconid wasp was reported from 39<sup>th</sup> MSW to 51<sup>st</sup> MSW. The highest and lowest population was reported during 42<sup>nd</sup> (2.5) and 51<sup>st</sup> (0.33) MSW respectively. Cotesia wasp infestation occurred in several phases. First phase lasted from 3<sup>rd</sup> to 24<sup>th</sup> MSW while the 2<sup>nd</sup> and 3<sup>rd</sup> phase was recorded during (39-46) and (50-52) MSW respectively. The highest population was recorded during 18<sup>th</sup> MSW while lowest population was during 46<sup>th</sup> MSW respectively. Eocanthecona bug were reported at the starting *i.e.*, 3<sup>rd</sup> -30<sup>th</sup> MSW as well as end *i.e.*, 38<sup>th</sup> to 44<sup>th</sup> MSW of the year. 2.5 bugs/panicle was recorded during 39<sup>th</sup> MSW which was highest while 30<sup>th</sup> week recorded lowest population *i.e.*, 0.03 bugs/panicle.

Ichneumonid wasps were present throughout the year except during (26-49) MSW. It reached its peak during 21<sup>st</sup> MSW while lowest population was recorded during 30<sup>th</sup> MSW. The infestation of green lacewing recorded during (1-25) and (38-52) MSW. The highest and lowest population was 1.48 and 0.03 which were recorded during 4<sup>th</sup> and 25<sup>th</sup> MSW respectively. Red ant population was observed for the first-time during 4<sup>th</sup> MSW and it continued till 30<sup>th</sup> MSW. Highest red ant population was observed during 23 MSW (2.49) while lowest was recorded during 30 MSW (0.08). Two different phases of lady bird beetle infestation were recorded.

First phases infestation was from (1-21) and second phase infestation was from (40-52) MSW. Highest and lowest population was recorded during 11 and 21<sup>st</sup> MSW which was 2.78 and 0.07 beetles/panicle respectively. Rove beetle infestation was recorded during (7-29) MSW. It reached its peak at 17 MSW and lowest at 25 MSW. Syrphid fly was first recorded at 4<sup>th</sup> MSW and it continued till 26<sup>th</sup> MSW. It reached its peak during 15 MSW (1.6) while the lowest was during 26 MSW (0.02). Spider was observed throughout the year. It reached its peak during 22<sup>nd</sup> MSW while lowest was during 45<sup>th</sup> MSW. Tachinid fly was recorded throughout the year except during (25-42) MSW. Highest population was recorded during 16<sup>th</sup> MSW and lowest was during 24<sup>th</sup> MSW.



**Figure 4.4: Population dynamics of natural enemies associated with litchi ecosystem during 2019**

**Table 4.6: Population dynamics of natural enemies associated with litchi during 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

| MSW | Green lacewing | Spider | Lady bird beetle | Tachinid fly | Braconid wasp | Syrphid fly | Eocanthecona bug | Assasian bug | Black ant | Cotesia wasp | Red ant | Ichneumonid wasp | Rove beetle |
|-----|----------------|--------|------------------|--------------|---------------|-------------|------------------|--------------|-----------|--------------|---------|------------------|-------------|
| 1   | 1.13           | 0.30   | 1.62             | 0.50         | 0.00          | 0.00        | 0.00             | 0.00         | 1.84      | 0.00         | 0.00    | 0.83             | 0.00        |
| 2   | 1.24           | 0.36   | 1.56             | 0.70         | 0.00          | 0.00        | 0.00             | 0.21         | 1.95      | 0.00         | 0.00    | 0.67             | 0.00        |
| 3   | 1.30           | 0.41   | 1.66             | 0.85         | 0.00          | 0.00        | 0.13             | 0.41         | 1.99      | 1.67         | 0.00    | 1.00             | 0.00        |
| 4   | 1.48           | 0.43   | 1.90             | 0.98         | 0.67          | 0.16        | 0.25             | 0.63         | 2.04      | 2.17         | 0.42    | 0.67             | 0.00        |
| 5   | 1.07           | 0.63   | 2.08             | 1.16         | 0.50          | 0.20        | 0.41             | 0.60         | 1.86      | 2.00         | 0.56    | 0.33             | 0.00        |
| 6   | 1.02           | 0.60   | 2.31             | 1.33         | 0.83          | 0.23        | 0.47             | 0.65         | 2.13      | 1.33         | 0.82    | 0.67             | 0.00        |
| 7   | 1.07           | 0.70   | 2.45             | 1.36         | 0.33          | 0.29        | 0.53             | 0.63         | 2.40      | 1.17         | 1.00    | 1.00             | 0.50        |
| 8   | 0.98           | 0.83   | 2.40             | 1.58         | 0.83          | 0.41        | 0.58             | 0.68         | 2.77      | 2.50         | 1.12    | 1.33             | 1.00        |
| 9   | 1.30           | 1.02   | 1.88             | 1.63         | 1.33          | 0.45        | 0.65             | 0.70         | 2.96      | 2.00         | 1.24    | 0.67             | 1.17        |
| 10  | 1.39           | 1.07   | 2.52             | 1.48         | 1.67          | 0.70        | 0.69             | 0.72         | 3.32      | 1.83         | 1.66    | 0.50             | 0.67        |
| 11  | 1.58           | 1.09   | 2.78             | 1.38         | 2.33          | 1.07        | 0.83             | 0.63         | 3.42      | 2.67         | 1.92    | 1.33             | 1.67        |
| 12  | 1.66           | 1.25   | 1.76             | 1.26         | 1.83          | 1.24        | 0.93             | 0.60         | 3.71      | 3.83         | 2.04    | 1.67             | 2.17        |
| 13  | 1.79           | 1.35   | 1.82             | 1.66         | 1.50          | 1.25        | 1.11             | 0.62         | 2.97      | 2.33         | 2.39    | 2.00             | 1.67        |
| 14  | 1.25           | 1.53   | 1.61             | 1.72         | 1.00          | 1.58        | 1.20             | 0.65         | 1.76      | 2.83         | 1.72    | 1.00             | 1.50        |
| 15  | 0.98           | 1.57   | 1.30             | 1.75         | 1.33          | 1.60        | 1.27             | 0.68         | 1.70      | 2.50         | 1.39    | 0.83             | 1.00        |
| 16  | 0.78           | 1.80   | 1.20             | 1.90         | 1.67          | 1.50        | 1.39             | 0.67         | 1.64      | 3.00         | 1.03    | 0.33             | 1.17        |
| 17  | 0.69           | 1.85   | 0.88             | 1.87         | 2.00          | 1.01        | 1.26             | 0.71         | 1.56      | 3.50         | 0.97    | 1.50             | 2.50        |
| 18  | 0.71           | 2.08   | 0.78             | 1.28         | 1.00          | 0.89        | 1.00             | 0.65         | 1.70      | 4.17         | 1.83    | 0.83             | 2.17        |
| 19  | 0.59           | 2.22   | 0.32             | 1.25         | 1.33          | 0.61        | 1.44             | 0.78         | 2.48      | 3.50         | 2.04    | 1.17             | 1.67        |
| 20  | 0.54           | 2.45   | 0.19             | 0.52         | 0.83          | 0.38        | 1.48             | 0.82         | 3.43      | 3.33         | 2.11    | 1.67             | 1.83        |
| 21  | 0.50           | 2.41   | 0.07             | 0.39         | 0.50          | 0.18        | 0.90             | 0.63         | 3.29      | 3.00         | 2.17    | 2.17             | 1.33        |
| 22  | 0.17           | 2.55   | 0.00             | 0.09         | 1.17          | 0.16        | 0.85             | 0.58         | 3.33      | 2.33         | 2.30    | 1.50             | 1.17        |
| 23  | 0.09           | 2.08   | 0.00             | 0.21         | 0.67          | 0.20        | 0.78             | 0.43         | 2.68      | 1.00         | 2.49    | 0.83             | 0.83        |
| 24  | 0.05           | 1.98   | 0.00             | 0.15         | 0.50          | 0.09        | 0.60             | 0.37         | 2.48      | 0.83         | 0.85    | 0.50             | 0.50        |
| 25  | 0.03           | 1.83   | 0.00             | 0.00         | 0.83          | 0.04        | 0.63             | 0.23         | 1.66      | 0.00         | 0.76    | 0.17             | 0.17        |
| 26  | 0.00           | 1.53   | 0.00             | 0.00         | 0.50          | 0.02        | 0.53             | 0.14         | 1.38      | 0.00         | 0.61    | 0.00             | 0.33        |

**Table 4.6: Contd...**

| <b>MSW</b> | <b>Green lacewing</b> | <b>Spider</b> | <b>Lady bird beetle</b> | <b>Tachinid fly</b> | <b>Braconid wasp</b> | <b>Syrphid fly</b> | <b>Eocanthecona bug</b> | <b>Assasian bug</b> | <b>Black ant</b> | <b>Cotesia wasp</b> | <b>Red ant</b> | <b>Ichneumonid wasp</b> | <b>Rove beetle</b> |
|------------|-----------------------|---------------|-------------------------|---------------------|----------------------|--------------------|-------------------------|---------------------|------------------|---------------------|----------------|-------------------------|--------------------|
| 27         | 0.00                  | 1.24          | 0.00                    | 0.00                | 0.50                 | 0.00               | 0.28                    | 0.09                | 1.19             | 0.00                | 0.53           | 0.00                    | 0.17               |
| 28         | 0.00                  | 1.35          | 0.00                    | 0.00                | 0.67                 | 0.00               | 0.08                    | 0.05                | 1.13             | 0.00                | 0.33           | 0.00                    | 0.67               |
| 29         | 0.00                  | 0.98          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.05                    | 0.03                | 0.73             | 0.00                | 0.28           | 0.00                    | 1.00               |
| 30         | 0.00                  | 0.74          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.03                    | 0.03                | 0.63             | 0.00                | 0.08           | 0.00                    | 0.00               |
| 31         | 0.00                  | 0.60          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.01                | 0.28             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 32         | 0.00                  | 0.70          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.19             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 33         | 0.00                  | 0.42          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.13             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 34         | 0.00                  | 0.40          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.00             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 35         | 0.00                  | 0.51          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.00             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 36         | 0.00                  | 0.70          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.00             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 37         | 0.00                  | 0.60          | 0.00                    | 0.00                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.00             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 38         | 0.51                  | 0.57          | 0.00                    | 0.00                | 0.00                 | 0.00               | 1.83                    | 0.00                | 0.00             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 39         | 0.56                  | 0.53          | 0.00                    | 0.00                | 2.17                 | 0.00               | 2.50                    | 0.14                | 0.00             | 1.67                | 0.00           | 0.00                    | 0.00               |
| 40         | 0.62                  | 0.50          | 0.40                    | 0.00                | 1.33                 | 0.00               | 0.09                    | 0.18                | 0.00             | 2.00                | 0.00           | 0.00                    | 0.00               |
| 41         | 0.65                  | 0.39          | 0.37                    | 0.00                | 1.83                 | 0.00               | 0.13                    | 0.23                | 0.00             | 2.67                | 0.00           | 0.00                    | 0.00               |
| 42         | 0.70                  | 0.21          | 0.40                    | 0.00                | 2.50                 | 0.00               | 0.09                    | 0.25                | 0.00             | 3.50                | 0.00           | 0.00                    | 0.00               |
| 43         | 0.63                  | 0.19          | 0.47                    | 0.28                | 2.00                 | 0.00               | 0.08                    | 0.33                | 0.00             | 3.83                | 0.00           | 0.00                    | 0.00               |
| 44         | 0.60                  | 0.24          | 0.62                    | 0.56                | 1.50                 | 0.00               | 0.05                    | 0.41                | 0.00             | 1.33                | 0.00           | 0.00                    | 0.00               |
| 45         | 0.74                  | 0.13          | 0.83                    | 0.60                | 1.00                 | 0.00               | 0.00                    | 0.46                | 0.28             | 1.17                | 0.00           | 0.00                    | 0.00               |
| 46         | 0.70                  | 0.14          | 0.88                    | 0.66                | 0.67                 | 0.00               | 0.00                    | 0.53                | 0.48             | 0.50                | 0.00           | 0.00                    | 0.00               |
| 47         | 0.77                  | 0.17          | 0.50                    | 0.67                | 1.17                 | 0.00               | 0.00                    | 0.37                | 0.58             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 48         | 0.79                  | 0.17          | 0.53                    | 0.70                | 0.83                 | 0.00               | 0.00                    | 0.30                | 0.73             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 49         | 0.80                  | 0.16          | 1.34                    | 0.81                | 1.50                 | 0.00               | 0.00                    | 0.13                | 0.58             | 0.00                | 0.00           | 0.00                    | 0.00               |
| 50         | 0.83                  | 0.14          | 1.39                    | 0.66                | 0.67                 | 0.00               | 0.00                    | 0.04                | 0.17             | 0.83                | 0.00           | 0.33                    | 0.00               |
| 51         | 0.84                  | 0.19          | 1.48                    | 0.73                | 0.33                 | 0.00               | 0.00                    | 0.02                | 0.08             | 1.00                | 0.00           | 0.67                    | 0.00               |
| 52         | 1.03                  | 0.28          | 1.52                    | 0.50                | 0.00                 | 0.00               | 0.00                    | 0.00                | 0.00             | 0.67                | 0.00           | 1.00                    | 0.00               |

Few previous literatures in agreement with our present study are collected and cited below. Boopathi *et al.*, 2011 reported that population of Litchi stink bug, *Tessaritoma papillosa*, was found to be highest in the summer, moderate during monsoon season, and lowest in the winter. Menzel (2002) claims that the litchi erinose mite, *Aceria litchii* (Keifer), is a significant pest of litchi (*Litchi chinensis* Sonn) grown in semi-humid tropical regions at higher elevations, often in Asia. Hameed *et al.* (1992) revealed that Litchi erineum mite destroyed leaves, inflorescences, and young fruits all year round and the highest population was during April-May, while the lowest population was observed during November - December. Hameed *et al.* (1999) discovered that the leaf roller was particularly destructive during the onset of new flush and also saw the infesting of leaves during August and November, but the leaf roller was not seen during the rest of the year. Chakraborty and Samanta (2005) reported the highest incidence (48.00%) of, *Platyepela aprobola* Meyer (litchi leaf roller) in West Bengal in October. Lall and Mallik (1976) reported that leaf rollers breed between August and February on litchi leaves. During November, moth populations reached their peak (0.71 / leaf) while in January they reached their lowest (0.20 / leaf). Nair and Sahoo (2006b) found that the fruit borer, *C. cramerella*, infests litchi fruit (from March to May) and leaves (from July to November). Further, they reported that raw and ripened fruits dropped between 26.0 and 89.0% because of this pest. Bhatia and Gupta (2003) found that *C. cramerella* caused 10 to 50 per cent damage to litchi trees in six districts of Himachal Pradesh during the nine-year survey between 1991-1999. Bhatia *et al.* (2000) observed that, in the two years studied, borer incidence ranged between 13.6% and 64.9%. Hameed *et al.* (1992) observed that *Conopomorpha sinensis* caused most damage to fruits during May and July, and its population was highest in August. The population was not observed in the orchards from October to March, but was observed again in April. Hameed *et al.* (1999) recorded moderate to severe infestations of bark-eating caterpillars that damaged stems and shoots. There was a high infestation between August and October, and a moderate infestation in other months. According to Singh (1971) Populations of the weevil *Mylocerus discolor* Boh and *M. undecimpustulatus* Faust were largest during November -February and smallest during April-July.

#### **4.2. Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 and 2019 at Pantnagar, Uttarakhand**

The mean population of different insect pest recorded with respect to different mean standard weeks were further correlated with different prevailing weather parameters to understand the impact of these abiotic factors on insect pest population. The Pearson's co-efficient value (R Value) obtained for different insect pest during the year 2018 and 2019 were represented in **Table 4.7** and **Table 4.8**.

##### **4.2.1. Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 at Pantnagar, Uttarakhand**

The mean population of different insect pest and their associated natural enemies were recorded and correlated with different weather parameters to study the effect of different abiotic factors on insect pest population. The Pearson's correlation co-efficient (R Value) obtained by correlating the insect pest population with different weather parameters for the year 2018 were presented in **Table 4.7**.

The mean population of bag worms had a significant negative correlation with maximum, minimum temperature and sunshine hour with r values -0.805, -0.758 and -0.726 respectively. Whereas, minimum RH had a significantly positive correlation with bag worm with r value 0.838. Maximum RH and Rainfall had a positive and negative correlation with bag worm population with r values 0.453 and -0.007 respectively. Bark eating caterpillar had positive correlation with maximum temperature, minimum temperature and sunshine hours with r values 0.522, 0.567 and 0.532 respectively. However, a negative correlation of bark eating caterpillars were found with maximum RH, minimum RH and rainfall with r values - 0.705, -0.889 and -0.375 respectively. Similar results were also observed in case of citrus Aphids. A significant positive correlation was recorded between the mean population of citrus aphids with maximum temperature, minimum temperature and sunshine hour with r values 0.969, 0.915 and 0.898 respectively. Whereas, a significant negative correlation was found with maximum RH (-0.705) and minimum RH (-0.889). Negative correlation of rainfall (-0.375) was found with citrus aphids. The mean population of gundhi bugs had significant positive correlation with maximum temperature, minimum temperature and

significant negative correlation with maximum RH with r values 0.846, 0.672 and 0.764 respectively. Positive correlation of gundhi bug was found with minimum RH, rainfall and sunshine hours with r values 0.0, 0.11 and 0.462 respectively.

Jewel bugs had positive correlation with minimum temperature, maximum RH, minimum RH, rainfall with r values 0.488, 0.515, 0.421 and 0.607 respectively. However, negative correlation of jewel bug was found with maximum temperature (-0.118) and sunshine hour (-0.441). grey weevils had significant positive correlation with maximum temperature, minimum temperature and sunshine hours with r values 0.843, 0.668 and 0.853 respectively. Maximum and minimum RH had significant negative correlation with r values -0.59 and -0.896 respectively. Rainfall had negative correlation (-0.123) with the mean population of grey weevils. Leaf rollers had a significant positive correlation (0.338) with sunshine hours. Whereas, positive correlation was found with maximum temperature (0.028) and maximum RH (0.17). Negative correlation of leaf roller population was found with minimum temperature, minimum RH and rainfall with r values -0.195, -0.178 and -0.222 respectively. Litchi bugs had significant positive and negative correlation with maximum temperature (0.553) and maximum RH (-0.771). Positive correlation of litchi bug was found with minimum temperature (0.087) and sunshine hours (0.444). Negative correlation was found between mean population of litchi bug with minimum RH and rainfall with r values -0.457 and -0.051 respectively.

Litchi fruit borer had significantly positive and positive correlation with maximum temperature, minimum temperature and sunshine hours with r values 0.598, 0.191 and 0.448 respectively. Significantly negative correlation was found between fruit borer population and maximum RH (-0.658), minimum RH (-0.357) and rainfall (-0.104). Litchi mite had a significant positive correlation with maximum temperature, minimum temperature and sunshine hours with r values 0.689, 0.59 and 0.312 respectively. However, significant negative correlation of mite was found with maximum and minimum RH with r values -0.712 and 0.303 respectively. Rainfall had a positive correlation (0.074) with litchi mite. Mango leaf hopper attacking to the litchi plants had a significant positive and significant negative correlation with sunshine hours, minimum temperature, minimum RH and rainfall with r values 0.425, -0.28, -

0.497 and -0.315 respectively. However, Minimum temperature was positively correlated and negatively correlated with maximum temperature and maximum RH with r values 0.039 and -0.139 respectively. The correlation values obtained for mealy bug were 0.376, 0.22, -0.22, -0.333, -0.012 and 0.46 for maximum temperature, minimum temperature, maximum RH, minimum RH, rainfall and sunshine hours respectively.

The mean population of scale insects recorded during the period of study had a significant negative correlation with maximum temperature (-0.525), minimum temperature (-0.68), minimum RH (-0.329) and RH (-0.492). Maximum RH and sunshine hours had a positive correlation with scale insect with r values 0.158 and 0.156 respectively. Semiloopers had a significantly negative and positive correlation with minimum temperature and maximum RH with r values -0.704 and 0.612 respectively. Whereas, the r values obtained for other weather parameters viz. maximum temperature, minimum RH, rainfall and sunshine hours were -0.434, 0.046, -0.027 and -0.112 respectively. Stink bugs had significant negative correlation with maximum and minimum temperature and significant positive correlation with maximum RH with r values -0.273, -0.366 and 0.321 respectively. However, the r values obtained with minimum RH, rainfall and sunshine hours were -0.03, -0.242 and 0.09 respectively. Thrips had a significantly negative correlation with maximum temperature (-0.453), minimum temperature (-0.61) and rainfall (-0.358). Correlation co-efficient (r values) obtained for maximum RH, minimum RH and sunshine hours were 0.241, -0.263 and 0.119 respectively. Similarly, the r values obtained by correlating different weather parameters with mean population of tiger moth were 0.45, -0.546, -0.487, -0.386, 0.009 and 0.456 for maximum temperature, minimum temperature, maximum RH, minimum RH, rainfall and sunshine hours respectively.

Similar observations on the population of different natural enemies were taken and correlated with the weather parameters prevailing during the period of study to obtain the values of correlation co-efficient (r values). Amongst the natural enemies, Assasian bug and black ant had significant negative correlation with minimum temperature (-0.606, -0.306), minimum RH (-0.608, -0.528), rainfall (-0.588, -0.33) and significant positive correlation with sunshine hours (0.481 and 0.343). The population

**Table 4.7: Correlation coefficient of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 at Pantnagar, Uttarakhand**

| SI No                  | Insect pest             | WEATHER PARAMETERS |                    |                |                |               |                    |
|------------------------|-------------------------|--------------------|--------------------|----------------|----------------|---------------|--------------------|
|                        |                         | Maximum Temp. (°C) | Minimum Temp. (°C) | Maximum RH (%) | Minimum RH (%) | Rainfall (mm) | Sunshine Hour (hr) |
| 1                      | Bag Worm                | -0.805**           | -0.758*            | 0.453          | 0.838**        | -0.007        | -0.726*            |
| 2                      | Bark Eating Caterpillar | 0.522              | 0.567              | -0.092         | -0.571         | -0.001        | 0.532              |
| 3                      | Citrus Aphid            | 0.969**            | 0.915**            | -0.705*        | -0.889**       | -0.375        | 0.898**            |
| 4                      | Gundhi Bug              | 0.846**            | 0.672**            | -0.764**       | 0.01           | 0.11          | 0.462              |
| 5                      | Jewel Bug               | -0.118             | 0.488              | 0.515          | 0.421          | 0.607         | -0.441             |
| 6                      | Grey weevil             | 0.843**            | 0.668**            | -0.59*         | -0.896**       | -0.123        | 0.853**            |
| 7                      | Leaf Roller             | 0.028              | -0.195             | 0.17           | -0.178         | -0.222        | 0.338*             |
| 8                      | Litchi Bug              | 0.553*             | 0.087              | -0.771**       | -0.427         | -0.051        | 0.444              |
| 9                      | Litchi Fruit Borer      | 0.598**            | 0.191              | -0.658**       | -0.357         | -0.104        | 0.448              |
| 10                     | Litchi Mite             | 0.689**            | 0.59**             | -0.712**       | -0.303*        | 0.074         | 0.312*             |
| 11                     | Mango leaf Hopper       | 0.039              | -0.28*             | -0.139         | -0.497**       | -0.315*       | 0.425**            |
| 12                     | Mealy bug               | 0.376              | 0.22               | -0.022         | -0.333         | -0.012        | 0.46               |
| 13                     | Scale Insect            | -0.525**           | -0.68**            | 0.158          | -0.329*        | -0.492**      | 0.156              |
| 14                     | Semilooper              | -0.434             | -0.704**           | 0.612*         | 0.406          | -0.027        | -0.112             |
| 15                     | Stink Bug               | -0.273*            | -0.366**           | 0.321*         | -0.03          | -0.242        | 0.09               |
| 16                     | Thrips                  | -0.453**           | -0.61**            | 0.241          | -0.263         | -0.358**      | 0.119              |
| 17                     | Tiger Moth              | 0.45               | -0.546             | -0.487         | -0.386         | 0.009         | 0.456              |
| <b>NATURAL ENEMIES</b> |                         |                    |                    |                |                |               |                    |
| 1                      | Assasian Bug            | -0.209             | -0.606**           | -0.119         | -0.608**       | -0.588**      | 0.481**            |
| 2                      | Black Ant               | 0.039              | -0.306*            | -0.376**       | -0.528**       | -0.33*        | 0.343*             |
| 3                      | Braconid Wasp           | -0.063             | -0.445**           | -0.09          | -0.483**       | -0.545**      | 0.552**            |
| 4                      | Cotesia Wasp            | -0.041             | -0.583**           | -0.277         | -0.517**       | -0.523**      | 0.552**            |
| 5                      | Eocanthecona Bug        | 0.493**            | 0.29*              | -0.755**       | -0.5**         | -0.085        | 0.342*             |
| 6                      | Lace Wing Bug           | -0.791**           | -0.942**           | 0.417**        | -0.209         | -0.593**      | 0.065              |
| 7                      | Ichneumonid Wasp        | 0.235              | -0.029             | -0.029         | -0.404         | -0.038        | 0.379              |
| 8                      | Lady bird Beetle        | -0.662**           | -0.855**           | 0.346*         | -0.31*         | -0.502**      | 0.117              |
| 9                      | Red Ant                 | -0.13              | -0.29              | 0.111          | -0.146         | 0.174         | 0.375              |
| 10                     | Rove Beetle             | 0.21               | -0.26              | -0.315         | -0.424         | -0.018        | 0.407              |
| 11                     | Spider                  | 0.667**            | 0.393**            | -0.875**       | -0.584**       | -0.132        | 0.499**            |
| 12                     | Syrphid Fly             | 0.044              | -0.306*            | -0.255         | -0.573**       | -0.331*       | 0.411**            |
| 13                     | Tachnid Fly             | -0.294*            | -0.672**           | -0.136         | -0.645**       | -0.583**      | 0.414**            |

\*5 per cent level of significance, \*\* 1 per cent level of significance and \*\*\* 10 per cent level of significance

of black ants also showed a negative correlation with maximum RH (-0.376). Assasian bugs had a significant negative correlation with maximum temperature (-0.209) and maximum RH (-0.119). However, black ants had a positive correlation with maximum temperature with  $r$  value 0.039. Both the braconid wasp and cotesia wasp had significantly negative correlation with maximum temperature (-0.445, - 0.583), minimum RH (-0.483, -0.517), rainfall (-0.545, -0.523) and significant positive correlation with sunshine hour (0.552, 0.552). Whereas, negative correlation of both the wasp were found with maximum temperature (-0.063, -0.041) and maximum RH (-0.09, 0.277).

Eocantecona bugs showed positive correlation with maximum temperature (0.493), minimum temperature (0.29), sunshine hours (0.342). However, significant negative correlation of eocantecona bug was found with maximum RH (-0.755) and minimum RH (-0.5). Rainfall showed a negative correlation (-0.085) with the bug population.

Lace wing bugs had a significantly negative correlation with maximum temperature, minimum temperature and rainfall with  $r$  values -0.791, -0.942 and -0.593 respectively. Whereas a significantly positive correlation of maximum RH (0.417) was found with the green lace wing bugs. The correlation coefficient values obtained for maximum RH and sunshine hours were -0.209 and 0.065 respectively. The  $r$  values obtained in relation with maximum temperature, minimum temperature, maximum RH, minimum RH, rainfall and sunshine hours were 0.235, -0.029, -0.029, -0.404, -0.038 and 0.379 respectively. The weather parameters *viz.* maximum temperature, minimum temperature and minimum RH and rainfall had significant negative correlation with the lady bird beetle population with  $r$  values -0.662, -0.855, -0.31 and -0.502 respectively. However, a significant positive and positive correlation of the beetle population was found with maximum RH (0.346) and rainfall (0.117). The  $r$  values obtained by correlating the red ant population with different weather parameters were -0.13, -0.29, 0.111, -0.146, 0.174 and 0.375 and  $r$  values for rove beetle were 0.21, -0.26, -0.315, -0.424, -0.018 and 0.407 for maximum temperature, minimum temperature, maximum RH, minimum RH, rainfall and sunshine hours respectively. The population of spiders had significantly positive correlation with maximum temperature, minimum

temperature and rainfall with  $r$  values 0.667, 0.393 and 0.499 respectively. However, Relative humidity had significantly negative correlation with the spider population and the  $r$  values obtained were -0.875 for maximum RH and -0.584 for minimum RH. The correlation value for rainfall was -0.132. Minimum temperature, minimum RH and rainfall had a significantly negative correlation with the syrphid fly population with  $r$  values -0.306, -0.573 and -0.331 respectively. Whereas, the  $r$  values obtained for the remaining weather parameters were 0.044, -0.255 for maximum temperature and maximum RH respectively. Sunshine hour had a significantly positive correlation with syrphid flies and tachinid flies with  $r$  values 0.411 and 0.414 respectively. All the remaining weather parameters had negative correlation with the tachinid fly population. Significantly negative correlation was found with maximum temperature, minimum temperature, minimum RH and rainfall with  $r$  values -0.294, -0.672, -0.645 and -0.583 respectively. Maximum RH had negative correlation (-0.136) with the tachinid fly population.

#### **4.2.2. Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2019 at Pantnagar, Uttarakhand**

The mean population of different insect pest and their associated natural enemies were recorded and correlated with different weather parameters to study the effect of different abiotic factors on insect pest population. The Pearson's correlation co-efficient ( $r$  Value) obtained by correlating the insect pest population with different weather parameters for the year 2018 were presented in **Table 4.8**.

The mean population of bag worms had a significant negative correlation with maximum, minimum temperature and rainfall with  $r$  values -0.716, -0.792 and -0.471 respectively, whereas, maximum RH, minimum RH and sunshine hour had recorded correlation with bag worm with  $r$  value of 0.465, -0.043 and -0.003 respectively. Bark eating caterpillar had significantly negative correlation with maximum temperature, minimum temperature and rainfall with  $r$  values -0.611, -0.669 and -0.371 respectively. However, significantly positive correlation of bark eating caterpillars was found with maximum RH with  $r$  value 0.506 whereas minimum RH and sunshine hour recorded a correlation value of 0.018 and -0.01 with bark eating caterpillars, respectively. Mean

population of citrus aphids recorded significant negative correlation with maximum temperature and minimum temperature with r value of -0.439 and -0.506 respectively whereas maximum RH, minimum RH, rainfall and sunshine hour with r values 0.239, -0.169, -0.267 and 0.034 respectively. Gundhi bug had significant negative correlation with minimum temperature, minimum RH and rainfall with r values -0.389, -0.571 and -0.599 respectively. Whereas, negative correlation (-0.112) was found with maximum RH. Non-significant positive correlation of gundhi bug was found with maximum temperature and sunshine hours with r values 0.095 and 0.281 respectively.

Jewel bug recorded positive correlation with maximum temperature (0.516), minimum temperature (0.16) and sunshine hour (0.502) while it recorded negative correlation with maximum RH (-0.404), minimum RH (-0.535) and rainfall (0.27). Similar results were also obtained with grey weevil. It recorded positive correlation with maximum temperature (0.103) and sunshine hour (0.083) whereas negative correlation was found with minimum temperature (-0.134), maximum RH (-0.187) and minimum RH (-0.289) and rainfall (-0.011). Leaf roller showed non-significant positive correlation with every weather parameter except maximum RH (0.286) which showed positive correlation with the mean population of leaf roller. Significant correlation was found between maximum temperature (0.681), maximum RH (-0.742) with litchi bug whereas non-significant correlation was found between minimum temperature (0.388), minimum RH (-0.342), rainfall (-0.147), and sunshine hour (0.389). Litchi fruit borer had significant positive correlation with maximum temperature and sunshine hours with r value 0.724 and 0.653 respectively. Whereas, significant negative correlation was found with maximum and minimum RH with r values -0.69 and -0.686 respectively.

Maximum temperature (0.655), minimum temperature (0.648), maximum RH (-0.495) and rainfall (0.305) had a significant correlation with mean population of litchi mite while minimum RH (-0.123) and sunshine hour (0.102) showed non-significant correlation. Mango leaf hopper had a significant positive correlation with maximum temperature (0.802) and sunshine hour (0.434) whereas significant negative correlation was found between maximum RH (-0.768) and minimum RH (-0.489). Minimum temperature and rainfall had also correlation with mean population of mango leaf hopper with r value of 0.247 and -0.279 respectively. Mean population of mealy bug

showed non-significant correlation with all the weather parameters except maximum RH (0.458) which had significantly positive correlation. Significant correlation was found between maximum temperature (0.343), maximum RH (- 0.635), minimum RH (-0.717), rainfall (-0.322) and sunshine hour (0.546) with mean population of scale insect while there was no significant correlation between minimum temperature (-0.064) and scale insect population. All the weather parameters showed non-significant negative correlation with mean population of semilopper. The r values obtained were -0.062, -0.134, -0.014, -0.204, -0.157 and -0.036 for maximum temperature, minimum temperature, maximum RH, minimum RH, rainfall and sunshine hours, respectively. Stink bug showed negative correlation with maximum temperature (-0.321), minimum temperature (- 0.446), maximum RH (0.341) and rainfall (-0.327) whereas non-significant correlation was found with minimum RH (-0.03) and sunshine hour (0.144). There was significant negative correlation found between maximum temperature (-0.406), minimum temperature (-0.608), minimum RH (-0.302) and rainfall (-0.367) with mean population of thrips while maximum RH (0.214) and sunshine hour (0.173) showed non-significant correlation. Tiger moth showed significantly negative correlation with maximum RH (-0.697) and minimum RH (-0.621) while significantly positive correlation was found with sunshine hour (0.673). It also showed non- significant correlation with maximum temperature (0.284), minimum temperature (-0.452) and rainfall (-0.04).

Amongst the natural enemies, five natural enemies *viz.* assasian bug, black ant, braconid wasp, cotesia wasp and eocanthecona bug had significant negative correlation with maximum and minimum RH. The r values obtained for maximum RH were -0.508, -0.465, -0.383, -0.602, -0.488 and r values obtained for minimum RH were -0.757, -0.505, -0.633, -0.735, -0.516 respectively. However, sunshine hour had significant positive correlation with assasian bug (0.615), black ant (0.356), braconid wasp (0.633), cotesia wasp (0.672) and eocanthecona bug (0.456). Rainfall had significant negative correlation with assasian bug, black ant, braconid wasp and cotesia wasp with r values -0.515, -0.311, -0.421 and -0.458 respectively. Whereas, non-significant negative correlation (-0.303) was found with eocanthecona bug. All the five natural enemies had non-significant negative correlation with minimum temperature

with r values -0.258, -0.11, -0.177, -0.168 and -0.022 for assasian bug, black ant, braconid wasp, cotesia wasp and eocanthecona bug respectively. Significant positive correlation of maximum temperature was found with braconid wasp (0.274), cotesia wasp (0.285) and eocanthecona bug (0.326). Non-significant positive correlation of assasian bug and black ant was found with maximum temperature with r values 0.173, 0.139 respectively.

Lacewing bugs had significant negative correlation with maximum temperature, minimum temperature, minimum RH, rainfall with r values -0.474, -0.804, -0.479 and -0.622 respectively. A significant correlation of sunshine hour with r value 0.339 was found with lace wing bugs. Whereas, maximum RH had negative non-significant correlation (0.071) with lace wing bugs. Ichneumon wasp had negative significant correlation with maximum RH, minimum RH and rainfall with r values -0.538, -0.551, -0.365 respectively. Sunshine hour had significant positive correlation (0.415) with ichneumon wasp. Non- significant positive and negative correlation of ichneumon wasp was found with maximum and minimum temperature with r value 0.106 and -0.204 respectively. Lady bird beetle had significant negative correlation with maximum temperature, minimum temperature, minimum RH and rainfall with r values -0.556, -0.804, -0.398 and -0.522 respectively. Maximum RH and sunshine hours had positive correlation with the beetle population with r value 0.205 and 0.217 respectively. A significantly negative correlation of red ant population was found with maximum RH, minimum RH and rainfall with r value -0.501, -0.525 and -0.397 respectively. Significantly positive correlation (0.673) was found with sunshine hours. Whereas, non-significant positive and negative correlation with r values 0.331, -0.122 was found with maximum and minimum temperature. Sunshine hour had significantly positive correlation with rove beetle, spider, syrphid fly and tachinid fly. The r values obtained were 0.631, 0.401, 0.469 and 0.453 respectively.

Rove beetles and spiders were found in a significantly negative correlation with maximum RH (-0.58, -0.856) and minimum RH (-0.549, -0.467). Non-significant positive correlation of rove beetle was found with maximum temperature (0.212) and negative correlation with minimum temperature (-0.272) and rainfall (-0.303). However, spiders had significant positive correlation with maximum temperature

(0.701), minimum temperature (0.51) and non-significant negative correlation (-0.015) with rainfall. Syrphid flies had significant negative correlation with minimum RH (-0.537) and negative correlation with minimum temperature (-0.147), maximum RH (-0.26) and rainfall (-0.213). Non-significant positive correlation (0.193) was found with maximum temperature. Tachinid flies had significantly negative correlation with minimum temperature (-0.518), minimum RH (-0.693) and rainfall (-0.51). However, non-significant negative correlation of tachinid fly was found with maximum temperature (-0.129) and maximum RH (-0.242).

Amongst the natural enemies, Spiders were found associated with different insect pest throughout the year. Maximum and minimum population of spiders *i.e.* 2.75/panicle and 0.22/panicle were reported during 22<sup>nd</sup> and 49<sup>th</sup> MSW respectively. Lady bird beetles were also reported in two phases on the crop. The beetle population was absent from 19<sup>th</sup> to 41<sup>st</sup> MSW. Highest and lowest population of lady bird beetles were observed on the crop during 10<sup>th</sup> and 18<sup>th</sup> MSW with a mean population of 2.67 beetles/panicle and 0.28 beetles/panicle respectively. Green lace wing bugs were found absent on the crop from 21<sup>st</sup> to 34<sup>th</sup> MSW. Highest mean population (1.62 bugs/panicle) of lace wing bugs were reported during 1<sup>st</sup> MSW. Whereas, lowest mean population of 0.18 bugs/panicle was reported on 20<sup>th</sup> MSW.

Assasian bug was present throughout the year except from 27<sup>th</sup> to 34<sup>th</sup> MSW. Peak population of assasian bugs *i.e.*, 1.25 bugs/panicle were reported during 12<sup>th</sup> MSW and least population of bugs, 0.03 bugs/panicle was reported during 35<sup>th</sup> MSW. Similarly, black ants were also observed on the litchi panicle throughout the year except 33<sup>rd</sup> to 46<sup>th</sup> MSW. The maximum and minimum population of black ants were reported during 22<sup>nd</sup> and 32<sup>nd</sup> MSW with 3.37 and 0.19 ants/panicle respectively. However, presence of red ants on the litchi panicle were reported from 7<sup>th</sup> to 26<sup>th</sup> MSW. Lowest mean population of red ants *i.e.*, 0.21/panicle were reported on 26<sup>th</sup> MSW. Whereas, the highest mean population of red ants, 2.08/panicle were recorded during 23<sup>rd</sup> and 12<sup>th</sup> MSW. The observations on the population of natural enemies viz. braconid wasp, cotesia wasp and ichneumonid wasp were taken by using yellow sticky trap. Braconid wasps were absent from 26<sup>th</sup> to 36<sup>th</sup> MSW. The maximum and minimum population of braconid wasps, 2.33 and 0.5 wasps/trap were reported during 41<sup>st</sup> and 1<sup>st</sup> MSW respectively.

**Table 4.8: Correlation coefficient of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2019 at Pantnagar, Uttarakhand**

| SI No                  | Insect pest             | WEATHER PARAMETERS |                    |                |                |               |                    |
|------------------------|-------------------------|--------------------|--------------------|----------------|----------------|---------------|--------------------|
|                        |                         | Maximum Temp. (°C) | Minimum Temp. (°C) | Maximum RH (%) | Minimum RH (%) | Rainfall (mm) | Sunshine Hour (hr) |
| 1                      | Bag Worm                | -0.716**           | -0.792**           | 0.465**        | -0.043         | -0.471**      | -0.003             |
| 2                      | Bark Eating Caterpillar | -0.611**           | -0.669**           | 0.506**        | 0.018          | -0.371**      | -0.01              |
| 3                      | Citrus Aphid            | -0.439**           | -0.506***          | 0.293*         | -0.169         | -0.267        | 0.034              |
| 4                      | Gundhi Bug              | 0.095              | -0.389*            | -0.112         | -0.571***      | -0.599***     | 0.281              |
| 5                      | Jewel Bug               | 0.516              | 0.16               | -0.404         | -0.535         | -0.27         | 0.502              |
| 6                      | Grey weevil             | 0.103              | -0.134             | -0.187         | -0.289         | -0.011        | 0.083              |
| 7                      | Leaf Roller             | 0.041              | 0.015              | 0.286*         | 0.1            | 0.115         | 0.028              |
| 8                      | Litchi Bug              | 0.681**            | 0.388              | -0.742**       | -0.342         | -0.147        | 0.389              |
| 9                      | Litchi Fruit Borer      | 0.724**            | 0.259              | -0.69**        | -0.686**       | -0.432        | 0.653*             |
| 10                     | Litchi Mite             | 0.655**            | 0.648**            | -0.495**       | -0.123         | 0.305*        | 0.102              |
| 11                     | Mango leaf Hopper       | 0.802**            | 0.247              | -0.768**       | -0.489**       | -0.279        | 0.434**            |
| 12                     | Mealy bug               | -0.159             | -0.401             | 0.458*         | -0.094         | -0.165        | 0.073              |
| 13                     | Scale Insect            | 0.343*             | -0.064             | -0.635**       | -0.717**       | -0.322*       | 0.546**            |
| 14                     | Semilooper              | -0.062             | -0.134             | -0.014         | -0.204         | -0.157        | -0.036             |
| 15                     | Stink Bug               | -0.321*            | -0.446**           | 0.341*         | -0.03          | -0.327*       | 0.144              |
| 16                     | Thrips                  | -0.406**           | -0.608**           | 0.214          | -0.302*        | -0.367**      | 0.173              |
| 17                     | Tiger Moth              | 0.284              | -0.452             | -0.697**       | -0.621*        | -0.04         | 0.673*             |
| <b>NATURAL ENEMIES</b> |                         |                    |                    |                |                |               |                    |
| 1                      | Assasian Bug            | 0.173              | -0.258             | -0.508***      | -0.757***      | -0.515***     | 0.615***           |
| 2                      | Black Ant               | 0.139              | -0.11              | -0.465***      | -0.505***      | -0.311*       | 0.356**            |
| 3                      | Braconid Wasp           | 0.274*             | -0.177             | -0.383**       | -0.633**       | -0.421**      | 0.633**            |
| 4                      | Cotesia Wasp            | 0.285*             | -0.168             | -0.602**       | -0.735**       | -0.458**      | 0.672**            |
| 5                      | Eocantecona Bug         | 0.326*             | -0.022             | -0.488**       | -0.516***      | -0.303        | 0.456**            |
| 6                      | Lace Wing Bug           | -0.474**           | -0.804**           | 0.071          | -0.479**       | -0.622**      | 0.339*             |
| 7                      | Ichneumon Wasp          | 0.106              | -0.204             | -0.538***      | -0.551***      | -0.365**      | 0.415**            |
| 8                      | Lady bird Beetle        | -0.556***          | -0.804***          | 0.205          | -0.398**       | -0.522***     | 0.217              |
| 9                      | Red Ant                 | 0.331              | -0.122             | -0.501**       | -0.525**       | -0.397*       | 0.673**            |
| 10                     | Rove Beetle             | 0.212              | -0.272             | -0.58**        | -0.549**       | -0.303        | 0.631**            |
| 11                     | Spider                  | 0.701**            | 0.51**             | -0.856**       | -0.467**       | -0.015        | 0.401**            |
| 12                     | Syrphid Fly             | 0.193              | -0.147             | -0.26          | -0.537**       | -0.213        | 0.469*             |
| 13                     | Tachnid Fly             | -0.129             | -0.518***          | -0.242         | -0.693***      | -0.51***      | 0.453***           |

\*5 per cent level of significance, \*\* 1 per cent level of significance and \*\*\* 10 per cent level of significance

Ichneumonid wasps were present from 1<sup>st</sup> MSW to 23<sup>rd</sup> MSW. The highest mean number of ichneumon wasp (1.83 wasps/trap) were recorded on 12<sup>th</sup> MSW. Whereas, lowest number of wasps (0.33/trap) were recorded on 1<sup>st</sup> and 19<sup>th</sup> MSW. Cotesia wasps were observed on the trap from 8<sup>th</sup> to 21<sup>st</sup> MSW and 37<sup>th</sup>- 43<sup>rd</sup> MSW. The highest and least population of cotesia wasps were reported during 39<sup>th</sup> and 43<sup>rd</sup> MSW with 4.33 and 1.00 wasps/trap respectively. Rove beetles were present from 10<sup>th</sup> to 27<sup>th</sup> MSW. The maximum and minimum population of rove beetles were reported during 21<sup>st</sup> and 27<sup>th</sup> MSW with 1.83 and 0.33 beetles/panicle. Tachnid flies and syrphid flies were also observed through-out the period of study except 23<sup>rd</sup>-39<sup>th</sup> MSW and 23<sup>rd</sup> to 48<sup>th</sup> MSW respectively. Peak population of both the flies were recorded during 16<sup>th</sup> and 13<sup>th</sup> MSW with a mean population of 1.68/ panicle and 1.29/panicle for tachnid flies and syrphid flies respectively. Whereas, lowest mean population *i.e.*, 0.18 and 0.06/panicle were reported during 40<sup>th</sup> and 49<sup>th</sup> MSW for tachnid flies and syrphid flies respectively. Eocanthecona bugs were present almost throughout the year except 43<sup>rd</sup> to 46<sup>th</sup> MSW. The mean population of eocanthecona bug was on peak *i.e.*, 1.07/panicle during 22<sup>nd</sup> MSW. Whereas, lowest mean population of 0.03 bugs/panicle were reported during 41<sup>st</sup> and 42<sup>nd</sup> MSW.

#### 4.2.3 Multiple linear regressions (MLR) for major insect pests

Multiple linear regression analyses were conducted to investigate the relationship between the population of insect pests and various environmental factors, including maximum temperature, minimum temperature, relative humidity, rainfall, sunshine hours, wind velocity, and evaporation. The estimated coefficient values for each independent variable and their associated P-values are presented in the accompanying tables. Specifically, **Table 4.9** and **Table 4.10** represent the results for the years 2018 and 2019, respectively.

For litchi fruit borer found the wind velocity was the sole variable that exhibited statistically significant effects at the 95% confidence level on the population dynamics of litchi fruit borer, while maximum temperature and maximum relative humidity showed significant effects at the 90% confidence level. These findings suggest that the population of litchi fruit borer is influenced by a combination of maximum temperature, maximum relative humidity, and wind velocity, with positive coefficients indicating that an increase in the values of these independent variables is associated

with an increase in the population of litchi fruit borer. The amount of variation in the population of litchi fruit borer that can be explained by the model, as indicated by the coefficient of determination ( $R^2$ ), is 70% or variation captured is  $R^2 = 70\%$ .

The findings from the analysis of the litchi bug dataset revealed that only evaporation was statistically significant at the 95% significance level, with the remaining variables exhibiting no significant association at either the 95% or 90% significance levels. Notably, the positive coefficient estimates of 1.12 for evaporation suggests that an increase in evaporation would lead to a corresponding increase in the population of insect pests. The analysis captured a considerable amount of the variation, with an R-squared value of 0.78.

The impact of wind velocity and evaporation on litchi mite population was found to be statistically significant at a 95% and 90% confidence level, respectively. The positive coefficient values of both variables indicate that an increase in wind velocity and evaporation leads to a corresponding increase in the population of the insect pest. The R-squared value of 0.77 indicates that these two factors explain 77% of the total variation in litchi mite population.

The study found that maximum temperature, sunshine hours, and evaporation had a statistically significant impact on the population of leaf roller, with a 95% confidence level. The positive coefficient values of maximum temperature and sunshine hours indicate that an increase in these variables leads to an increase in the population of the insect pest. However, the negative coefficient value of evaporation suggests that a decrease in evaporation results in a decrease in pest population. The R-squared value of 0.62 indicates that these three factors explain 62% of the total variation in leaf roller population.

Based on the statistical analysis at a 95% significance level, it was found that sunshine hour and wind velocity have a positive effect on the population of bark eating caterpillar, whereas evaporation has a negative effect. The coefficient values for sunshine hour and wind velocity were positive, indicating that an increase in these factors would lead to an increase in the population of the caterpillar. Conversely, the coefficient value for evaporation was negative, suggesting that a decrease in evaporation would result in a higher population of bark eating caterpillar. The model explains 70% of the variation in the population of bark eating caterpillar, as indicated by an R-squared value of 0.70.

**Table 4.9: Shows the coefficient of determination ( $r^2$ ) for the major insect pests of litchi in relation to weather parameters for the year 2018.**

| <b>LITCHI FRUIT BORER</b>      |             |                              |                              |                 |                 |                  |                        |                          |                     |                |
|--------------------------------|-------------|------------------------------|------------------------------|-----------------|-----------------|------------------|------------------------|--------------------------|---------------------|----------------|
| Variables                      | (Intercept) | Max. Temp<br>( $^{\circ}$ C) | MinTemp<br>( $^{\circ}$ C)   | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R <sup>2</sup> |
| Coefficient                    | -181.55     | 3.50                         | 0.38                         | 0.69            | 0.03            | 0.05             | 1.69                   | 2.02                     | -1.39               | 0.70           |
| p-value                        | 0.02        | 0.08                         | 0.63                         | 0.09            | 0.91            | 0.18             | 0.30                   | 0.05                     | 0.59                |                |
| <b>LITCHI BUG</b>              |             |                              |                              |                 |                 |                  |                        |                          |                     |                |
| Variables                      | (Intercept) | Max. Temp<br>( $^{\circ}$ C) | Min. Temp<br>( $^{\circ}$ C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R <sup>2</sup> |
| Coefficient                    | 18.01       | -0.52                        | 0.04                         | -0.04           | -0.02           | -0.01            | -0.05                  | -0.27                    | 1.12                | 0.78           |
| p-value                        | 0.08        | 0.11                         | 0.74                         | 0.33            | 0.49            | 0.24             | 0.85                   | 0.25                     | 0.03                |                |
| <b>LITCHI MITE</b>             |             |                              |                              |                 |                 |                  |                        |                          |                     |                |
| Variables                      | (Intercept) | Max. Temp<br>( $^{\circ}$ C) | Min. Temp<br>( $^{\circ}$ C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R <sup>2</sup> |
| Coefficient                    | 53.20       | -2.10                        | 1.52                         | -0.11           | -0.36           | 0.05             | 0.90                   | 2.96                     | 4.72                | 0.77           |
| p-value                        | 0.39        | 0.15                         | 0.17                         | 0.84            | 0.26            | 0.33             | 0.65                   | 0.01                     | 0.06                |                |
| <b>LEAF ROLLER</b>             |             |                              |                              |                 |                 |                  |                        |                          |                     |                |
| Variables                      | (Intercept) | Max. Temp<br>( $^{\circ}$ C) | Min. Temp<br>( $^{\circ}$ C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R <sup>2</sup> |
| Coefficient                    | -28.92      | 1.90                         | -0.50                        | -0.12           | 0.19            | 0.02             | 2.22                   | 0.77                     | -5.50               | 0.62           |
| p-value                        | 0.34        | 0.01                         | 0.37                         | 0.65            | 0.22            | 0.44             | 0.03                   | 0.18                     | 0.00                |                |
| <b>BARK EATING CATERPILLAR</b> |             |                              |                              |                 |                 |                  |                        |                          |                     |                |
| Variables                      | (Intercept) | Max. Temp<br>( $^{\circ}$ C) | Min. Temp<br>( $^{\circ}$ C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R <sup>2</sup> |
| Coefficient                    | -3.21       | 0.00                         | 0.05                         | 0.03            | 0.01            | 0.00             | 0.31                   | 0.29                     | -0.58               | 0.70           |
| p-value                        | 0.33        | 0.97                         | 0.40                         | 0.37            | 0.76            | 0.81             | 0.01                   | 0.00                     | 0.00                |                |

**Table 4.10: Shows the coefficient of determination ( $r^2$ ) for the major insect pests of litchi in relation to weather parameters for the year 2019.**

| <b>FRUIT BORER</b>             |           |                   |                   |                 |                 |                  |                        |                          |                     |      |
|--------------------------------|-----------|-------------------|-------------------|-----------------|-----------------|------------------|------------------------|--------------------------|---------------------|------|
| Variables                      | Intercept | Max. Temp<br>(°C) | Min. Temp<br>(°C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R2   |
| Coefficient                    | 38.07     | 0.14              | -0.29             | -0.42           | 0.22            | 0.00             | -1.10                  | -2.15                    | 3.80                | 0.44 |
| p-value                        | 0.64      | 0.95              | 0.86              | 0.35            | 0.67            | 0.99             | 0.59                   | 0.40                     | 0.32                |      |
| <b>LITCHI BUG</b>              |           |                   |                   |                 |                 |                  |                        |                          |                     |      |
| Variables                      | Intercept | Max. Temp<br>(°C) | Min. Temp<br>(°C) | Max. R.H<br>(%) | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R2   |
| Coefficient                    | 4.40      | -0.07             | -0.01             | -0.03           | 0.00            | 0.00             | 0.01                   | -0.02                    | 0.27                | 0.91 |
| p-value                        | 0.16      | 0.37              | 0.90              | 0.10            | 0.84            | 1.00             | 0.86                   | 0.86                     | 0.09                |      |
| <b>LITCHI MITE</b>             |           |                   |                   |                 |                 |                  |                        |                          |                     |      |
| Variables                      | Intercept | Max. Temp<br>(°C) | Min. Temp<br>(°C) | Max R.H<br>(%)  | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R2   |
| Coefficient                    | -52.98    | 1.56              | -1.01             | 0.08            | 0.45            | 0.03             | -0.71                  | 0.55                     | 3.95                | 0.56 |
| p-value                        | 0.34      | 0.26              | 0.34              | 0.85            | 0.15            | 0.54             | 0.60                   | 0.74                     | 0.11                |      |
| <b>LEAF ROLLER</b>             |           |                   |                   |                 |                 |                  |                        |                          |                     |      |
| Variables                      | Intercept | Max. Temp<br>(°C) | Min. Temp<br>(°C) | Max R.H<br>(%)  | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R2   |
| Coefficient                    | -47.17    | 1.86              | -0.51             | 0.19            | 0.27            | -0.05            | 0.20                   | -0.08                    | -2.24               | 0.52 |
| p-value                        | 0.13      | 0.02              | 0.38              | 0.41            | 0.12            | 0.04             | 0.79                   | 0.93                     | 0.10                |      |
| <b>BARK EATING CATERPILLAR</b> |           |                   |                   |                 |                 |                  |                        |                          |                     |      |
| Variables                      | Intercept | Max. Temp<br>(°C) | Min. Temp<br>(°C) | Max R.H<br>(%)  | Min. R.H<br>(%) | Rainfall<br>(mm) | Sunshine Hours<br>(hr) | Wind Velocity<br>(km/hr) | Evaporation<br>(mm) | R2   |
| Coefficient                    | -1.92     | 0.03              | -0.05             | 0.03            | 0.00            | 0.00             | 0.15                   | 0.02                     | -0.15               | 0.65 |
| p-value                        | 0.50      | 0.65              | 0.32              | 0.20            | 0.80            | 0.82             | 0.04                   | 0.81                     | 0.23                |      |

The statistical analysis showed that the litchi fruit borer was not significant at both the 95% and 90% significance level for all independent variables, including maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, sunshine hours, wind velocity, evaporation, and rainfall ( $p > 0.05$ ). The variation in the litchi fruit borer population was explained by the independent variables with an R-squared value of 0.44. Overall, the statement suggests that while none of the independent variables had a significant impact on the litchi fruit borer population, they still explained some of the variation in the population. It is possible that other variables not included in the analysis could have a more significant impact on the litchi fruit borer population.

The population dynamics of the litchi bug were significantly impacted by evaporation, with a statistically significant positive coefficient ( $p < 0.1$ ) indicating that an increase in evaporation was associated with an increase in the population of the insect pest. However, other independent variables such as maximum temperature and maximum relative humidity did not show any significant effects at a 90% confidence level. The analysis captured a substantial amount of variation, with an  $R^2$  value of 0.91.

Litchi mite population was not found to be statistically significant at either the 95% or 90% level of significance for any of the independent variables, such as maximum and minimum temperature, relative humidity, sunshine hours, wind velocity, evaporation, and rainfall ( $p > 0.05$ ), they did account for some of the variation observed in the population, as indicated by an R-squared value of 0.56. Additionally, there is a possibility that other factors that were not included in the analysis could have a more notable impact on the litchi mite population.

The study found that maximum temperature and evaporation were both significant predictors of leaf roller population at a 90% significance level, with positive coefficient values indicating that an increase in these variables was associated with an increase in pest population. Conversely, rainfall was also a significant predictor, but with a negative coefficient value, indicating that an increase in rainfall was associated with a decrease in leaf roller population. The overall model captured 52% of the variance in the data.

For the barkeating caterpillar, only sunshine hours were found to be significant at a 95% significance level. The positive correlation coefficient value indicates that the population of the insect pest increases with an increase in sunshine hours. The variation captured for the barkeating caterpillar was  $R^2 = 0.65$ .

Literatures from few earlier studies in support with our present experiment were collected and cited below. **Boopathi et al. (2015)** studied the population dynamics of litchi stink bug, *Tessaratomya papillosa* and observed an increase in population of *T. papillosa* with increasing temperature and decreasing relative humidity from April to July. **Ranjan and Ray (2015)** reported the population dynamics of litchi mite in relation to the different abiotic factors. Results have shown that the maximum leaf infestation was recorded during the month of May *i.e.*, 56.20 and 60.40 per cent during the years 2012 and 2013, respectively. **Ray and Mukherjee (2012)** observed the effect of abiotic factors on infestation of litchi leaf roller. The maximum leaf infestation was recorded during the month of October *i.e.*, 50.90 per cent and 53.20 per cent during the years 2010-11 and 2012. In the month of January leaf infestation found to be minimum in both the years. Moreover, all the abiotic factors *viz.*, relative humidity 0700 hrs, 1400 hrs ( $r = 0.696$  and  $0.640$ , respectively) and rainfall ( $r = 0.407$ ) were significantly correlated with the leaf infestation individually. **Boopathi et al. (2011)** studied the population dynamics of stink bug, *Tessaratomya papillosa* during summer, monsoon and winter season on litchi. The highest population of bugs was recorded in summer (92.13%), moderate during monsoon season (81.34%) and lowest in winter (73.55%). The monthly incidence of *T. papillosa* was found to be positively correlated with maximum temperature ( $r = 0.533$ ), minimum temperature ( $r = 0.181$ ), relative humidity ( $r = 0.205$ ) and rainfall ( $r = 0.071$ ). **Charak et al. (2020)** reported that leaf roller activity peaked during the first fortnight of September (50.74%) to the second fortnight of October (54.97%). Correlation and regression studies found positive relationships between leaf roller incidence and average temperatures, relative humidity, sunshine hours, and rainfall, as well as negative relationships with average wind velocity. **Kumar et al. (2008)** observed a significant positive correlation between litchi bug population and maximum temperature, while a significant negative correlation was found with maximum humidity. Moreover, rainfall and maximum temperature were significantly positively correlated with insect population, while relative humidity was

significantly negative correlated with R.H. Litchi bugs emerged in late April and disappeared after the beginning of August, after which they hibernated in adulthood. **Dalui and Sarkar (2021)** found that litchi fruit infestation by the borer *Conopomorpha sinensis* Bradley began at 3.3%, reaching a peak of 42.66% after 60 days. Infestation decreased significantly thereafter. Rainfall did not significantly affect pest activity, while temperature, particularly for larval activity, was significant.

#### **4.3 To analyze Volatile compounds from different parts of the litchi plant, including tender shoots, flowers, immature fruit, and mature fruit**

##### **4.3.1 Biochemical analysis**

Biochemical analysis is a powerful analytical technique that is commonly used to study the chemical composition of plant volatiles, including those that may play a role in attracting or repelling insects. It is often used to study the chemical composition of plant volatiles that may be involved in plant-insect interactions, such as those that attract or repel insects or influence their behavior. The aim of present study is to investigate the factors that contribute to the selection of litchi as a suitable host by the insect *C. sinensis* and to identify any volatile compounds produced by litchi plants that may be attractive to *C. sinensis*. Understanding the mechanisms underlying host selection and the role of plant volatiles in this process can provide insights into the biology of *C. sinensis* and may have potential applications in the control of this insect pest.

##### **4.3.2 Isolation and identification of volatiles from different litchi tissues**

The results of the biochemical analysis showed that the volatiles present in different litchi tissues were diverse. A chromatogram of litchi different litchi tissues is presented, with Figure 1 representing the flowers, **Figure 2** displaying the tender shoots, Figure 3 showing the immature fruits, and **Figure 4** depicting the mature fruits. The number of chromatographic peaks were observed in the analysis for each tissue type. A list of the different chemical compounds and their percentages in the volatile emissions of different litchi tissues shown in **Table 4.11**. The analysis revealed that terpenes, alcohols, and esters were the main chemical compounds present in the volatiles emitted from various litchi tissues, with terpenes comprising 21%, alcohols comprising 3%, and esters comprising 2%. In addition, there were large differences

between the volatiles. The relative contents of volatile compounds detected from different litchi tissues is described and presented in **Table 4.11**.

#### 4.3.2.1 Litchi flower

In litchi flower 11 different volatile compounds were identified and the content ranged from 2.04% Cholestane-3,5,6-triol (3b,5a,6b)- to 19.7% (+)-Aromadendrene. The plant volatile compounds, 1,4,7,-Cycloundecatriene,1,5,9,9-tetramethyl-, Z,Z,Z- (6.06%), Cholestane-3,5,6-triol,(3b,5a,6b)- (2.04%),  $\alpha$ -Cubebene (9.54%), 1H- Cyclopenta[1,3]cyclopropa[1,2]benzene, octahydro-7-methyl- 3-methylene -4-(1- methylethyl)-, [3aS-(3a $\alpha$ ,3b $\alpha$ ,4 $\alpha$ ,7 $\alpha$ ,7aS\*)]- (7.27%),  $\alpha$ -Copaene (11.78%) (+)-Aromadendrene (19.7%), Caryophyllene (29.11%), d-Cadinene (3.78%), Seychellene (3.5%), Naphthalene, 1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1- methylethenyl)-, [1S- (1 $\alpha$ ,7 $\alpha$ ,8 $\alpha$ )]- (8.65%) and (12.04%) are major constituents and remaining compounds are either minor or trace amounts

#### 4.3.2.2 Litchi tender shoot

In tender shoot, 11 different volatile compounds were identified and their content ranged from 0.78% Docosahexaenoic acid, 1,2,3-propanetriyl ester (0.78%) to 39.3%  $\beta$ - Elemene. Major volatiles compounds are, T-Cadinol (4.01%),  $\beta$ -Patchoulene (0.83%), Cedrene (2.5%), Docosahexaenoic acid, 1,2,3-propanetriyl ester (0.78%),  $\alpha$ -Copaene (2.70%) (+)-Epi-bicyclosesquiphellandrene (14.56%) (+)-Aromadendrene (30.12%), Caryophyllene (7.57%), Seychellene (2.13%), T-Cadinol (4.04%),  $\beta$ -Elemene (39.3%) and other not detected compounds.

#### 4.3.2.3 Immature fruit

In immature fruits, 8 different volatile compounds were identified and their content ranged from eicosyl ester (4.03%), to 7-Epizingiberene (40.10%). Major volatiles compounds are, 1- $\beta$ -Bisabolene (28.02%), Docosahexaenoic acid, 1,2,3-propanetriyl ester (4.2%), Oleic acid, eicosyl ester (4.03%) (+)-Aromadendrene (9.43%), Benzene, 1-(1,5-dimethyl-4- hexenyl) -4-methyl- (10.2%), Cedrane, 8-propoxy- (5.04%), 7-Epizingiberene (40.10%) and Lycoxanthin (4.05%) and other not detected compounds.

**Table 4.11: Relative contents of volatile compounds detected from different litchi tissues. ND: not detected; F: flower; TS: tender shoots; IF: immature fruit; MF: mature fruit.**

| No. | CAS                        | Compounds   | Molecular formula                               | F     | TS    | IF    | MF    |
|-----|----------------------------|---|---|-------|-------|-------|-------|
| 1   | 1474790                    | T-Cadinol   | C <sub>15</sub> H <sub>26</sub> O               | ND    | 4.01  | ND    | ND    |
| 2   | PubChem<br>CID:<br>5368784 | 1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethyl-, Z,Z,Z-  | C <sub>15</sub> H <sub>24</sub>                 | 6.06  | ND    | ND    | ND    |
| 3   | 1253-84-5                  | Cholestane-3,5,6-triol,(3b,5a,6b)-  | C <sub>27</sub> H <sub>48</sub> O <sub>3</sub>  | 2.04  | ND    | ND    | ND    |
| 4   | 495-61-4                   | 1- $\beta$ -Bisabolene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | 28.02 | 28.12 |
| 5   | 514-51-2                   | $\beta$ -Patchoulene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | 0.83  | ND    | 0.08  |
| 6   | 17699-14-8                 | $\alpha$ -Cubebene  | C <sub>15</sub> H <sub>24</sub>                 | 9.54  | ND    | ND    | 0.09  |
| 7   | 2306-78-7                  | Nerolidyl acetate   | C <sub>17</sub> H <sub>28</sub> O <sub>2</sub>  | ND    | ND    | ND    | 0.9   |
| 8   | 13744-15-5                 | 1H-Cyclopenta[1,3]cyclopropa [1,2]benzene, octahydro-7-methyl-3-methylene-4-(1-methylethyl)-, [3aS-(3aa,3ba,4a,7a,7aS*)]- | C <sub>15</sub> H <sub>24</sub>                 | 7.27  | ND    | ND    | ND    |
| 9   | 11028-42-5                 | Cedrene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | 2.5   | ND    | 1.98  |
| 10  | 150320-52-8                | 2-Isopropyl-5-methyl-9-methylenebicyclo[4.4.0]dec-1-ene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 0.97  |
| 11  | 6753-98-6                  | Isocaryophyllene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 4.41  |
| 12  | 11094-59-0                 | Docosahexaenoic acid, 1,2,3-propanetriyl ester  | C <sub>69</sub> H <sub>101</sub> O <sub>6</sub> | ND    | 0.78  | 4.2   | ND    |
| 13  | 3856-25-5                  | $\alpha$ -Copaene   | C <sub>15</sub> H <sub>24</sub>                 | 11.78 | 2.70  | ND    | 4.04  |
| 14  | 73744-93-1                 | (+)-Epi-bicyclosesquiphellandrene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | 14.56 | ND    | 3.57  |
| 15  | 150320-52-8                | 2-Isopropyl-5-methyl-9-methylenebicyclo[4.4.0]dec-1-ene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 0.96  |
| 16  | 22393-88-0                 | Oleic acid, eicosyl ester   | C <sub>38</sub> H <sub>74</sub> O <sub>2</sub>  | ND    | ND    | 4.03  | ND    |
| 17  | 489-39-4                   | (+)-Aromadendrene   | C <sub>15</sub> H <sub>24</sub>                 | 19.7  | 30.12 | 9.43  | 0.61  |
| 18  | 22469-52-9                 | (+)-Cyclosativene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 0.88  |
| 19  | 644-30-4                   | Benzene, 1-(1,5-dimethyl-4-hexenyl)-4-methyl-   | C <sub>15</sub> H <sub>22</sub>                 | ND    | ND    | 10.2  | 7.9   |
| 20  | 19870-75-8                 | Cedrane, 8-propoxy-   | C <sub>18</sub> H <sub>32</sub> O               | ND    | ND    | 5.04  | ND    |
| 21  | 87-44-5                    | Caryophyllene   | C <sub>15</sub> H <sub>24</sub>                 | 29.11 | 7.57  | ND    | 9.79  |
| 22  | 158848-19-2                | 7-Epizingiberene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | 40.10 | 36.67 |
| 23  | 13474-59-4                 | $\alpha$ -trans-Bergamotene   | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 0.99  |
| 24  | 483-76-1                   | d-Cadinene  | C <sub>15</sub> H <sub>24</sub>                 | 3.78  | ND    | ND    | 0.67  |
| 25  | 52617-34-2                 | Seychellene   | C <sub>15</sub> H <sub>24</sub>                 | 3.5   | 2.13  | ND    | ND    |
| 26  | 1066-40-6                  | Silanol, trimethyl-   | C <sub>3</sub> H <sub>10</sub> OSi              | ND    | ND    | ND    | 5.21  |
| 27  | 1474790                    | T-Cadinol   | C <sub>15</sub> H <sub>26</sub> O               | ND    | 4.04  | ND    | ND    |
| 28  | 10219-75-7                 | Naphthalene, 1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methylethenyl)-, [1S-(1a,7a,8a)]-                              | C <sub>15</sub> H <sub>24</sub>                 | 8.65  | ND    | ND    | ND    |
| 29  | 19891-74-8                 | Lycoxanthin   | C <sub>40</sub> H <sub>56</sub> O               | ND    | ND    | 4.05  | ND    |
| 30  | 33880-83-0                 | $\beta$ -Elemene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | 39.3  | ND    | 0.5   |
| 31  | 110-83-8                   | Cyclohexene   | C <sub>6</sub> H <sub>10</sub>                  | ND    | ND    | ND    | 0.21  |
| 32  | 18794-84-8                 | $\beta$ -Farnesene  | C <sub>15</sub> H <sub>24</sub>                 | 12.04 | ND    | ND    | 1.98  |
| 33  | 88-84-6                    | $\beta$ -Guaiene  | C <sub>15</sub> H <sub>24</sub>                 | ND    | ND    | ND    | 0.06  |

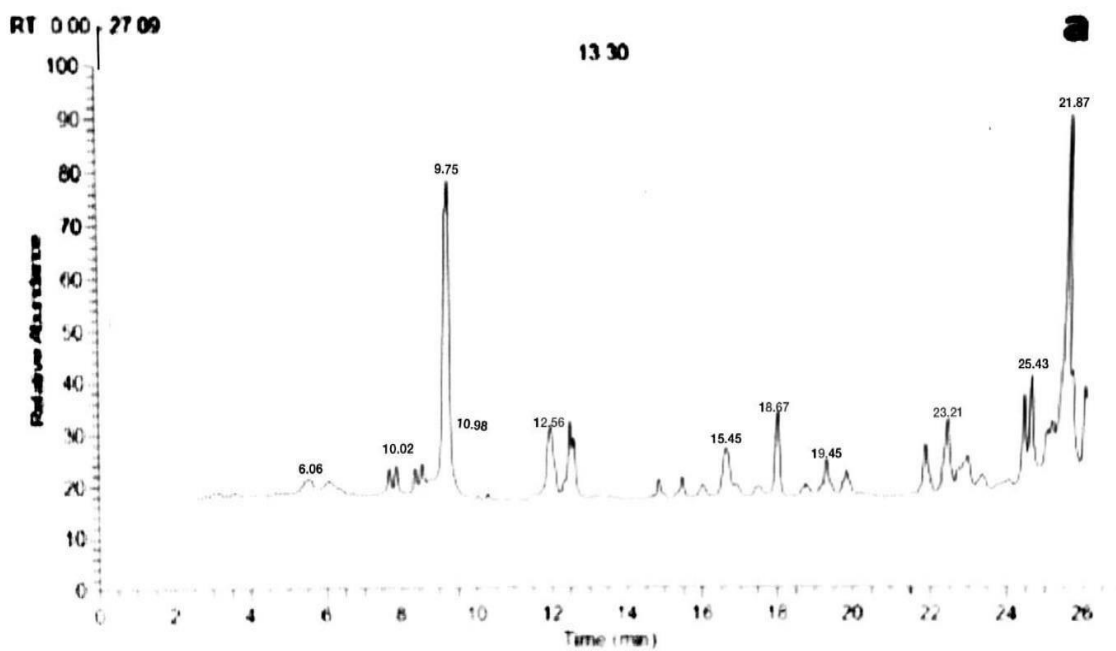


Figure 4.5: Biochemical graph of volatiles from litchi flower

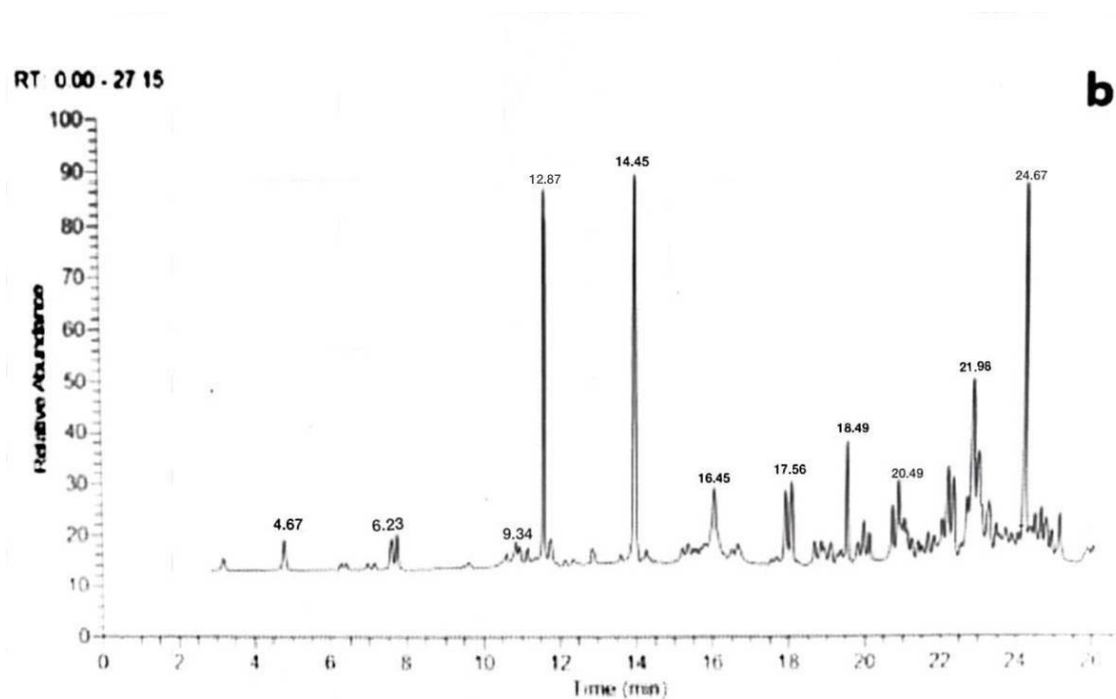


Figure 4.6: Biochemical graph of volatiles from tender shoot

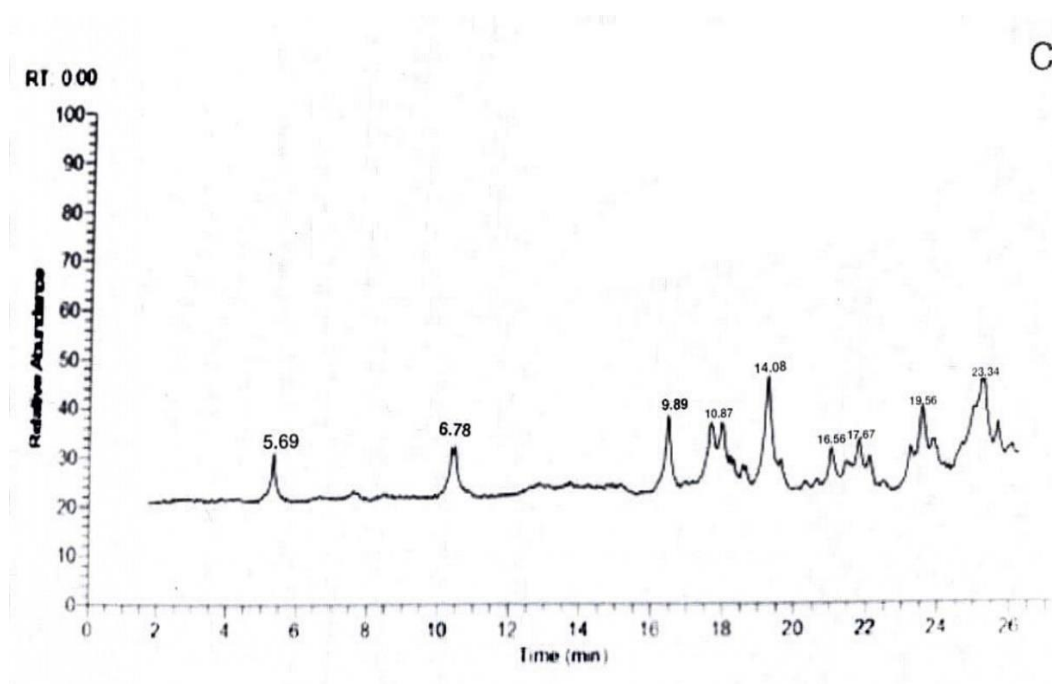


Figure 4.7: Biochemical graph of volatiles from immature fruit

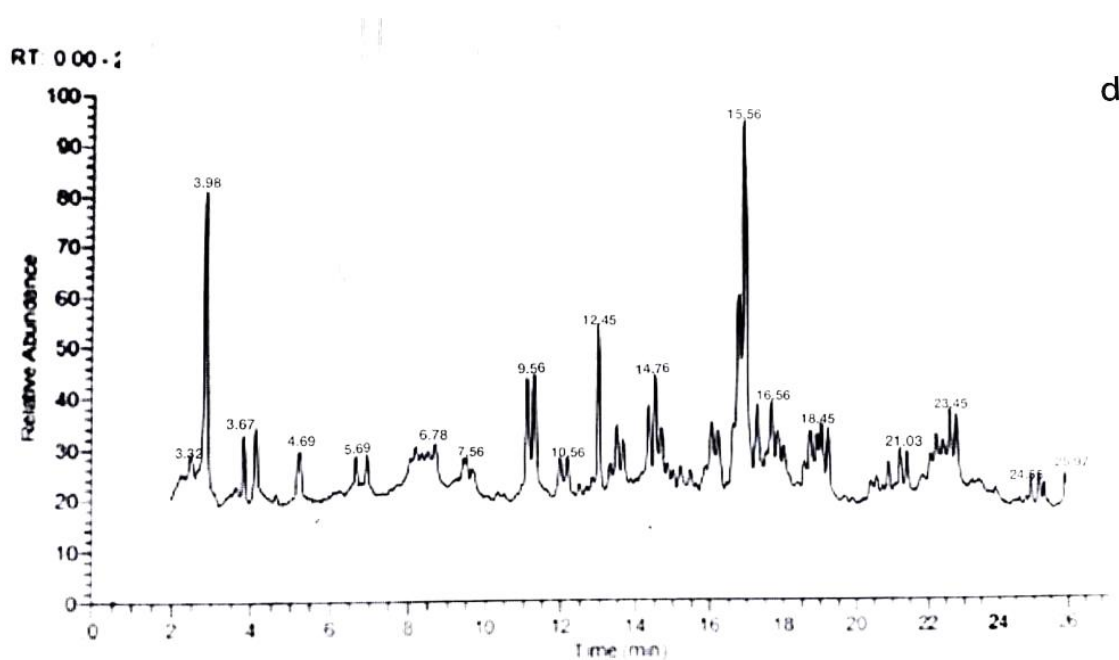
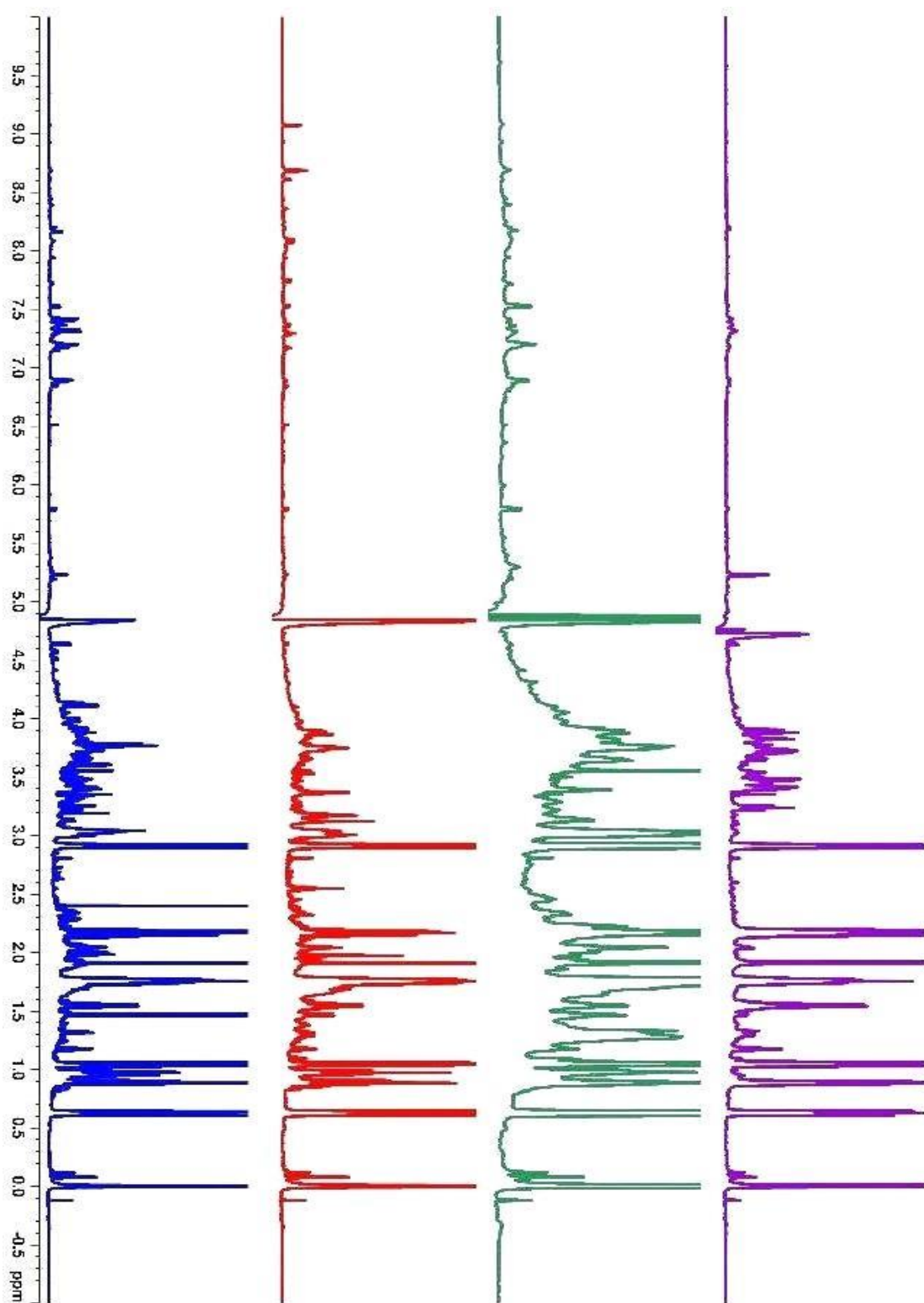


Figure 4.8: Biochemical graph of volatiles from mature fruit



**Figure 4.9:** NMR analysis of the litchi flower (purple), tender shoot (green), immature fruit (red) and mature fruit (blue)

#### 4.3.2.4 Mature fruits

In mature fruits, 22 different volatile compounds were identified and their content ranged from 0.06% of  $\beta$ -Guaiene to 36.67% of 7-Epizingiberene. 1- $\beta$ -Bisabolene (28.12%),  $\beta$ - Patchoulene (0.08%),  $\alpha$ -Cubebene (0.09%), Nerolidyl acetate (0.9%), Cedrene (1.98%), 2-Isopropyl-5-methyl-9-methylenebicyclo[4.4.0]dec-1-ene (0.97%), Isocaryophyllene (4.41%),  $\alpha$ -Copaene (4.04%) (+)-Epi-bicyclosesquiphellandrene (3.57%), 2-Isopropyl-5-methyl-9- methylenebicyclo[4.4.0]dec-1-ene (0.96%) (+)-Aromadendrene (0.61%) (+)-Cyclosativene (0.88%), Benzene, 1-(1,5-dimethyl-4-hexenyl)-4-methyl- (7.9%), Caryophyllene (9.79%), 7- Epizingiberene (36.67%),  $\alpha$ -trans-Bergamotene (0.99%), d-Cadinene (0.67%), Silanol, trimethyl- (5.21%),  $\beta$ -Elemene (0.5%), Cyclohexene (0.21%),  $\beta$ -Farnesene (1.98%),  $\beta$ - Guaiene (0.06%) and other not detected compounds.

Plants are capable of producing complex odor blends, with a large number of volatiles comprising of various compounds in specific ratios (**Bruce and Pickett, 2011**). The volatiles produced by plants play a significant role in the ecological interactions between plants and insects (**Krieger and Breer, 1999**). In this study, a total of 33 compounds were identified in the volatile blend emitted from various litchi tissue samples. Many of these compounds were terpenes, as shown in **Table 4.11**. Similarly, **Zhao et al. (2021)** identified 128 different aroma compounds, which were grouped into six chemical categories: esters (39), alcohols (16), acids (16), terpenes (22), aldehydes and ketones (17), and other compounds (18). The concentrations of the total aroma components were ranked from highest to lowest as follows: esters, terpenes, acids, alcohols, other compounds, and aldehydes and ketones. **Johnstom et al. (1980)** identified and confirmed 42 different volatile compounds in litchi. Results showed that P- phenethyl alcohol, its derivatives, and terpenoids made up the majority of the volatile compounds present in litchi fruit. **Wu et al. (2009)** identified 43 volatiles from 9 cultivars of litchi, including 17 that were common to all samples. These included compounds such as linalool, cis-rose oxide, and ethanol. **Ma et al., 2015** identified volatile components of 'Guanyinlü' litchi fruit. A total of 66 components were identified, including 20 alkenes, 11 esters, and 11 alcohols. The major components were D-limonene, 2-buten-1-ol, and  $\beta$ -myrcene. **Zhao et al., 2021** detected at least 60

odor-active volatiles, with more present in the ethyl acetate extract. Geraniol, guaiacol, vanillin, 2-acetyl-2-thiazoline, 2-phenylethanol, unknown (58) (Z)-2-nonenal,  $\beta$ -damascenone, 1-octen-3-ol, Furaneol, and linalool were found to have the most odor activity. In a study by **Jiang *et al.* (2021)**, the polyphenol metabolite differences in five different cultivars of litchi fruit were analyzed using targeted metabolomics. A total of 126 polyphenol metabolites were identified, and 15 common and 20 specific differential metabolites were found among the cultivars. The main polyphenol metabolites found were flavonoids, flavonols, hydroxycinnamoyls and catechins.

**Mahattanatawee *et al.* (2007)** analyzed the odor volatiles in three major lychee cultivars. A total of 59 odor-active compounds were identified, including 8 sulfur volatiles. **Fang *et al.* (2011)** conducted a study that revealed that terpenes were the primary source of the flower scent in litchi. Additionally, the study found that the terpenoid production in litchi flowers was closely associated with the expression level of the TPS gene family members.

#### **4.4 Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant**

Biochemical analysis, is a powerful analytical technique that allows for the separation and identification of individual components present in a sample mixture. The present study was carried out to investigate the changes in volatile chemical compounds in the leaves of *Aceria mite*-infested plants using biochemical analysis of methanolic extracts of normal and galled leaves. The results of this analysis provide insights into the mechanisms behind *Aceria mite* infestation, plant defence and its impact on plant chemistry.

##### **4.4.1 Isolation and identification of volatiles of mite infested and non-infested leaves of litchi**

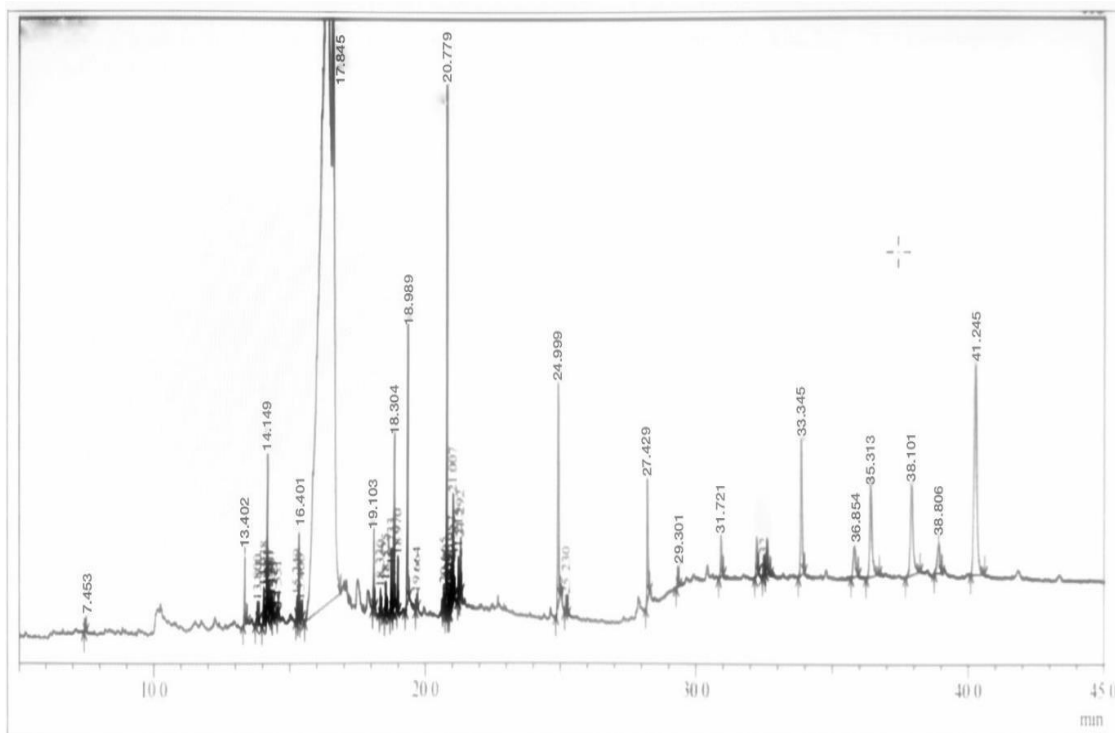
The biochemical analysis of methanolic extracts from normal and mite-infested leaves indicated the presence of 41 phytochemicals in normal leaves (as depicted in **Figure 4.10**) and 42 in mite infested leaves (as depicted in **Figure 4.11**). The biochemical analysis identified a diverse range of chemical compounds in the methanolic extracts of both normal and mite-infested leaves. These compounds included sesquiterpenes, terpenes, esters, antioxidants, steroids, vitamins, and fatty acids, among

others. These results suggest that the leaves contain a variety of biologically active compounds that may play a role in the plant's defence against mite infestation. **Table 4.12** displays the retention times and area percentages of the phytochemicals detected in the biochemical analysis of normal leaves, while **Table 4.13** shows the same information for the phytochemicals detected in the mite infested leaves.

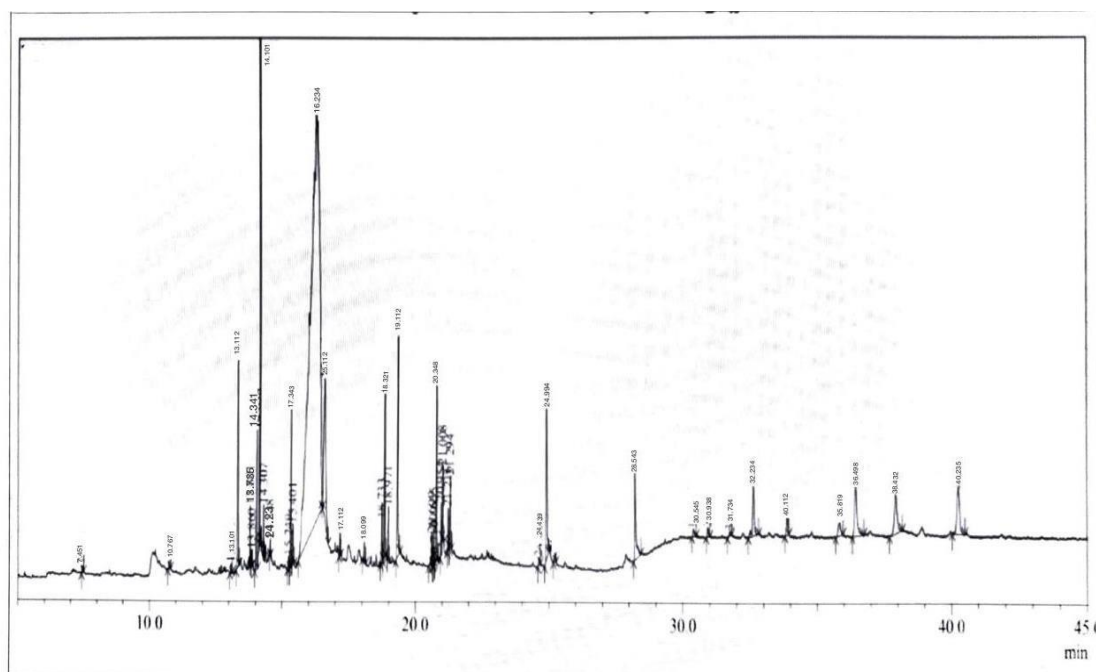
In **Table 4.14**, significant amounts of compounds are compared for normal and galled leaves. The results of our analysis showed that the area percentage of alpha-methyl mannofuranoside decreased from 65.03% in normal leaves to 62.2% in mite-infested leaves. Similarly, the percentage of phytol decreased from 1.12% in normal leaves to 0.81% in mite-infested leaves, and the percentage of vitamin E dropped from 1.56% in normal leaves to 0.52% in mite-infested leaves.

It was found that a certain chemical compound concentration was higher in mite infested leaves than in normal leaves. Specifically, the levels of caryophyllene and 1-(+)-ascorbic acid 2,6-dihexadecanoate were found to be higher in mite-infested leaves compared to normal leaves. In particular, the concentration of caryophyllene increased from 0.37% in normal leaves to 2.03% in mite-infested leaves, and the concentration of 1-(+)-ascorbic acid 2,6-dihexadecanoate rose from 1.56% to 2.26% in mite-infested leaves.

In addition, the concentration of hexadecanoic acid 2-hydroxy-1-(hydroxymethyl) ethyl ester and octadecanoic acid 2,3-dihydroxypropyl ester was found to be higher in mite-infested leaves compared to normal leaves. Specifically, the concentration of hexadecanoic acid 2-hydroxy-1-(hydroxymethyl) ethyl ester increased from 2.05% in normal leaves to 2.44% in mite-infested leaves, and the concentration of octadecanoic acid 2,3-dihydroxypropyl ester rose from 0.99% to 1.83% in mite-infested leaves. Mite-infested leaves contained certain compounds that were not present in normal leaves, such as beta-Longipinene (4.45%) and Lupeol (1.97%). On the other hand, some phytochemicals, such as gamma-Sitosterol (3.12%) and Betulinaldehyde (3.12%), were absent in mite-infested leaves. These chemical compounds are significant due to their medicinal properties and their role in plant defense.



**Figure 4.10: Biochemical graphs of methanolic extract of normal Litchi leaves**



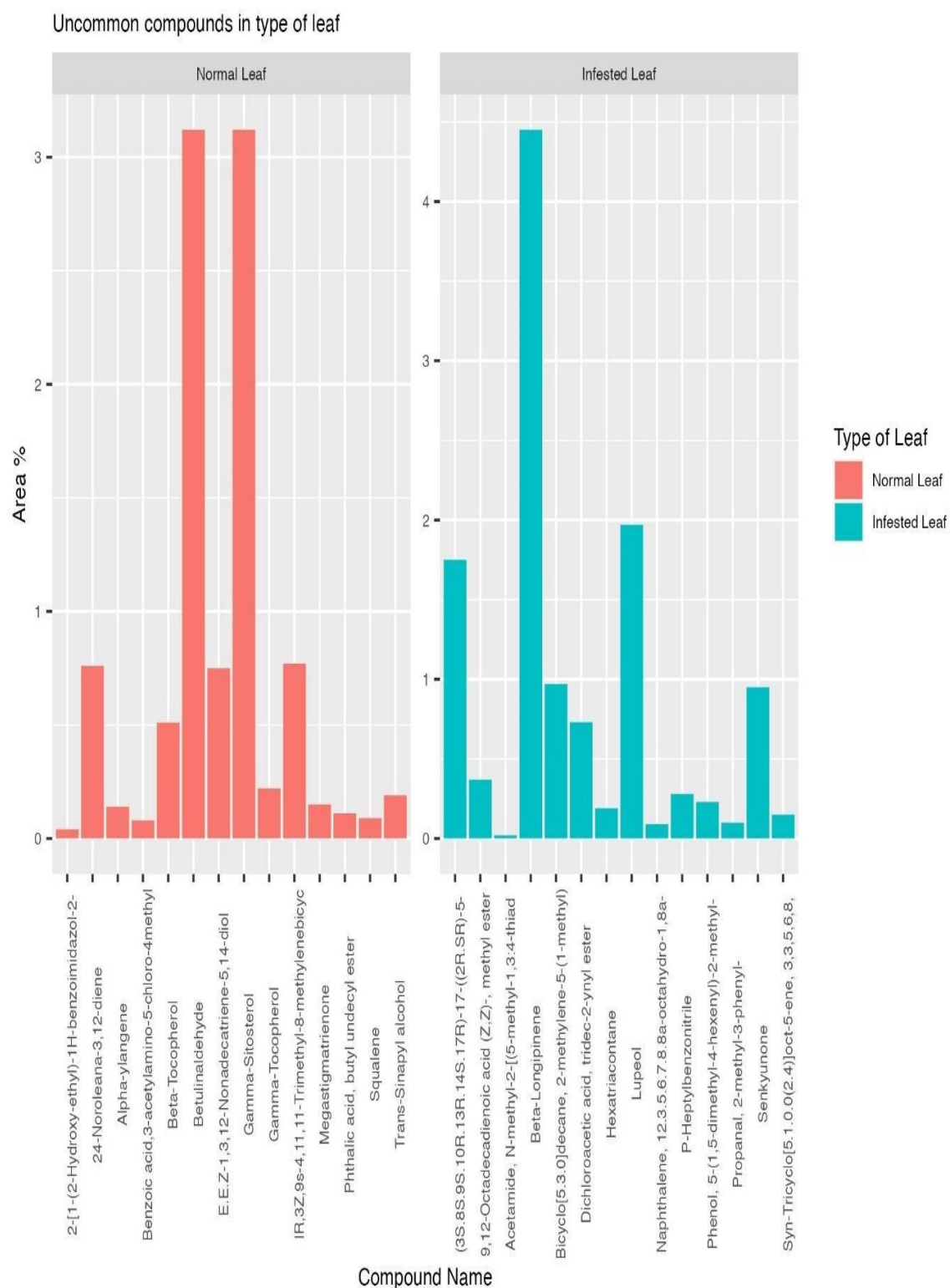
**Figure 4.11: biochemical graph of methanolic extract of mite infested Litchi leaves**

**Table 4.12: Components detected in Biochemical analysis of methanolic extract of normal leaves of Litchi**

| Peak | R.Time | F.Time | Area% | A/H   | Name   |
|------|--------|--------|-------|-------|--|
| 1    | 35.313 | 35.71  | 1.81  | 5.39  | stigmasterol                                   |
| 2    | 41.245 | 41.34  | 3.12  | 6.44  | betulinaldehyde                                |
| 3    | 19.555 | 19.611 | 9.23  | 1.3   | 8,11,14-Docosatrienoic acid, methyl ester      |
| 4    | 27.241 | 27.299 | 0.99  | 2.56  | Octadecanoic acid, 2,3-dihydroxypropyl ester   |
| 5    | 36.854 | 36.941 | 0.75  | 7.42  | Ergost-5-en-3-ol,(3.beta)-                     |
| 6    | 21.981 | 21.981 | 0.08  | 1.85  | Benzoic acid,3-acetylamino-5-chloro-4methyl    |
| 7    | 14.149 | 14.184 | 0.77  | 1.56  | IR,3Z,9s-4,11,11-Trimethyl-8-methylenebicyc    |
| 8    | 15.451 | 15.451 | 0.12  | 2.02  | Caryophyllene oxide                            |
| 9    | 19.103 | 19.111 | 0.39  | 1.49  | Neophytadiene                                  |
| 10   | 31.509 | 31.543 | 0.22  | 3.19  | gamma-Tocopherol                               |
| 11   | 13.721 | 13.823 | 0.11  | 1.67  | 1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethyl- |
| 12   | 21.906 | 21.906 | 0.04  | 0.92  | 2-[1-(2-Hydroxy-ethyl)-1H-benzoimidazol-2-     |
| 13   | 19.457 | 19.569 | 0.19  | 2.31  | trans-Sinapyl alcohol                          |
| 14   | 32.711 | 32.765 | 0.41  | 3.57  | (R)-2,8-Dimethyl-2-((3E,7E)-4,8,12-trimethyl   |
| 15   | 14.111 | 14.312 | 0.08  | 1.56  | alpha-Muurolene                                |
| 16   | 20.201 | 20.213 | 0.29  | 1.49  | Hexadecanoic acid, methyl ester                |
| 17   | 17.845 | 17.867 | 65.03 | 36.08 | alpha-Methyl mannofuranoside                   |
| 18   | 27.429 | 27.431 | 0.99  | 2.48  | Octadecanoic acid, 2,3-dihydroxypropyl ester   |
| 19   | 17.301 | 17.372 | 0.11  | 1.48  | Phthalic acid, butyl undecyl ester             |
| 20   | 31.721 | 32.064 | 0.52  | 4.44  | delta-Tocopherol                               |
| 21   | 18.304 | 18.321 | 0.34  | 2.78  | 3,7,11,Trimethyl-8, 10- dodecedienylacetate    |
| 22   | 16.401 | 16.403 | 0.61  | 1.7   | 1H-Cycloprop[e]Jazulen-7-ol, decahydro-1,1,7   |
| 23   | 21.308 | 21.345 | 0.75  | 1.92  | E.E.Z-1,3,12-Nonadecatriene-5,14-diol          |
| 24   | 38.806 | 39.009 | 0.76  | 6.56  | 24-Noroleana-3,12-diene                        |
| 25   | 13.401 | 13.403 | 0.37  | 1.76  | Caryophyllene                                  |
| 26   | 24.231 | 24.292 | 0.16  | 2.79  | 3',8,8-Trimethoxy-3-piperidyl-2,2'-binaphthale |
| 27   | 20.674 | 20.675 | 0.14  | 1.35  | Linoelaidic acid                               |
| 28   | 20.779 | 20.834 | 1.12  | 1.78  | Phytol   |
| 29   | 14.113 | 14.343 | 0.23  | 1.97  | Benzene, 1-(1,5-dimethyl-4-hexenyl)-4-methy    |
| 30   | 21.113 | 21.244 | 0.22  | 1.67  | Ethyl iso-allocholate                          |
| 31   | 14.09  | 14.131 | 0.4   | 1.47  | IR,32,9s-4,11,11-Trimethyl-8-methylenebicyc    |
| 32   | 24.999 | 25.004 | 2.05  | 2.72  | Hexadecanoic acid, 2-hydroxy-1-(hydroxymet     |
| 33   | 21.21  | 21.213 | 0.28  | 1.61  | Thunbergol                                     |
| 34   | 38.101 | 38.454 | 3.12  | 7.45  | gamma-Sitosterol                               |
| 35   | 18.989 | 19.005 | 1.56  | 1.74  | 1-(+)-Ascorbic acid 2,6-dihexadecanoate        |
| 36   | 15.112 | 15.454 | 0.15  | 1.52  | Megastigmatrienone                             |
| 37   | 14.125 | 14.232 | 0.14  | 1.56  | alpha-ylangene                                 |
| 38   | 29.301 | 29.302 | 0.09  | 2.34  | Squalene                                       |
| 39   | 14.114 | 14.312 | 0.19  | 1.25  | isolekene                                      |
| 40   | 33.118 | 33.345 | 1.56  | 4.16  | Vitamin E                                      |
| 41   | 32.132 | 32.349 | 0.51  | 3.45  | beta-Tocopherol                                |

**Table 4.13: Components detected in biochemical analysis of methanolic extract of mite infested leaves of Litchi.**

| Peak | R.Time | F.Time | Area % | A/H   | Name   |
|------|--------|--------|--------|-------|--|
| 1    | 20.348 | 20.867 | 0.81   | 1.74  | Phytol   |
| 2    | 20.234 | 20.589 | 0.37   | 1.98  | 9,12-Octadecadienoic acid (Z,Z)-, methyl ester             |
| 3    | 17.112 | 17.119 | 0.23   | 1.58  | Phenol, 5-(1,5-dimethyl-4-hexenyl)-2-methyl-               |
| 4    | 30.938 | 31.017 | 0.17   | 2.91  | delta-Tocopherol   |
| 5    | 25.112 | 25.34  | 0.15   | 1.92  | syn-Tricyclo[5.1.0.0(2.4)]oct-5-ene, 3,3,5,6,8,            |
| 6    | 21.007 | 21.061 | 0.73   | 1.63  | Dichloroacetic acid, tridec-2-ynyl ester                   |
| 7    | 24.23  | 24.453 | 0.13   | 1.3   | isolekene  |
| 8    | 18.567 | 18.757 | 0.56   | 2.79  | 3,7,11,Trimethyl-8,10- dodecedienylacetate                 |
| 9    | 17.343 | 17.115 | 1.68   | 1.71  | 1H-Cycloprop clazulen-7-ol, decahydro-1,1,7                |
| 10   | 23.412 | 23.345 | 0.3    | 1.39  | Caryophyllene oxide  |
| 11   | 10.767 | 10.803 | 0.1    | 1.83  | Propanal, 2-methyl-3-phenyl-                               |
| 12   | 16.234 | 16.34  | 62.2   | 22.67 | alpha.-Methyl mannofuranoside                              |
| 13   | 13.112 | 13.396 | 2.03   | 1.61  | Caryophyllene  |
| 14   | 13.101 | 13.102 | 0.09   | 1.64  | Naphthalene, 12.3.5.6.7.8.8a-octahydro-1,8a-               |
| 15   | 7.451  | 7.501  | 0.98   | 1.94  | Benzeneacetaldehyde  |
| 16   | 13.45  | 13.891 | 0.97   | 1.35  | Bicyclo[5.3.0]decane, 2-methylene-5-(1-methyl)             |
| 17   | 13.735 | 13.831 | 0.46   | 1.37  | 1.4.7-Cycloundecatriene, 1.5.9.9-tetramethyl-              |
| 18   | 14.101 | 14.171 | 4.45   | 1.49  | beta-Longipinene   |
| 19   | 19.112 | 19.34  | 2.26   | 1.76  | 1-(+)-Ascorbic acid 2,6-dihexadecanoate                    |
| 20   | 18.989 | 19.005 | 0.42   | 1.37  | Hexadecanoic acid, methyl ester                            |
| 21   | 18.099 | 18.142 | 0.16   | 1.33  | Neophytadiene  |
| 22   | 14.214 | 14.331 | 0.98   | 1.29  | alpha.-Muurolene   |
| 23   | 21.237 | 21.569 | 0.41   | 1.68  | Ethyl iso-allocholate                                      |
| 24   | 24.994 | 25.004 | 2.44   | 2.8   | Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester |
| 25   | 32.234 | 32.675 | 1.99   | 4.78  | (R)-2,8-Dimethyl-2-((3E7F)-4.8.12-trimethyl                |
| 26   | 35.437 | 35.97  | 0.49   | 6.31  | Ergost-5-en-3-ol (3.beta.)-                                |
| 27   | 20.717 | 20.717 | 0.02   | 0.82  | Acetamide, N-methyl-2-[(5-methyl-1,3:4-thiad               |
| 28   | 28.543 | 28.945 | 1.83   | 4.12  | Octadecanoic acid, 2,3-dihydroxypropyl ester               |
| 29   | 25.118 | 25.287 | 0.13   | 2.71  | 3,8,8'-Trimethoxy-3-piperidyl-2,2'-binaphthale             |
| 30   | 30.545 | 30.523 | 0.19   | 3.46  | Hexatriacontane  |
| 31   | 24.439 | 24.563 | 0.28   | 2.68  | p-Heptylbenzotrile   |
| 32   | 38.432 | 38.654 | 1.75   | 7.49  | (3S.8S.9S.10R.13R.14S.17R)-17-((2R.SR)-5-                  |
| 33   | 40.112 | 40.321 | 0.52   | 3.78  | Vitamin E  |
| 34   | 20.651 | 20.954 | 0.44   | 1.58  | Linoclaidic acid   |
| 35   | 31.734 | 31.829 | 0.95   | 2.99  | Senkyunone   |
| 36   | 21.219 | 21.345 | 0.82   | 1.84  | Thunbergol   |
| 37   | 40.234 | 40.543 | 1.97   | 7.54  | Lupeol   |
| 38   | 36.498 | 36.735 | 1.97   | 7.06  | Stigmasterol   |
| 39   | 34.112 | 34.232 | 1.56   | 1.86  | Benzene, 1-(1.5-dimethyl-4-hexenyl)-4-methy                |
| 40   | 18.321 | 18.894 | 1.64   | 1.66  | 3,7,11,Trimethyl-8,10- dodecedienylacetate                 |
| 41   | 16.453 | 16.712 | 4.35   | 5.31  | alpha.-Methyl mannofuranoside                              |
| 42   | 20.543 | 20.656 | 0.37   | 1.69  | 8,11,14-Docosatrienoic acid, methyl ester                  |



**Figure 4.12: Bar graph showing the uncommon compounds present in both normal and mite infested litchi leaf**



**Figure 4.13: Bar graph showing the comparison of area% of normal and mite infested litchi leaf**

**Table 4.14: Showing peak area percentages of notable phytochemicals in normal and mite infested leaves**

| Name of the compound                                      | Nature of Compound        | Area% normal leaf | Area% mite infested leaf |
|---|---------------------------|-------------------|--------------------------|
| Alpha methyl mannofuranoside                              | Glycoside                 | 65.03             | 62.2                     |
| Vitamin E   | Antioxidant               | 1.56              | 0.52                     |
| Phytol  | Diterpene                 | 1.12              | 0.81                     |
| Caryophellene   | Sesquiterpene             | 0.37              | 2.03                     |
| 1-(+)-Ascorbic acid 2,6-dihexadecanoate                   | Sugar acid                | 1.56              | 2.26                     |
| Hexadecanoic acid, 2-hydroxy-1 (hydroxymethyl)ethyl ester | Palmitic acid ethyl ester | 2.05              | 2.44                     |
| Octadecanoic acid, 2,3-dihydroxypropyl ester              | Linoleic acid ester       | 0.99              | 1.83                     |
| Betulinaldehyde   | Triterpenoid              | 3.12              | 0                        |
| gamma-Sitosterol  | Steroid                   | 3.12              | 0                        |
| beta-Longipinene  | Sesquiterpene             | 0                 | 4.45                     |
| Lupeol  | Triterpene                | 0                 | 1.97                     |

Previous literature that pertains to the comparative analysis of volatiles in relation to the development of different insects is cited in support of the current study. According to **Nonomura *et al.* (2020)**, the compound alpha methyl mannofuranoside acts as a plant growth regulator by altering glycoregulation in plants. The reduced quantity of alpha methyl mannofuranoside in mite infested litchi leaves suggests that mite infestation has disrupted the normal growth of the plant by affecting the metabolic processes involved, resulting in mite infestation symptoms on litchi leaf. **Fryer (1993)** observed that Vitamin E, a significant compound that is greatly reduced in abundance in mite infested leaves, is an antioxidant that protects plant cell membranes from damage caused by light. The reduced quantity of Vitamin E in mite infested leaves suggests that the mite has disrupted the pathway involved in the plant's defence mechanisms. Quantity of Phytol, a diterpene alcohol, also reduced in mite infested litchi leaves. In previous studies on other species of *Premna*, such as those conducted by **(Renjana and Thoppi, 2013)**, it was found that the chemical compositions of these plants were rich in caryophyllene,  $\beta$ -cadinene,  $\alpha$ -selinene, and phytol. The essential oils of *P. angolensis* and *P. quadrifolia* have been shown to have insecticide properties against contact adult insects

*S. cerealella*, potentially due to the main volatile compounds present in these oils acting alone or in combination with other minor constituents. One of the chemical compounds that was found to increase in quantity in mite infested litchi leaves was Caryophellene, which is a significant finding as it may be related to the biological activity of the plant in response to the mite infestation. Moreover, **Da Silva *et al.* (2015)** conducted an experiment to test the oviposition deterrent effect of two sesquiterpenes (E)-caryophyllene and  $\alpha$ -humulene. The results showed that both sesquiterpenes had significant oviposition deterrent effects, as the mean number of eggs laid on filter paper soaked with each of the sesquiterpenes was significantly lower than the control. **Huang *et al.* (2012)** observed that caryophyllene is released from non-floral parts of plants to act against herbivores. This has been demonstrated in several studies, including the work of **Langenheim (1994)**, who found that caryophyllene reduced the growth of insects feeding on cotton and *Hymenaea* plants. Additionally, the

higher amount of caryophyllene present in mite-infested leaves suggests that mite infestation triggers the plant's defence system to release more of this compound (**Langenheim, 1994**). These findings suggest that caryophyllene plays an important role in plant defense mechanisms. 1- (+)- Ascorbic acid 2, 6-dihexadecanoate also increased in the galled leaf.

In the present study, some compounds were found to be completely absent in mite- infested leaves, but present in normal leaves. One such compound, betulinaldehyde, is a pentacyclic triterpenoid with insecticidal activities (**Sushma and Tabassum, 2022**). Its absence in mite-infested leaves suggests that mite infection may affect the synthesis of betulinaldehyde, leading to litchi leaf mite infestation. These findings indicate that the presence or absence of certain compounds may be used as indicators of litchi leaf mite infestation. Another important compound found absent in galled leaves but present in normal leaves is gamma-Sitosterol (3.12%). According to a study by **Mishra et al. (2020)**, dietary  $\beta$ -sitosterol, a phytochemical found in *T. neriifolia* stem extract, caused developmental abnormalities in *H. armigera* at concentrations of 0.1-10 ppm. These effects were observed in the physiological fitness and midgut enzymes of the *H. armigera*. Hence, the complete loss of this substance in mite-infested tissue suggests that it was either completely used during the infestation process or that the pathway involved in its synthesis was altered by the mites. In contrast to the previously mentioned phytochemicals, some compounds were only detected in mite-infested leaves. One such compound is lupeol, a pentacyclic triterpenoid. Lupeol, a pentacyclic triterpenoid, serves as a precursor for other triterpenoid metabolites that are important for plant defense, as reported by **Cárdenas et al (2019)**. The finding that lupeol was present only in mite-infested leaves suggests that mite infection may stimulate the production of lupeol in the affected tissue as a defensive mechanism of the plant. The presence of Beta longipinene exclusively in mite-infested leaves indicates its potential role in plant defense mechanisms against mite infection.

#### 4.5 To study the olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits

Olfaction, or the sense of smell, plays a key role in the long-distance orientation of phytophagous insects to host plants. These insects use their sense of smell to locate and identify suitable plants to feed on or lay eggs on. The olfactory system of phytophagous insects is highly sensitive and can detect the presence of volatile organic compounds (VOCs) released by plants. These VOCs serve as chemical cues that can attract or repel insects and influence their behaviour. After contacting a plant, phytophagous insects use their olfactory system to evaluate the physicochemical properties of the plant surface. This can help them determine whether the plant is suitable for feeding or egg-laying. The olfactory system of phytophagous insects is complex and involves several different types of sensory organs, including antennae, maxillary palps, and labial palps. These organs contain specialized sensory cells that are sensitive to specific VOCs and play a role in the insects' ability to locate and identify host plants.

In this study, 5 arm olfactometer was used to investigate the taxis behavior of adult litchi fruit borer insects towards different tissues of litchi trees. The olfactometer is a specialized device that is used to study the responses of insects to different odors or volatile compounds. In five arm olfactometer four host plant tissues solutions namely litchi flower, litchi tender shoot, litchi mature fruit, and litchi immature fruit and water was subjected. The mean orientation of the male and female towards different host tissue solution was observed in 1hr, 2hr and 3hr intervals. After five minutes of saturation of different host odour in the olfactometer, thirty numbers of male and female adult litchi fruit borer were released in the olfactometer through a central hole. Observation was made on number litchi fruit borer settled on each arm at 1hr, 2hr, and 3hr HAR (hours after release) for their host preference. This experiment was replicated four times. Hence, the results of the study showed that there were differences in the taxis behavior of female and male adult litchi fruit borers towards different tissues of the litchi tree. Specifically, the female litchi fruit borer adults were found to exhibit a stronger preference for the host tissues compared to the male adults. **Figure 4.14** illustrates the mean orientation of male and female litchi fruit borer moths towards different treatments over various time intervals in hours, while **Figure 4.15** presents a

boxplot showing the mean orientation of litchi fruit borer moths of both sexes combined over all time intervals for the different treatments.

Initial observations of the data indicate that there does exist differences in preferences of litchi fruit borer for different treatments. In order to test whether these differences are statistically significant, initially we conduct one-way ANOVA for male, female, and different time intervals separately keeping different treatments as the independent factor. The ANOVA results indicates significant differences between the mean orientation of litchi fruit borer for different treatments. Duncan Multiple Range Test (DMRT) was used for post-hoc analysis. Further, the Duncan Multiple Range Test (DMRT) is a statistical test that is used to compare the means of multiple groups or treatments in an experiment. It is a type of multiple comparison test, which means it is used to determine whether there are significant differences between the means of two or more groups. The DMRT is based on the idea that if the means of two groups are significantly different, then it is likely that the means of the groups are different in a meaningful way, rather than due to random chance. Results of One-way ANOVA post hoc analysis results are shown in **Table 4.15**.

The results showed that during a 1<sup>st</sup> hour observation period, the maximum number of female adult moths (35.75 moths/arms) preferred mature fruits, while no adults were found in the control arm of the olfactometer. Tender shoots, immature fruit, and flowers were preferred by 26.75, 21.25, and 14.75 moths/arms, respectively. Whereas male moth showed maximum preference for tender shoot (28.25 moths/arms) and no preference for control arms furthermore, preference for mature fruits, immature fruits, and flower was as follows 23.25, 18.50, and 7.75 moths/arms of olfactometer.

During 2<sup>nd</sup> hr of observation period the maximum orientation of female adult's (35 moths/arms) were observed towards mature fruit tissue and no orientation was shown by female moths towards control arms, followed by tender shoot (29.75 moths/arms), immature fruits (22.50 moths/arms), and flowers (12.25 moths/arms). Whereas the maximum orientation of male adult's moths was observed towards tender shoot (31.75 moths/arms) and no orientation towards control arms. Furthermore, orientation towards other tissues was as follows mature fruits (23.50 moths/ arms), immature fruit (22.75 moths/arm), and flowers (12.75 moths/arms).



Figure 4.14: Mean orientation o Litchi fruit borer for different time intervals

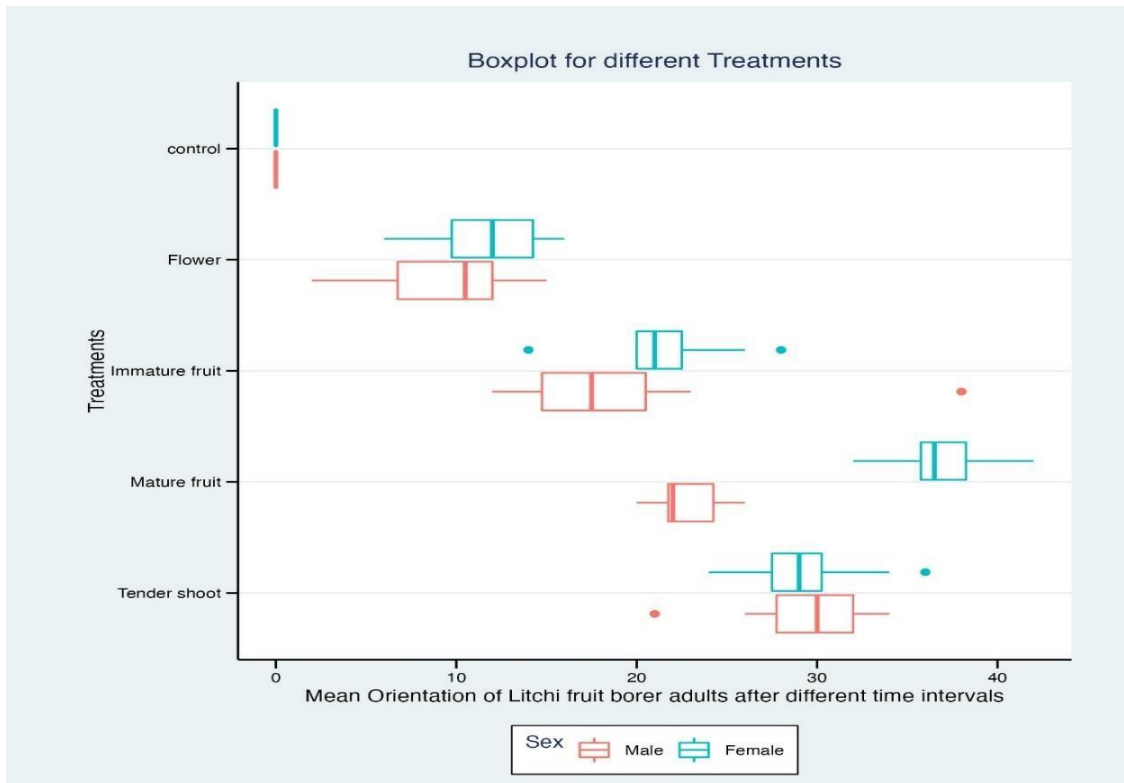


Figure 4.15: Boxplot of mean orientation of Litchi fruit borer

**Table 4.15: The mean orientation of the male and female adults of litchi fruit borer towards different host tissue solution was observed in 1hr, 2hr and 3hr intervals**

| Treatment             | Mean orientation of litchi fruit borer adults towards different host tissue |                  |                 |                  |                 |                 |                 |                  |
|-----------------------|---|------------------|-----------------|------------------|-----------------|-----------------|-----------------|------------------|
|                       | 1hr   |                  | 2hr             |                  | 3hr             |                 | Mean            |                  |
|                       | Female ♀  | Male ♂           | Female ♀        | Male ♂           | Female ♀        | Male ♂          | Female ♀        | Male ♂           |
| <b>Flower</b>         | 14.75<br>(3.96)   | 7.75<br>(2.86)   | 12.25<br>(3.63) | 12.75<br>(3.70)  | 8.25<br>(3.03)  | 8.25<br>(3.02)  | 11.75<br>(3.54) | 9.58<br>(3.19)   |
| <b>Tender shoot</b>   | 26.75<br>(5.27)   | 28.25<br>(5.40)  | 29.75<br>(5.54) | 31.75<br>(5.72)  | 31.00<br>(5.64) | 27.75<br>(5.35) | 29.17<br>(5.48) | 29.25<br>(5.49)  |
| <b>Immature fruit</b> | 21.25<br>(4.71)   | 18.50<br>(4.40)  | 22.50<br>(4.84) | 22.75<br>(4.78)  | 20.75<br>(4.63) | 15.50<br>(4.06) | 21.50<br>(4.73) | 18.92<br>(4.41)  |
| <b>Mature fruit</b>   | 35.75<br>(6.06)   | 23.25<br>(4.92)  | 35.75<br>(6.06) | 23.50<br>(4.95)  | 39.50<br>(6.36) | 21.75<br>(4.77) | 37.00<br>(6.16) | 22.83<br>(4.88)  |
| <b>Control</b>        | 0.00<br>(1.00)  | 0.00<br>(1.00)   | 0.00<br>(1.00)  | 0.00<br>(1.00)   | 0.00<br>(1.00)  | 0.00<br>(1.00)  | 0.00<br>(1.00)  | 0.00<br>(1.00)   |
| <b>C.D.</b>           | 2.75<br>(0.28)  | 4.70<br>(0.69)   | 2.52<br>(0.27)  | 7.91<br>(0.80)   | 5.72<br>(0.59)  | 3.99<br>(0.45)  | 3.67<br>(0.38)  | 5.53<br>(0.65)   |
| <b>SE(m)</b>          | 0.90<br>(0.09)  | 1.55<br>(0.23)   | 0.83<br>(0.09)  | 2.60<br>(0.26)   | 1.88<br>(0.19)  | 1.31<br>(0.15)  | 0.45<br>(0.12)  | 1.82<br>(0.21)   |
| <b>C.V.</b>           | 9.18<br>(4.36)  | 19.87<br>(12.27) | 8.27<br>(4.18)  | 28.64<br>(13.09) | 18.91<br>(8.18) | 17.91<br>(8.18) | 12.12<br>(5.57) | 22.14<br>(11.18) |

Similarly, 3hr after releasing of moths, the orientation of female adults was found to be highest towards mature fruit tissue arms with 39.50 moths/arms followed by tender shoot with 31.00 moths/arms, immature fruits with 20.75 moths/arms, flowers with 8.25 moths/arms and no orientation towards control was observed. The orientation of male moths towards different tissues was observed with highest orientation towards tender shoot (27.75 moths/arms), mature fruits (21.75 moths/arms), immature fruits (15.50 moths/arms), flowers (8.25 moths/arms), and no orientation towards control was observed.

Since, the one-way ANOVA analysis was conducted separately for all the time intervals and sex, these results are not comparable across different time and sex groups. In order to compare these preference differences across these groups two-way ANOVA

was conducted which comprises of three independent factors i.e., treatment, sex, and the interaction variable of treatment and sex. **Table 4.16** shows the results of the two-way ANOVA analysis.

**Table 4.16: Two- way ANOVA results**

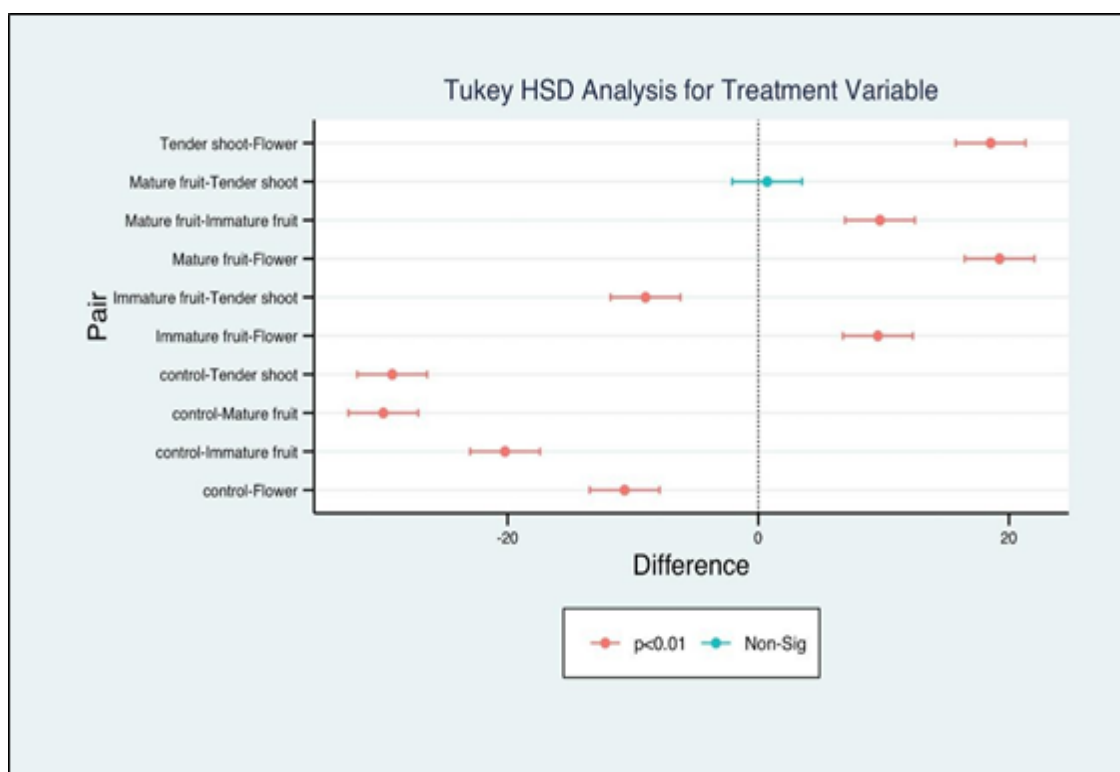
| Term            | df  | Sumsq    | Meansq  | F statistic | p.value |
|-----------------|-----|----------|---------|-------------|---------|
| Treatments      | 4   | 15606.92 | 3901.73 | 321.57      | 0.00    |
| Sex             | 1   | 425.63   | 425.63  | 35.08       | 0.00    |
| Treatments: Sex | 4   | 846.78   | 211.70  | 17.45       | 0.00    |
| Residuals       | 110 | 1334.67  | 12.13   | NA          | NA      |

The two-way ANOVA results indicate that there is a significant difference in the mean orientation of the litchi fruit borer adults with respect to all the independent factors considered here. Tukey HSD post hoc analysis was used to conduct pair wise comparisons. **Table 4.17**. Shows the comparison between the sex variable. The results of the study have shown that female adults have a higher mean preference for the various treatments compared to male adults. The results also give a 95% confidence interval range of the differences in the mean orientation between the sex groups.

**Table 4.17: Difference between the sex groups in the mean orientation of Litchi fruit borer**

| Sex         | Difference | Lower | Upper | p adj |
|-------------|------------|-------|-------|-------|
| Female-Male | 3.76       | 2.51  | 5.03  | 0.00  |

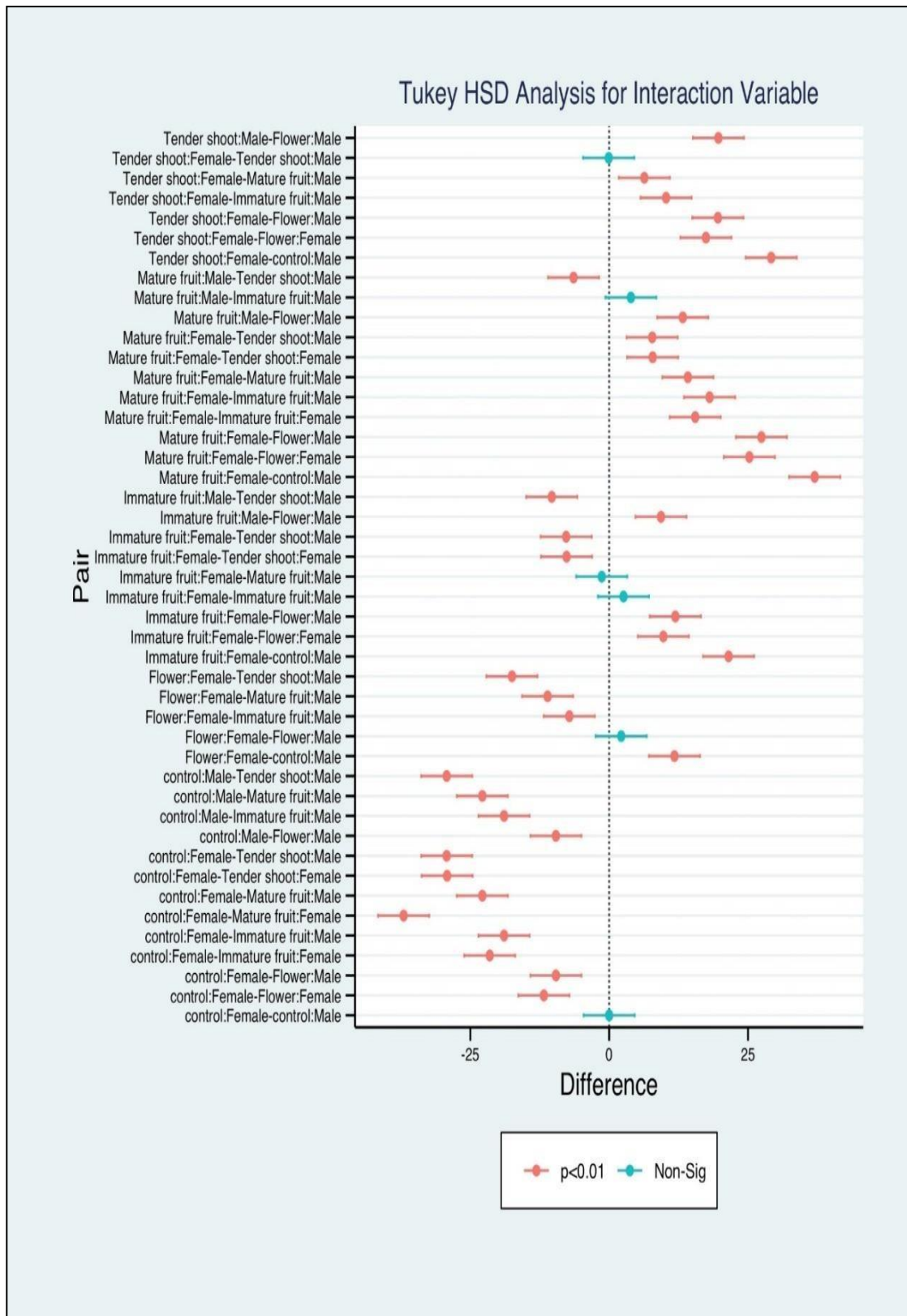
Further, pairwise comparison of different treatment groups using the Tukey HSD post hoc analysis was conducted to identify which specific pairs of means are significantly different from one another, rather than just indicating that there is a significant difference among the means overall. Hence, **figure 4.16** depicts the pairwise comparison of different treatment groups.



**Figure 4.16: Pair wise comparison of different treatment groups**

The range of the differences are plotted using line bar graph where the orange colour indicates statically significant difference ( $p < 0.01$ ) between the pair groups and the green colour indicates insignificant difference ( $p > 0.05$ ). Results showed that there is no significant difference between mature fruit and tender shoot treatments when we combine readings for both sex groups. The difference between these two groups can be further analysed by looking into the results of the interaction variable. All the other treatment groups differ significantly from each other with mature fruit and tender shoot being the highest preferred treatments. Litchi fruit borer moths are significantly more attracted to immature fruits than flowers. All the treatment groups were preferred significantly higher than the control group.

Moreover, pair wise comparison for the interaction variable was performed to depict the relationship between two or more variables and how they influence each other. The results are shown in **Figure 4.17**.



**Figure 4.17: Pair wise comparison of the interaction variable**

**Figure 4.17** plots the results of pair wise comparison for the interaction variable using the line bar graph with orange colour as significant whereas green colour as insignificant. These results are important to analyse the difference between treatment groups while categorizing them through sex. Furthermore, results indicated that female moths have the highest preference for mature fruits whereas, the male moths have the highest preference for tender shoot. This is the reason that significant difference was not observed between mature fruits and tender shoot when sex is not accounted for, as the highest preference of different sex groups are different.

**Table 4.18 : Pair wise comparison of different treatment groups**

| Treatments                  | Difference | Lower  | Upper  | p adj |
|-----------------------------|------------|--------|--------|-------|
| Tender shoot-Flower         | 18.54      | 15.75  | 21.33  | 0.00  |
| Immature fruit-Flower       | 9.54       | 6.75   | 12.33  | 0.00  |
| Mature fruit-Flower         | 19.25      | 16.46  | 22.04  | 0.00  |
| control-Flower              | -10.67     | -13.46 | -7.88  | 0.00  |
| Immature fruit-Tender shoot | -9.00      | -11.79 | -6.21  | 0.00  |
| Mature fruit-Tender shoot   | 0.71       | -2.08  | 3.50   | 0.96  |
| Control-Tender shoot        | -29.21     | -32.00 | -26.42 | 0.00  |
| Mature fruit-Immature fruit | 9.71       | 6.92   | 12.50  | 0.00  |
| Control-Immature fruit      | -20.21     | -23.00 | -17.42 | 0.00  |
| Control-Mature fruit        | -29.92     | -32.71 | -27.13 | 0.00  |

Both male and female prefer flower, tender shoot, and immature fruit treatment equally. Moreover, results showed that male prefer mature fruit and immature fruit equally whereas female shows higher preference for mature fruits. Similarly other pair wise comparison can be observed in the interaction plot. The table for both **figure 4.16** and **4.17** is provided in **Table 4.18** and **Table 4.19**.

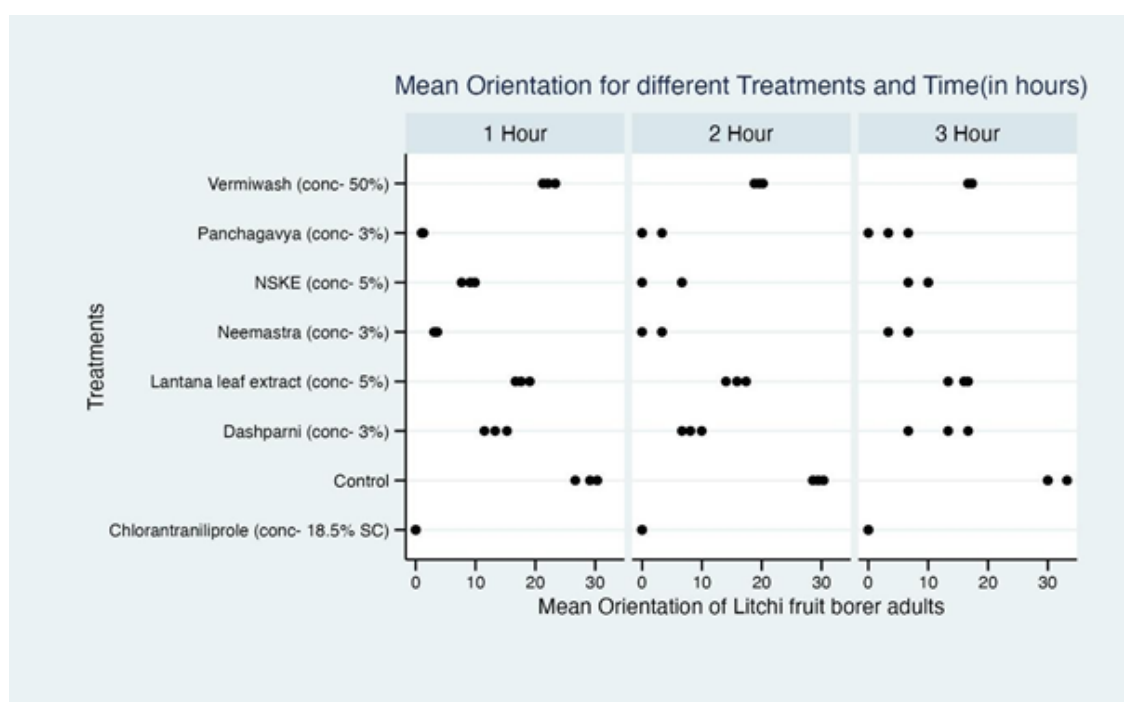
**Table 4.19: Pair wise comparison of the interaction variable**

| <b>Pair</b>                               | <b>Difference</b> | <b>Lower</b> | <b>Upper</b> | <b>p adj</b> |
|---|-------------------|--------------|--------------|--------------|
| Tender shoot:Male-Flower:Male             | 19.67             | 15.07        | 24.26        | 0.00         |
| Immature fruit:Male-Flower:Male           | 9.33              | 4.74         | 13.93        | 0.00         |
| Mature fruit:Male-Flower:Male             | 13.25             | 8.66         | 17.84        | 0.00         |
| Control:Male-Flower:Male                  | -9.58             | -14.18       | -4.99        | 0.00         |
| Flower:Female-Flower:Male                 | 2.17              | -2.43        | 6.76         | 0.88         |
| Tender shoot:Female-Flower:Male           | 19.58             | 14.99        | 24.18        | 0.00         |
| Immature fruit:Female-Flower:Male         | 11.92             | 7.32         | 16.51        | 0.00         |
| Mature fruit:Female-Flower:Male           | 27.42             | 22.82        | 32.01        | 0.00         |
| Control:Female-Flower:Male                | -9.58             | -14.18       | -4.99        | 0.00         |
| Immature fruit:Male-Tender shoot:Male     | -10.33            | -14.93       | -5.74        | 0.00         |
| Mature fruit:Male-Tender shoot:Male       | -6.42             | -11.01       | -1.82        | 0.00         |
| Control:Male-Tender shoot:Male            | -29.25            | -33.84       | -24.66       | 0.00         |
| Flower:Female-Tender shoot:Male           | -17.50            | -22.09       | -12.91       | 0.00         |
| Tender shoot:Female-Tender shoot:Male     | -0.08             | -4.68        | 4.51         | 1.00         |
| Immature fruit:Female-Tender shoot:Male   | -7.75             | -12.34       | -3.16        | 0.00         |
| Mature fruit:Female-Tender shoot:Male     | 7.75              | 3.16         | 12.34        | 0.00         |
| Control:Female-Tender shoot:Male          | -29.25            | -33.84       | -24.66       | 0.00         |
| Mature fruit:Male-Immature fruit:Male     | 3.92              | -0.68        | 8.51         | 0.17         |
| Control:Male-Immature fruit:Male          | -18.92            | -23.51       | -14.32       | 0.00         |
| Flower:Female-Immature fruit:Male         | -7.17             | -11.76       | -2.57        | 0.00         |
| Tender shoot:Female-Immature fruit:Male   | 10.25             | 5.66         | 14.84        | 0.00         |
| Immature fruit:Female-Immature fruit:Male | 2.58              | -2.01        | 7.18         | 0.72         |
| Mature fruit:Female-Immature fruit:Male   | 18.08             | 13.49        | 22.68        | 0.00         |
| Control:Female-Immature fruit:Male        | -18.92            | -23.51       | -14.32       | 0.00         |
| Control:Male-Mature fruit:Male            | -22.83            | -27.43       | -18.24       | 0.00         |
| Flower:Female-Mature fruit:Male           | -11.08            | -15.68       | -6.49        | 0.00         |
| Tender shoot:Female-Mature fruit:Male     | 6.33              | 1.74         | 10.93        | 0.00         |
| Immature fruit:Female-Mature fruit:Male   | -1.33             | -5.93        | 3.26         | 0.99         |
| Mature fruit:Female-Mature fruit:Male     | 14.17             | 9.57         | 18.76        | 0.00         |
| Control:Female-Mature fruit:Male          | -22.83            | -27.43       | -18.24       | 0.00         |
| Flower:Female-control:Male                | 11.75             | 7.16         | 16.34        | 0.00         |
| Tender shoot:Female-control:Male          | 29.17             | 24.57        | 33.76        | 0.00         |
| Immature fruit:Female-control:Male        | 21.50             | 16.91        | 26.09        | 0.00         |
| Mature fruit:Female-control:Male          | 37.00             | 32.41        | 41.59        | 0.00         |
| Control:Female-control:Male               | 0.00              | -4.59        | 4.59         | 1.00         |
| Tender shoot:Female-Flower:Female         | 17.42             | 12.82        | 22.01        | 0.00         |
| Immature fruit:Female-Flower:Female       | 9.75              | 5.16         | 14.34        | 0.00         |
| Mature fruit:Female-Flower:Female         | 25.25             | 20.66        | 29.84        | 0.00         |
| Control:Female-Flower:Female              | -11.75            | -16.34       | -7.16        | 0.00         |
| Immature fruit:Female-Tender shoot:Female | -7.67             | -12.26       | -3.07        | 0.00         |
| Mature fruit:Female-Tender shoot:Female   | 7.83              | 3.24         | 12.43        | 0.00         |
| Control:Female-Tender shoot:Female        | -29.17            | -33.76       | -24.57       | 0.00         |
| Mature fruit:Female-Immature fruit:Female | 15.50             | 10.91        | 20.09        | 0.00         |
| Control:Female-Immature fruit:Female      | -21.50            | -26.09       | -16.91       | 0.00         |
| Control:Female-Mature fruit:Female        | -37.00            | -41.59       | -32.41       | 0.00         |

The relationship between herbivorous insects and the compounds in their host plants is a key factor in the insects' preference for certain plants (**Yongjun and Fushun 1994**). Different tissues and volatile cues from host plants are crucial for attracting insects and influencing their choice of feeding sites, oviposition behavior, locating and recognizing a suitable host plant for larval growth and assistance in finding a mating partner (**Scheirs and Bruyn, 2002; Bruce et al., 2005, Cunningham et al., 2001; Anderson and Anton 2014**). Behavioural assays using a five-arm olfactometer showed that adult female *C. sinensis* preferred mature fruits over other tissues of host plants. In contrast, male adult *C. sinensis* did not show significant differences in their reactions to the different litchi tissues in the behavioural assays. The survival of offspring may be influenced by the compounds present in the host plants and the nutritional quality of these plants **Ballabeni et al., 2001**. Olfactometer bioassays conducted by **Xu et al. (2008)** revealed that female cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), exhibited a robust olfactory response to volatiles emitted by cotton flowers, cotton bolls, and leaves, while males demonstrated a heightened olfactory response to volatiles emitted by cotton flowers and leaves. (**Wang et al., 2007**) studied the olfactory response of male and female *Spodoptera litura* to various plant volatiles using a Y-tube olfactometer. Results showed that both sexes were attracted to volatiles from the host plants, but the females were more attracted than the males. (**Chen et al., 2010**) observed the olfactory response of the Oriental fruit moth, *Cydia molesta*, to different parts of the apple tree. Results revealed that females were more attracted to volatiles from apple leaves, while males were more attracted to volatiles from apple fruit. An investigation on the olfactory response of the rice stem borer, *Chilo suppressalis*, was conducted using a Y-tube olfactometer by **Jiang et al. (2011)**, the results of the study indicated that both male and female moths were attracted to volatiles emitted from rice plants, however, the females exhibited a higher level of attraction to volatiles emitted from rice panicles than males. **Zhang et al. (2012)** used a Y-tube olfactometer to investigate the olfactory response of the Indian meal moth, *Plodia interpunctella*, to volatiles emitted from wheat flour. The study results revealed that both male and female adults were attracted to volatiles from wheat flour, but females were more attracted than males.

#### 4.6 To study the impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults

In the present study, plant and animal based natural formulations, previously identified as insect repellents, were assessed for their ability to disrupt the olfactory orientation of litchi fruit borer adults in choice olfactometer bioassays. A visual representation of the mean orientation of litchi fruit borer for different treatments over different time intervals in hours is shown in **Figure 4.18**.



**Figure 4.18: Mean orientation of Litchi fruit borer for different time intervals**

The preliminary observations based on the data indicate that there are differences in the repellent activity of different formulations towards litchi fruit borer adult. To determine whether these differences are statistically significant, A one-way analysis of variance (ANOVA) was conducted for litchi fruit borer in different time intervals with different treatments as the independent factor. An analysis of variance indicates significant differences between the mean orientations of litchi fruit borer under different treatments. A post-hoc analysis was performed using the Duncan Multiple Range Test (DMRT), where the DMRT works by comparing the means of the different treatments and used determine whether they are significantly different from one another or not. The results are shown in **Table 4.20**.

**Table 4.20: Mean orientation of litchi fruit borer adults after different time intervals**

| Treatments           | Conc. % | Mean orientation of litchi fruit borer adults after different time intervals |                 |                 |                 |
|----------------------|---------|--|-----------------|-----------------|-----------------|
|                      |         | 1hr  | 2hr             | 3hr             | Cumulative mean |
| Panchagavya          | 3%      | 1.11<br>(1.45)   | 1.11<br>(1.36)  | 3.33<br>(1.95)  | 1.85<br>(1.59)  |
| Vermiwash            | 50%     | 22.22<br>(4.82)  | 19.52<br>(4.53) | 17.11<br>(4.26) | 19.62<br>(4.53) |
| NSKE                 | 5%      | 8.89<br>(3.14)   | 4.45<br>(2.18)  | 8.89<br>(3.13)  | 7.41<br>(2.82)  |
| Dashparni            | 3%      | 13.33<br>(3.78)  | 8.24<br>(3.03)  | 12.22<br>(3.59) | 11.26<br>(3.47) |
| Neemastra            | 3%      | 3.33<br>(2.08)   | 2.22<br>(1.72)  | 5.56<br>(2.54)  | 3.70<br>(2.11)  |
| Chlorantraniliprole  | 18.5%SC | 0.00<br>(1.00)   | 0.00<br>(1.00)  | 0.00<br>(1.00)  | 0.00<br>(1.00)  |
| Lantana leaf extract | 5%      | 17.78<br>(4.33)  | 15.76<br>(4.09) | 15.33<br>(4.04) | 16.29<br>(4.15) |
| Control              | --      | 28.71<br>(5.54)  | 29.44<br>(5.52) | 31.06<br>(5.66) | 29.74<br>(5.54) |
| SEM ±                |         | 0.68   | 1.10            | 1.46            | 1.08            |
| CD@5%                |         | 2.05   | 3.33            | 4.42            | 3.26            |
| CV                   |         | 9.83   | 18.89           | 21.64           | 16.79           |

#### **Olfactometer studies on odour repellency of different natural formulations on litchi fruit borer under laboratory condition**

The repellent activity of different natural formulations towards litchi fruit borer was observed in eight arm olfactometer, where gauzes impregnated with natural formulations solution were used. The odor of each natural formulation was tested against a control (clean gauze) to find out the relative repellent activity of different natural formulations on fruit borer adults with respect to orientation of the fruit borer towards different natural formulations. The repellent effect of natural formulations on orientation of litchi fruit borer adults was observed after 1 hour, 2 hours, and 3 hours of their release. In the olfactometer, the insects were allowed to move for 10 minutes. Total three of olfactometer were used at the same time. For each olfactometer, 30 insects were released. To avoid biased results due to light, all behavioural measurements were performed in the dark (Martin *et al.*, 2020). The data recorded on the odor preference of litchi fruit borer adults towards 8 different arms of an olfactometer each arm having gauzes impregnated with natural formulations and

untreated control gauze is presented in **Table 4.20**. Clearly depicted that the gauzes impregnated with natural formulations were less preferred by the litchi fruits borers as their orientation observed was very less towards the treated gauzes at different time interval of exposure to treatments.

There was a significant reduction in the number of insects moving towards the chlorantraniliprole 18.5% SC treated gauzes after 1 hour of release, as there were no litchi fruit borers oriented towards the treatment. Vermiwash 50% showed the least repellent activity towards litchi fruit borers, with 22.22 borers per arm in the olfactometer among the treatments, followed by lantana leaf extract 5% with 17.78 borers per arm, Dashparni 3% with 11.33 borers per arm, NSKE 5% with 8.89 borers per arm, neemastra 3% with 3.33 borers per arm and panchgavya 3% with 1.11 borers per arm as compared to maximum preference with 28.71 borers per arm was observed in untreated control.

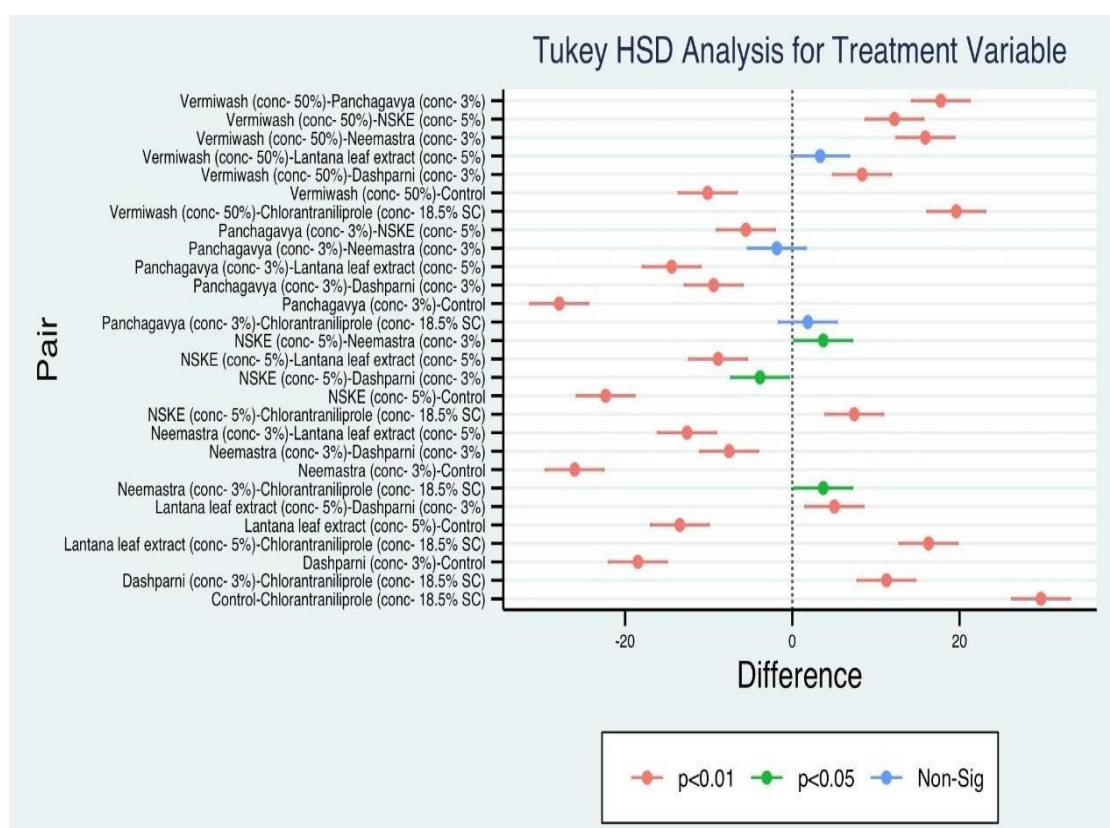
After 2hr of release of litchi fruit borer adults, highest repellency towards insects was shown by chlorantraniliprole 18.5%SC treated gauze, where no litchi fruit borers were oriented towards the treated gauze. In contrast, the panchgavya 3% treated gauze significantly repelled fruit borers, with an average of 1.11 borers per arm. Moreover, after 2 hours of release of litchi fruit borer adults, gauzes treated with neemastra 3% had an average of 2.22 borers per arm, NSKE 5% had 4.45 borers per arm, dashparni with 3% had 8.24 borers per arm, lantana leaf extract 5% had 15.76 borers per arm, and vermiwash 3% had 19.52 borers per arm. The untreated control gauze had the highest number of borers, with an average of 29.44 borers per arm. After 3hr of release, there were no litchi fruit borer adults oriented towards chlorantraniliprole 18.5%SC treated gauzes, the least number of litchi fruit borer adults were oriented towards panchgavya 3% with 3.33 followed by neemastra 3% with 5.56, NSKE 5% with 8.82, dashparni 3% with 12.22, lantana leaf extract 5% with 15.33, and vermiwash 3% with 17.11 as compared to 31.06 litchi fruit borer recorded in untreated control gauzes.

A one-way ANOVA results shows that there is a significant difference in the mean orientation of the litchi fruit borer adults with respect to all the independent factors considered here followed by Tukey HSD post- hoc test which was used to compare differences between the treatments.

**Table 4.21: One-way ANOVA results**

| Term       | df | sumsq   | meansq | F statistic | p.value |
|------------|----|---------|--------|-------------|---------|
| Treatments | 7  | 6514.14 | 930.59 | 169.92      | 0.00    |
| Residuals  | 64 | 350.51  | 5.48   | NA          | NA      |

**Figure 4.19** plots the pair wise comparison of different treatment groups using the Tukey HSD post hoc analysis. The range of the differences are plotted using line bar graph where the orange colour indicates statically significant difference at ( $p < 0.01$ ) between the pair groups, the green colour again indicates significant difference at ( $p > 0.05$ ), and the blue line bar graphs indicated non-significant. No significant difference in repelling litchi fruit borer is shown by a treatment pair of vermiwash and lantana, panchgavya and neemastra, and panchgavya and chlorantranilprole. All the other treatment groups differ significantly from each other.

**Figure 4.19: Pair wise comparison of different treatment groups**

In this study, we evaluated the repellent activity of indigenously prepared plant and animal-based formulations for their potential use in an integrated pest management program within a protected environment. The results of this study showed that some of the natural formulations had low to moderate repellent activity, while others had high levels of repellent activity. There is a lack of research in the literature on the olfactory response of insects to plant and animal-based natural formulations. Therefore, the findings of this study will serve as a useful reference for future research on the effectiveness of these natural formulations as insect repellents. **Jang *et al.* (1997)** observed that mated female oriental fruit flies were attracted to fresh mature whole panax leaves. **Pazhanisamy and Krishnan (2019)** reported 83.33% larval mortality among the fruit borers of okra with panchagavya (3%) + NSKE (5%) under in vitro condition.

#### **4.7. Evaluate the efficacy of different plant and animal based natural based formulations against the major pests associated with litchi.**

##### **4.7.1 Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2018 and 2019**

Field observation on the number of fruits infested with infested fruits in different treated and control plants were taken from 10 randomly tagged panicle per direction of the plant to access the efficacy of different treatments against infested fruits. Mean number of fruits infested per panicle before and after different days of 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> spraying was presented in **Table: 2.22; 2.23; 2.24** and **Fig. 4.20; 4.21; 4.21** respectively.

##### **4.7.2 Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2018**

The efficacy of different natural formulations and botanicals *viz.*, Panchgavya (T1), vermiwash (T2), NSKE(T3), dashparni (T4), neemastra (T5), chlorantraniliprole (T6), lantana (T7) and untreated control (T8) were evaluated against infested fruits during the year 2018. Three sprayings were carried out during the crop season. The efficacy of different treatments against litchi fruit borer for the year 2018 was presented in Table 2.22 and Figure 4.20.

#### **4.7.3 Observations on mean number of infested fruit before first spraying (1 DBS)**

The observations on mean number of infested fruits with fruit borer larvae before one day of spraying was counted from ten different panicle per direction of each plant and the mean number of infested fruits per panicle was calculated. The mean number of infested fruits in both treated and untreated plants ranged from 2.73 to 3.85 per panicle before spraying on any treatment. No significant difference among the number of fruit borer larvae were recorded during pre- spray observation.

#### **4.7.4 Observations on mean number of infested litchi fruits after different days of first spraying**

The mean number of infested fruit/panicle after different days of 1<sup>st</sup> spraying were presented in Table 2.22 after one day of first spraying, the mean number infested fruits/panicle varied from 1.5-3.75/plant. The least number of infested fruit (1.5/panicle) were recorded in chlorantraniliprole treated plant. Whereas, panchgavya was found most effective amongst the natural formulations with 1.95 infested fruit/ panicle, followed by neemastra (2.3 infested fruits/panicle), NSKE (2.48 infested fruits/panicle), dashparni (3.2 infested fruits/panicle), vermiwash (3.2 infested fruits/panicle), and lantana (3.33 infested fruits/panicle) as compared to highest number of infested fruits (3.75 infested fruits/panicle) in control plant.

A significant reduction in number of infested fruits were recorded after 3 days of spraying. The least number of infested fruit (0.85/panicle) were recorded in chlorantraniliprole treated plants followed by panchgavya (1.13infested fruits/panicle), neemastra (1.53 infested fruits/panicle), NSKE (1.73 infested fruits/panicle), dashparni (2.33 infested fruits/panicle), vermiwash (2.6 infested fruits/panicle) and lantana (3.25 infested fruits/panicle). However, the highest number of infested fruit were recorded in control plant (3.8 / panicle).

After 7 days of first spraying, the descending order of efficacy among different treatments with respect to reduction in number of infested fruit was, chlorantraniliprole (0.98 /panicle) followed by panchgavya (1.45/panicle), neemastra (1.58/panicle), NSKE (1.9 /panicle), dashparni (2.38/panicle), vermiwash (3.05/panicle), and lantana (3.53/panicle) as compared to highest number of infested fruits in control plant (3.9/panicle).

**Table 4.22: Mean number of infested litchi fruit after different days of first spraying during the year 2018**

| Treatments          | Conc./<br>Dose | Mean number of infested fruit/ panicle after 1 <sup>st</sup> spray |                |                 |                 |                |                |                |
|---------------------|----------------|--|----------------|-----------------|-----------------|----------------|----------------|----------------|
|                     |                | 1DBS   | 1DAS           | 3DAS            | 7DAS            | 10DAS          | 14DAS          | MEAN           |
| Panchgavya          | 3%             | 2.73<br>(1.93)   | 1.95<br>(1.72) | 1.13<br>(1.46)  | 1.45<br>(1.57)  | 1.68<br>(1.64) | 2.38<br>(1.84) | 1.72<br>(1.65) |
| Vermiwash           | 50%            | 3.08<br>(2.02)   | 3.2<br>(2.05)  | 2.6<br>(1.9)    | 3.05<br>(2.02)  | 3.00<br>(2)    | 3.68<br>(2.17) | 3.11<br>(2.03) |
| NSKE                | 5%             | 3.03<br>(2.01)   | 2.48<br>(1.87) | 1.73<br>(1.65)  | 1.9<br>(1.71)   | 2.6<br>(1.9)   | 3.08<br>(2.02) | 2.36<br>(1.83) |
| Dashparni           | 3%             | 3.85<br>(2.21)   | 3.2<br>(2.05)  | 2.33<br>(1.83)  | 2.38<br>(1.84)  | 2.83<br>(1.96) | 3.35<br>(2.09) | 2.82<br>(1.95) |
| Neemastra           | 3%             | 2.75<br>(1.94)   | 2.3<br>(1.82)  | 1.53<br>(1.59)  | 1.58<br>(1.6)   | 2.38<br>(1.84) | 2.58<br>(1.89) | 2.07<br>(1.75) |
| Chlorantraniliprole | 18.5% SC       | 3.1<br>(2.03)  | 1.5<br>(1.58)  | 0.85<br>(1.36)  | 0.98<br>(1.41)  | 1.53<br>(1.59) | 1.6<br>(1.62)  | 1.29<br>(1.51) |
| Lantana             | 5%             | 3.13<br>(2.03)   | 3.33<br>(2.08) | 3.25<br>(2.07)  | 3.53<br>(2.13)  | 3.58<br>(2.14) | 3.95<br>(2.23) | 3.53<br>(2.13) |
| Control             |                | 2.88<br>(1.97)   | 3.75<br>(2.18) | 3.8<br>(2.19)   | 3.9<br>(2.22)   | 3.95<br>(2.23) | 4.25<br>(2.3)  | 3.93<br>(2.22) |
| C.D.(p=0.05)        |                | N/A  | 0.29<br>(0.08) | 0.36<br>(0.11)  | 0.43<br>(0.13)  | 0.26<br>(0.07) | 0.3<br>(0.08)  | 0.33<br>(0.09) |
| SE(m)               |                | 0.24<br>(0.06)   | 0.1<br>(0.03)  | 0.12<br>(0.04)  | 0.15<br>(0.05)  | 0.09<br>(0.03) | 0.1<br>(0.03)  | 0.11<br>(0.04) |
| C.V. (%)            |                | 15.69<br>(5.9)   | 6.99<br>(2.6)  | 11.09<br>(4.16) | 12.32<br>(4.73) | 6.37<br>(2.39) | 6.43<br>(2.39) | 8.64<br>(3.25) |

\*Values in the parentheses are square root transformed values

A slight increase in the number of infested fruits were recorded after 10 and 14 days of spraying. The number of infested fruits were 1.53, 1.68, 2.38, 2.6, 2.83, 3, 3.58, and 3.95 infested fruit per panicle in chlorantraniliprole, panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively after 10 days of spraying. The number of infested fruit were 3.95/panicle in control plant.

The highest number of infested fruits after 1<sup>st</sup> spraying was recorded during 14 DAS. The number of infested fruits/panicle were 1.6, 2.38, 2.58, 3.08, 3.35, 3.68 and 3.95 per panicle in chlorantraniliprole, panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 4.25 /panicle in control.

The data on mean number of infested fruit after 1<sup>st</sup> spray clearly revealed that all the treatments showed significant reduction in number of infested fruits as compared to control. The least number of infested fruit (1.29/panicle) was recorded in chlorantraniliprole treated plants and was closely followed by panchgavya (1.72 /panicle). Amongst the remaining treatments, the order of effectiveness among treatments against infested fruits was neemastra (2.07/panicle), NSKE (2.36/panicle), dashparni (2.82/panicle), vermiwash (3.11/panicle) and lantana (3.53/panicle), respectively. Whereas, the highest number of infested fruit (3.93/panicle) was recorded in control.

#### **4.7.5 Observations on mean number of infested litchi fruits after different days of second spraying**

The mean number of infested fruit after different days of 2<sup>nd</sup> spraying were presented in **Table 2.23** The mean number of infested fruit decreased gradually after 2<sup>nd</sup> spraying. After 1day of 2<sup>nd</sup> spraying, the mean number of infested fruits ranged from 1.38- 3.28/panicle. The least number (1.38/panicle) of infested fruits were recorded in chlorantraniliprole, followed by panchgavya (1.75/panicle), neemastra (2.03/panicle), NSKE (2.15/panicle), dashparni (2.3/panicle), vermiwash (2.68/panicle) and lantana (3.05/panicle) as compared to (3.28/panicle) in control.

After 3 days of second spraying, the lowest and highest number of infested fruits were recorded in chlorantraniliprole and control plant with 0.63 and 3.6 infested fruits/panicle, respectively. Amongst the natural formulations and botanicals, the least reduction in number of infested fruits were recorded in lantana (2.55/panicle). Amongst the remaining treatments, panchgavya was found most effective with 0.93 infested fruits/panicle, followed by neemastra, NSKE, dashparni and vermiwash with 1.5, 1.58, 1.78, 2.28 infested fruits/panicle, respectively.

**Table 4.23: Mean number of infested litchi fruit after different days of second spraying during the year 2018**

| Treatments          | Conc./<br>Dose | Mean number of infested fruit/ panicles after 2 <sup>nd</sup> spray |                |                |                |                 |                 |
|---------------------|----------------|---|----------------|----------------|----------------|-----------------|-----------------|
|                     |                | 1DAS  | 3DAS           | 7DAS           | 10DAS          | 14DAS           | MEAN            |
| Panchgavya          | 3%             | 1.75<br>(1.66)  | 0.93<br>(1.39) | 1.25<br>(1.5)  | 1.58<br>(1.61) | 2.2<br>(1.79)   | 1.54<br>(1.59)  |
| Vermiwash           | 50%            | 2.68<br>(1.92)  | 2.28<br>(1.81) | 3.08<br>(2.02) | 2.5<br>(1.87)  | 3.18<br>(2.05)  | 2.74<br>(1.93)  |
| NSKE                | 5%             | 2.15<br>(1.77)  | 1.58<br>(1.6)  | 1.75<br>(1.66) | 2.38<br>(1.84) | 3.05<br>(2.02)  | 2.18<br>(1.78)  |
| Dashparni           | 3%             | 2.3<br>(1.82)   | 1.78<br>(1.67) | 2.15<br>(1.78) | 2.45<br>(1.86) | 3.08<br>(2.02)  | 2.35<br>(1.83)  |
| Neemastra           | 3%             | 2.03<br>(1.74)  | 1.5<br>(1.58)  | 1.38<br>(1.54) | 1.95<br>(1.72) | 2.38<br>(1.84)  | 1.85<br>(1.69)  |
| Chlorantraniliprole | 18.5%<br>SC    | 1.38<br>(1.54)  | 0.63<br>(1.28) | 1.08<br>(1.44) | 1.48<br>(1.58) | 1.55<br>(1.6)   | 1.22<br>(1.49)  |
| Lantana             | 5%             | 3.05<br>(2.01)  | 2.55<br>(1.87) | 3.18<br>(2.05) | 3.08<br>(2.02) | 3.43<br>(2.11)  | 3.06<br>(2.01)  |
| Control             |                | 3.28<br>(2.07)  | 3.6<br>(2.15)  | 4.03<br>(2.25) | 3.83<br>(2.2)  | 4.13<br>(2.27)  | 3.77<br>(2.19)  |
| C.D.(p=0.05)        |                | 0.78<br>(0.22)  | 0.61<br>(0.18) | 0.46<br>(0.15) | 0.33<br>(0.09) | 0.44<br>(0.12)  | 0.53<br>(0.15)  |
| SE(m)               |                | 0.27<br>(0.08)  | 0.21<br>(0.07) | 0.16<br>(0.05) | 0.11<br>(0.03) | 0.15<br>(0.04)  | 0.18<br>(0.06)  |
| C.V. (%)            |                | 22.53<br>(8.06)   | 22.2<br>(7.32) | 13.83<br>(5.4) | 9.18<br>(3.33) | 10.19<br>(4.03) | 15.59<br>(5.63) |

\*Values in the parentheses are square root transformed values

After 7 days of second spraying, the order of efficacy among different treatments remained the same with 1.08, 1.25, 1.38, 1.75, 2.15, 3.08, 3.18 and 4.03 infested fruit/panicle in chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 4.03 infested fruits/panicle in control.

The number of infested fruits gradually increased after 10 and 14 days of 2<sup>nd</sup> spraying. The mean number of infested fruits recorded after 10 days of spraying were 1.48, 1.58, 1.95, 2.38, 2.45, 2.5, 3.08 and 3.83 infested fruit/panicle in chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 3.83 infested fruits/plant in control.

Similarly, the least number of infested fruits (1.22/panicle) were recorded in chlorantraniliprole treated plants followed by panchgavya (2.2/panicle), neemastra (2.38), NSKE (3.05/panicle), dashparni (3.08/panicle), vermiwash (3.18/panicle), and lantana (3.43 /panicle) as compared to 4.13 fruit borer/panicle in untreated control plant after 14 days of second spraying.

The mean number of infested fruits after 2<sup>nd</sup> spraying ranged from 1.22-3.77/panicle in chlorantraniliprole and control plant, respectively. Whereas, the least number of infested fruits amongst the treatments, were recorded in panchgavya (1.54/panicle), followed by neemastra (1.85/panicle), NSKE (2.18/panicle), dashparni (2.35/panicle), vermiwash (2.74/panicle), and lantana (3.06/panicle).

#### **4.7.6 Observations on mean number of infested litchi fruits after different days of third spraying**

The mean number of infested fruits after different days of 3<sup>rd</sup> spraying were presented in **Table 2.24**. After 1 day of 3<sup>rd</sup> spraying, the mean number of infested fruits ranged from 1.7-3.25/panicle. The least number (1.7/panicle) of infested fruits were recorded in chlorantraniliprole, followed by panchgavya (2.08/panicle), neemastra (2.25/panicle), NSKE (2.38/panicle), dashparni (2.65/panicle), vermiwash (3.08/panicle) and lantana (3.25/panicle) as compared to (3.83/panicle) in control.

After 3 days of first spraying, the highest and lowest number of infested fruits were recorded in chlorantraniliprole and control plant with 0.95 and 3.78 infested fruits/panicle, respectively. Amongst the natural formulations, highest and the least reduction in number of infested fruits were recorded in a lantana (3.45/panicle) and vermiwash (3.05/panicle). Amongst the remaining treatments, panchgavya was found most effective with 1.18 infested fruits/panicle, followed by NSKE, neemastra, and dashparni with 2.10, 2.18 and 2.80 infested fruits/panicle, respectively.

**Table 4.24: Efficacy of different treatments against infested fruits on litchi after 3<sup>rd</sup> spray during the year 2018**

| Treatment           | Conc./<br>Dose | Mean number of infested fruits / panicles after 3 <sup>rd</sup> spray |                |                 |                |                 |                |
|---------------------|----------------|---|----------------|-----------------|----------------|-----------------|----------------|
|                     |                | 1DAS  | 3DAS           | 7DAS            | 10DAS          | 14DAS           | MEAN           |
| Panchgavya          | 3%             | 2.08<br>(1.76)  | 1.18<br>(1.48) | 1.75<br>(1.66)  | 1.58<br>(1.61) | 2.2<br>(1.79)   | 1.76<br>(1.66) |
| Vermiwash           | 50%            | 3.08<br>(2.02)  | 3.05<br>(2.02) | 3.2<br>(2.05)   | 2.5<br>(1.87)  | 3.18<br>(2.05)  | 3<br>(2)       |
| NSKE                | 5%             | 2.38<br>(1.84)  | 2.1<br>(1.76)  | 2.15<br>(1.78)  | 2.38<br>(1.84) | 3.05<br>(2.02)  | 2.41<br>(1.85) |
| Dashparni           | 3%             | 2.65<br>(1.91)  | 2.8<br>(1.95)  | 2.75<br>(1.94)  | 2.45<br>(1.86) | 3.08<br>(2.02)  | 2.75<br>(1.94) |
| Neemastra           | 3%             | 2.25<br>(1.81)  | 2.18<br>(1.78) | 1.95<br>(1.72)  | 1.95<br>(1.72) | 2.38<br>(1.84)  | 2.14<br>(1.78) |
| Chlorantraniliprole | 18.5%<br>SC    | 1.7<br>(1.65)   | 0.95<br>(1.4)  | 1.43<br>(1.56)  | 1.73<br>(1.65) | 1.55<br>(1.6)   | 1.47<br>(1.57) |
| Lantana 5%          | 5%             | 3.25<br>(2.07)  | 3.45<br>(2.11) | 3.4<br>(2.1)    | 3.08<br>(2.02) | 3.43<br>(2.11)  | 3.32<br>(2.08) |
| Control             |                | 3.83<br>(2.2)   | 3.78<br>(2.19) | 4.43<br>(2.33)  | 3.83<br>(2.2)  | 4.13<br>(2.27)  | 4<br>(2.24)    |
| C.D.(p=0.05)        |                | 0.21<br>(0.06)  | 0.3<br>(0.09)  | 0.42<br>(0.11)  | 0.33<br>(0.09) | 0.44<br>(0.12)  | 0.34<br>(0.1)  |
| SE(m)               |                | 0.07<br>(0.02)  | 0.1<br>(0.03)  | 0.15<br>(0.04)  | 0.11<br>(0.03) | 0.15<br>(0.04)  | 0.12<br>(0.04) |
| C.V. (%)            |                | 5.28<br>(1.98)  | 8.09<br>(2.99) | 10.76<br>(3.82) | 9.05<br>(3.28) | 10.19<br>(4.03) | 8.67<br>(3.22) |

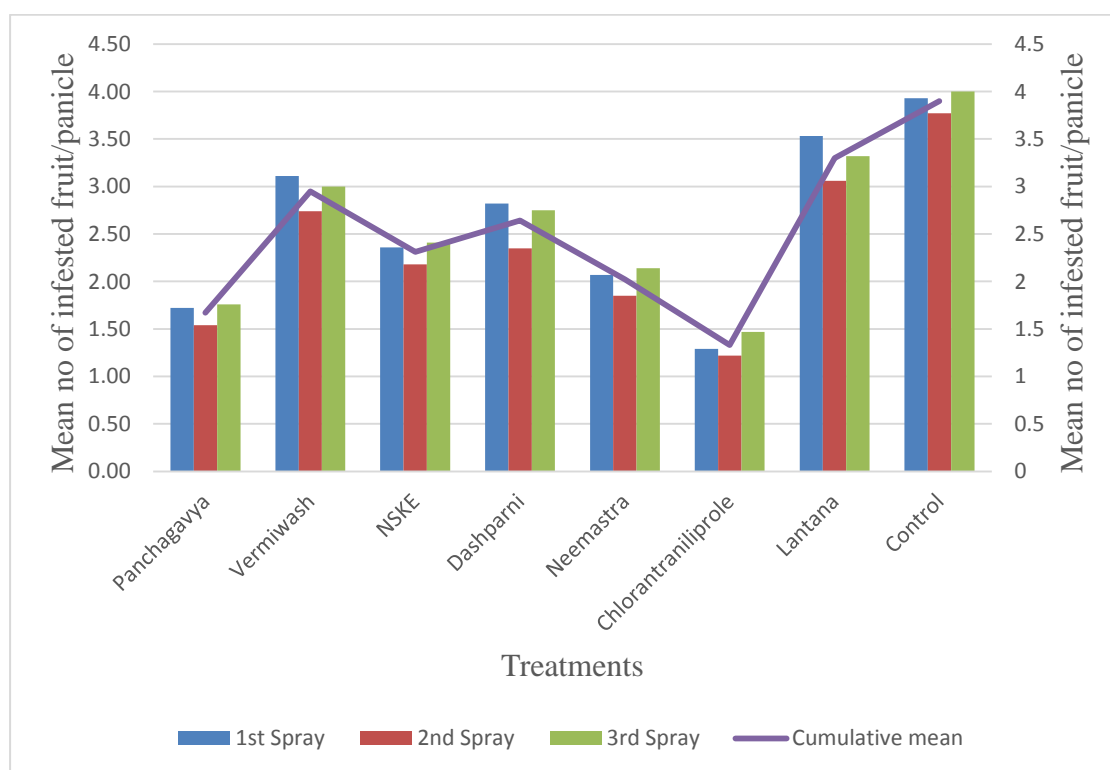
\*Values in the parentheses are square root transformed values

After 7 days of first spraying, the order of efficacy among different treatments remained the same with 1.43, 1.75, 1.95, 2.15, 2.75, 3.20, and 3.40 fruit borers/panicle in chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 4.43 infested fruits/panicle in control.

The number of infested fruits gradually increased after 10 and 14 days of 2<sup>nd</sup> spraying. The mean number of infested fruits recorded after 10 days of spraying were 1.73, 1.58, 1.95, 2.38, 2.45, 2.5, 3.08 and 3.18 fruit borer/panicle chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 3.83 infested fruits/plant in control.

Similarly, the least number of infested fruits (1.55/panicle) were recorded in chlorantraniliprole treated plants followed by panchgavya (2.2/panicle), neemastra (2.38), NSKE (3.05/panicle), dashparni (3.08/panicle), vermiwash (3.18/panicle), and lantana (3.43 /panicle) as compared to 4.13 fruit borer/panicle in untreated control plant after 14 days of second spraying.

The mean number of infested fruits after 2<sup>nd</sup> spraying ranged from 1.47-4.00/panicle in chlorantraniliprole and control plant, respectively. Whereas, the least number of infested fruits amongst the treatments, were recorded in panchgavya (1.76/panicle), followed by neemastra (2.14/panicle), NSKE (2.41/panicle), dashparni (2.75/panicle), vermiwash (3.00/panicle), and lantana (3.32/panicle).



**Fig 4.20: Efficacy of different treatments against litchi fruit borer during the year 2018**

#### 4.7.7. Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2019

The efficacy of different natural formulations and botanicals *viz.*, Panchgavya (T1), vermiwash (T2), NSKE(T3), dashparni (T4), neemastra (T5), chlorantraniliprole (T6), lantana (T7) and untreated control (T8) were evaluated against litchi fruit borer during the year 2019. Three sprayings were carried out during the crop season. The efficacy of different treatments against litchi fruit borer for the year 2019 was presented in Table 4.24 and Figure 4.20.

#### 4.7.8 Observations on number of infested litchi fruits before first spraying (1 DBS)

The observations on mean number of infested fruits with fruit borer larvae before one day of spraying was taken from ten different panicle per direction of each plant and the mean number larvae per panicle was calculated on the basis of infested fruits observed. The mean number of infested fruit in both treated and untreated plants ranged from 2.70 to 3.83 larvae per plant. No significant difference among the number of infested fruit were recorded during pre- spray observation.

#### 4.7.9 Observations on mean number of infested litchi fruits after different days of first spraying

The mean number of infested litchi fruits/panicle after different days of 1<sup>st</sup> spraying were presented in **Table 4.25**. After one day of first spraying, the mean number infested fruits/panicle varied from 1.45-3.78/plant. The least number of infested fruits (1.45/ panicle) were recorded in chlorantraniliprole treated plant. Whereas, panchgavya was found most effective amongst the natural formulations with 1.90 larvae/ panicle, followed by neemastra (2.23 larvae/ panicle), NSKE (2.43 larvae/panicle), dashparni (2.98 larvae/ panicle), vermiwash (3.1 larvae/ panicle), and lantana (3.15 larvae/ panicle) as compared to highest number of infested fruit (3.78/panicle) in control plant.

After 3 days of first spraying, the descending order of efficacy among different treatments with respect to reduction in number of infested fruit was, chlorantraniliprole (0.75 /panicle) followed by panchgavya (1.08/panicle), neemastra (1.30/panicle), NSKE (1.65 /panicle), dashparni (2.18/panicle), vermiwash (3.10/panicle), and lantana

(3.20/panicle) as compared to highest number of infested fruit in control plant (3.70/panicle).

A significant reduction in number of infested fruits were recorded after 7 days of spraying, the least number of infested fruits (0.93/panicle) were recorded in chlorantraniliprole treated plants followed by panchgavya (1.35/infested fruits/panicle), neemastra (1.50 infested fruits/panicle), NSKE (1.80 infested fruits/panicle), dashparni (2.20 infested fruits/panicle), vermiwash (2.98 infested fruits/panicle) and lantana (3.30 infested fruits/panicle). However, the highest number of infested fruits were recorded in control plant (3.95 / panicle).

The number of infested fruits were 1.45, 1.55, 2.35, 2.5, 2.78, 2.98 and 3.30 per panicle in chlorantraniliprole, panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively after 10 days of spraying. The number of infested fruits were 3.73/panicle in control plant.

The highest number of infested fruits after 1<sup>st</sup> spraying was recorded during 14 DAS. The number of infested fruits/panicle were 1.45, 2.25, 2.40, 3.03, 3.25, 3.43 and 3.88 per panicle in chlorantraniliprole, panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 4.00 /panicle in control.

The data on mean number of infested fruits after 1<sup>st</sup> spray clearly revealed that all the treatments showed significant reduction in number of infested fruits as compared to control. The least number of infested fruits (1.21/panicle) was recorded in chlorantraniliprole treated plants and was closely followed by panchgavya (1.63 /panicle). Amongst the remaining treatments, the order of effectiveness among treatments against litchi fruit borer was neemastra (1.96/panicle), NSKE (2.28/panicle), dashparni (2.68/panicle), vermiwash (2.98/panicle) and lantana (3.39/panicle), respectively. Whereas, the highest number of infested fruits (3.83/panicle) was recorded in control.

**Table 4.25: Efficacy of different treatments against infested fruits on litchi after 1st spray during the year 2019**

| Treatments                 | Conc./<br>Dose      | Mean number of infested fruits/ panicle after 1 <sup>st</sup> spray |                |                 |                 |                 |                 |                 |
|----------------------------|---------------------|---|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                            |                     | 1DBS  | 1DAS           | 3DAS            | 7DAS            | 10DAS           | 14DAS           | MEAN            |
| <b>Panchgavya</b>          | <b>3%</b>           | 2.70  | 1.9<br>(1.71)  | 1.08<br>(1.44)  | 1.35<br>(1.54)  | 1.55<br>(1.6)   | 2.25<br>(1.81)  | 1.63<br>(1.57)  |
| <b>Vermiwash</b>           | <b>50%</b>          | 3.05  | 3.1<br>(2.03)  | 2.4<br>(1.85)   | 2.98<br>(2.00)  | 3.00<br>(2.00)  | 3.43<br>(2.11)  | 2.98<br>(1.97)  |
| <b>NSKE</b>                | <b>5%</b>           | 3.00  | 2.43<br>(1.85) | 1.65<br>(1.63)  | 1.8<br>(1.68)   | 2.5<br>(1.87)   | 3.03<br>(2.01)  | 2.28<br>(1.76)  |
| <b>Dashparni</b>           | <b>3%</b>           | 3.83  | 2.98<br>(2.00) | 2.18<br>(1.79)  | 2.2<br>(1.79)   | 2.78<br>(1.95)  | 3.25<br>(2.07)  | 2.68<br>(1.92)  |
| <b>Neemastra</b>           | <b>3%</b>           | 2.73  | 2.23<br>(1.8)  | 1.3<br>(1.52)   | 1.5<br>(1.58)   | 2.35<br>(1.83)  | 2.4<br>(1.85)   | 1.96<br>(1.72)  |
| <b>chlorantraniliprole</b> | <b>18.5%<br/>SC</b> | 3.10  | 1.45<br>(1.57) | 0.75<br>(1.33)  | 0.93<br>(1.39)  | 1.45<br>(1.57)  | 1.45<br>(1.57)  | 1.21<br>(1.48)  |
| <b>Lantana</b>             | <b>5%</b>           | 3.10  | 3.15<br>(2.04) | 3.2<br>(2.05)   | 3.3<br>(2.08)   | 3.4<br>(2.1)    | 3.88<br>(2.21)  | 3.39<br>(2.1)   |
| <b>Control</b>             |                     | 2.85  | 3.78<br>(2.19) | 3.7<br>(2.17)   | 3.95<br>(2.23)  | 3.73<br>(2.18)  | 4.00<br>(2.24)  | 3.83<br>(2.2)   |
| <b>C.D.(p=0.05)</b>        |                     | N/A   | 0.28<br>(0.08) | 0.36<br>(0.11)  | 0.44<br>(0.13)  | 0.49<br>(0.13)  | 0.55<br>(0.14)  | 0.42<br>(0.12)  |
| <b>SE(m)</b>               |                     | 0.23  | 0.1<br>(0.03)  | 0.13<br>(0.04)  | 0.15<br>(0.05)  | 0.17<br>(0.05)  | 0.19<br>(0.05)  | 0.15<br>(0.04)  |
| <b>C.V. (%)</b>            |                     | 14.99   | 7.03<br>(2.61) | 11.96<br>(4.24) | 12.95<br>(4.89) | 12.56<br>(4.68) | 12.55<br>(4.71) | 11.41<br>(4.23) |

\*Values in the parentheses are square root transformed values

#### 4.7.10 Observations on mean number of infested litchi fruit after different days of second spraying

The mean number of infested fruits after different days of 2<sup>nd</sup> spraying was presented in Table 4.26. After 1 days of first spraying, the highest and lowest number of infested fruits were recorded in chlorantraniliprole and control plant with 1.13 and 3.3 infested fruits/panicle, respectively. Amongst the natural formulations, highest and the least reduction in number of infested fruits were recorded in a panchagavya (1.33/panicle) and lantana (3.05/panicle). Amongst the remaining treatments, neemastra was found most effective with 1.68 infested fruits/panicle, followed by NSKE and dashparni with 2 and 2.25 infested fruits/panicle, respectively.

The mean number of infested fruits decreased gradually after 2<sup>nd</sup> spraying. After 3<sup>rd</sup> day of 2<sup>nd</sup> spraying, the mean number of infested fruits ranged from 0.55-3.68/panicle. The least number (0.55/panicle) of infested fruits were recorded in chlorantraniliprole, followed by panchgavya (0.75/panicle), NSKE (1.23/panicle), neemastra (1.23/panicle), dashparni (1.8/panicle), vermiwash (2.18/panicle) and lantana (2.6/panicle) as compared to (3.68/panicle) in control.

After 7 days of 2<sup>nd</sup> spraying, the order of efficacy among different treatments remained the same with 0.98, 1.15, 1.25, 1.58, 2.1, 2.93 and 3.1 fruit borers/panicle in chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 3.93 infested fruits/panicle in control.

After 10 days of 2<sup>nd</sup> spraying, the highest and lowest number of infested fruits were recorded in control and chlorantraniliprole with 3.85 and 1.3 infested fruits/panicle, respectively. Amongst the natural formulations, lowest and the highest reduction in number of infested fruits were recorded in a lantana (3.1/panicle) and panchagavya (1.45/panicle). Amongst the remaining treatments, neemastra was found most effective with 1.9 infested fruits/panicle, followed by NSKE, dashparni with vermiwash with 2.13, 2.3 and 2.48 infested fruits/panicle, respectively.

After 14 days of 2<sup>nd</sup> spraying, the order of efficacy among different treatments remained the same with 1.45, 2.08, 2.3, 2.88, 3.03, 3.1 and 3.23 fruit borers/panicle in chlorantraniliprole, Panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 3.95 infested fruits/panicle in control.

**Table 4.26: Efficacy of different treatments against infested fruits on litchi after 2<sup>nd</sup> spray during the year 2019**

| Treatments          | Conc./<br>Dose | Mean number of infested fruits / panicle after 2 <sup>nd</sup> spray |                |                 |                 |                 |                 |
|---------------------|----------------|--|----------------|-----------------|-----------------|-----------------|-----------------|
|                     |                | 1DAS   | 3DAS           | 7DAS            | 10DAS           | 14DAS           | MEAN            |
| Panchgavya          | 3%             | 1.33<br>(1.53)   | 0.75<br>(1.33) | 1.15<br>(1.46)  | 1.45<br>(1.57)  | 2.08<br>(1.76)  | 1.35<br>(1.53)  |
| Vermiwash           | 50%            | 2.53<br>(1.88)   | 2.18<br>(1.79) | 2.93<br>(1.98)  | 2.48<br>(1.87)  | 3.1<br>(2.03)   | 2.64<br>(1.91)  |
| NSKE                | 5%             | 2.00<br>(1.73)   | 1.23<br>(1.5)  | 1.58<br>(1.6)   | 2.13<br>(1.77)  | 2.88<br>(1.97)  | 1.96<br>(1.72)  |
| Dashparni           | 3%             | 2.25<br>(1.81)   | 1.8<br>(1.67)  | 2.1<br>(1.76)   | 2.3<br>(1.82)   | 3.03<br>(2.00)  | 2.3<br>(1.81)   |
| Neemastra           | 3%             | 1.68<br>(1.64)   | 1.23<br>(1.49) | 1.25<br>(1.5)   | 1.9<br>(1.71)   | 2.3<br>(1.82)   | 1.67<br>(1.63)  |
| Chlorantraniliprole | 18.5% SC       | 1.13<br>(1.46)   | 0.55<br>(1.24) | 0.98<br>(1.41)  | 1.3<br>(1.52)   | 1.45<br>(1.57)  | 1.08<br>(1.44)  |
| Lantana             | 5%             | 3.05<br>(2.02)   | 2.6<br>(1.89)  | 3.1<br>(2.03)   | 3.1<br>(2.03)   | 3.23<br>(2.06)  | 3.02<br>(2.01)  |
| Control             |                | 3.3<br>(2.08)  | 3.68<br>(2.17) | 3.93<br>(2.22)  | 3.85<br>(2.21)  | 3.95<br>(2.23)  | 3.74<br>(2.18)  |
| C.D.(p=0.05)        |                | 0.51<br>(0.15)   | 0.64<br>(0.19) | 0.51<br>(0.16)  | 0.39<br>(0.12)  | 0.71<br>(0.19)  | 0.55<br>(0.16)  |
| SE(m)               |                | 0.17<br>(0.05)   | 0.22<br>(0.07) | 0.17<br>(0.06)  | 0.13<br>(0.04)  | 0.24<br>(0.07)  | 0.19<br>(0.06)  |
| C.V. (%)            |                | 15.74<br>(5.5)   | 24.4<br>(7.88) | 15.92<br>(5.93) | 11.19<br>(4.35) | 17.29<br>(6.41) | 16.91<br>(6.02) |

\*Values in the parentheses are square root transformed values

#### 4.7.11 Observations on mean number of infested litchi fruit after different days of third spraying

The mean number of infested fruits recorded after 1 day of 3<sup>rd</sup> spraying were 1.5, 1.9, 2.15, 2.33, 2.53, 2.85 and 3.1 infested fruit/panicle in chlorantraniliprole, panchgavya, neemastra, NSKE, dashparni, vermiwash and lantana treated plants, respectively as compared to 3.65 infested fruits/plant in control.

Similarly, the least number of infested fruits (1.08/panicle) were recorded in chlorantraniliprole treated plants followed by panchgavya (1.15/panicle), neemastra (1.38), NSKE (1.73/panicle), dashparni (2.35/panicle), vermiwash (3.25/panicle), and lantana (3.68 /panicle) as compared to 3.9 fruit borer/panicle in untreated control plant after 3 days of 3<sup>rd</sup> spraying.

The mean number of infested fruits after 7 days of 3<sup>rd</sup> spraying ranged from 1.28-4.28 infested fruits/panicle in chlorantraniliprole and control plant respectively. Whereas, the least number of infested fruits amongst the treatments, were recorded in panchgavya (1.55/panicle), followed by neemastra (1.78/panicle), NSKE (2.1/panicle), dashparni (2.63/panicle), vermiwash (3.08/panicle), and lantana (3.33/panicle).

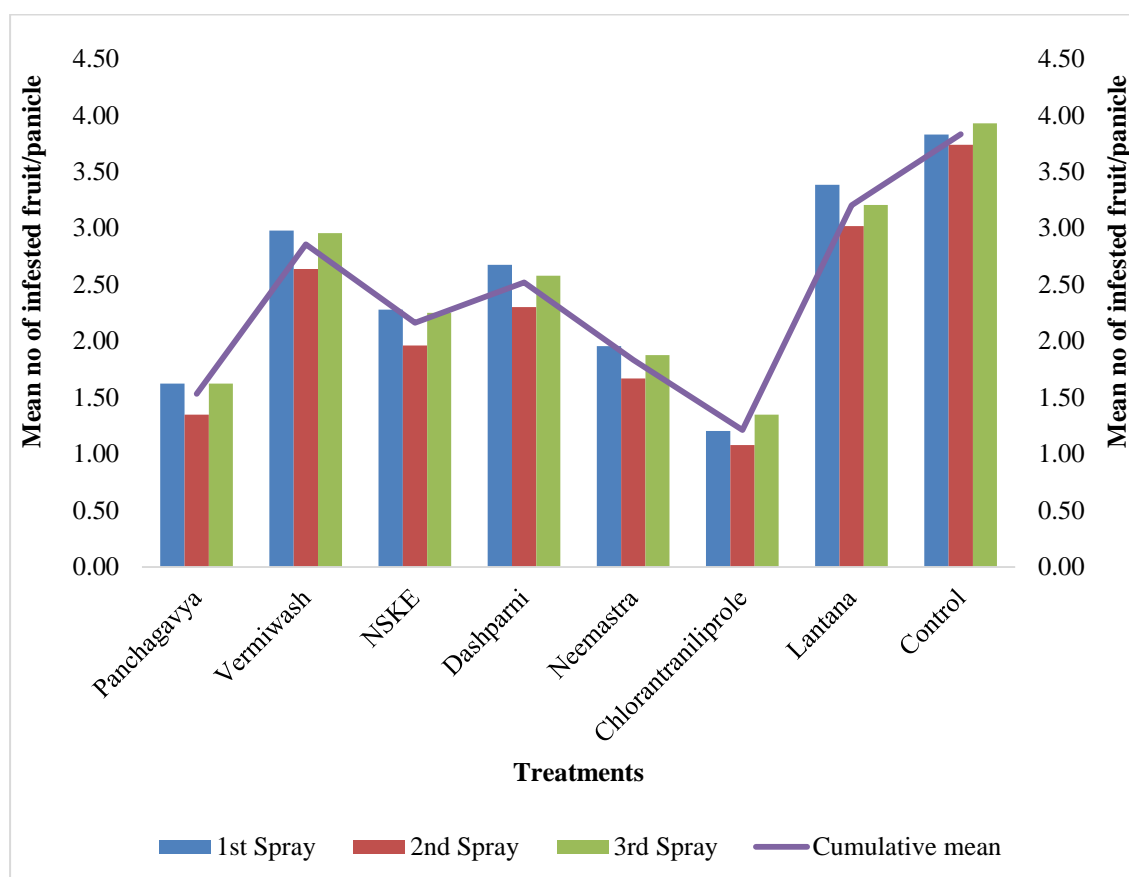
After 10 days of 3<sup>rd</sup> spraying, the highest and lowest number of infested fruits were recorded in chlorantraniliprole and control plant with 1.43 and 3.78 infested fruits/panicle, respectively. Amongst the natural formulations, highest and the least reduction in number of infested fruits were recorded in a panchagavya (1.5/panicle) and lantana (2.58/panicle). Amongst the remaining treatments, neemastra was found most effective with 1.75 infested fruits/panicle, followed by NSKE and dashparni with 2.13 and 2.4 infested fruits/panicle, respectively.

The mean number of infested fruits decreased gradually after 3<sup>rd</sup> spraying. After 14<sup>th</sup> day of 3<sup>rd</sup> spraying, the mean number of infested fruits ranged from 1.48-4.05/panicle. The least number (1.43/panicle) of infested fruits were recorded in chlorantraniliprole, followed by panchgavya (2.03/panicle), neemastra (2.33/panicle), NSKE (2.98/panicle), dashparni (3/panicle), vermiwash (3.15/panicle) and lantana (3.35/panicle) as compared to (4.05/panicle) in control.

**Table 4.27: Efficacy of different treatments against infested fruits on litchi after 3<sup>rd</sup> spray during the year 2019**

| Treatments          | Conc./<br>Dose | Mean number of infested fruits / panicle after 3 <sup>rd</sup> spray |                 |                 |                |                 |                 |
|---------------------|----------------|--|-----------------|-----------------|----------------|-----------------|-----------------|
|                     |                | 1DAS   | 3DAS            | 7DAS            | 10DAS          | 14DAS           | Mean            |
| Panchgavya          | 3%             | 1.9<br>(1.71)  | 1.15<br>(1.47)  | 1.55<br>(1.6)   | 1.5<br>(1.58)  | 2.03<br>(1.74)  | 1.63<br>(1.62)  |
| Vermiwash           | 50%            | 2.85<br>(1.96)   | 3.25<br>(2.06)  | 3.08<br>(2.02)  | 2.45<br>(1.86) | 3.15<br>(2.04)  | 2.96<br>(1.99)  |
| NSKE                | 5%             | 2.33<br>(1.83)   | 1.73<br>(1.65)  | 2.1<br>(1.75)   | 2.13<br>(1.77) | 2.98<br>(2)     | 2.25<br>(1.8)   |
| Dashparni           | 3%             | 2.53<br>(1.88)   | 2.35<br>(1.83)  | 2.63<br>(1.91)  | 2.4<br>(1.85)  | 3<br>(2)        | 2.58<br>(1.89)  |
| Neemastra           | 3%             | 2.15<br>(1.78)   | 1.38<br>(1.53)  | 1.78<br>(1.67)  | 1.75<br>(1.66) | 2.33<br>(1.83)  | 1.88<br>(1.69)  |
| Chlorantraniliprole | 18.5% SC       | 1.5<br>(1.58)  | 1.08<br>(1.43)  | 1.28<br>(1.51)  | 1.43<br>(1.56) | 1.48<br>(1.57)  | 1.35<br>(1.53)  |
| Lantana             | 5%             | 3.1<br>(2.03)  | 3.68<br>(2.17)  | 3.33<br>(2.08)  | 2.58<br>(1.89) | 3.35<br>(2.09)  | 3.21<br>(2.05)  |
| Control             |                | 3.65<br>(2.16)   | 3.9<br>(2.22)   | 4.28<br>(2.3)   | 3.78<br>(2.19) | 4.05<br>(2.25)  | 3.93<br>(2.22)  |
| C.D.(p=0.05)        |                | 0.48<br>(0.13)   | 0.74<br>(0.23)  | 0.65<br>(0.19)  | 0.55<br>(0.16) | 0.55<br>(0.15)  | 0.59<br>(0.17)  |
| SE(m)               |                | 0.16<br>(0.05)   | 0.25<br>(0.08)  | 0.22<br>(0.07)  | 0.19<br>(0.06) | 0.19<br>(0.05)  | 0.2<br>(0.06)   |
| C.V. (%)            |                | 12.74<br>(4.57)  | 21.48<br>(8.65) | 17.43<br>(6.82) | 16.5<br>(5.77) | 13.19<br>(5.02) | 16.27<br>(6.17) |

\*Values in the parentheses are square root transformed values



**Fig 4.21: Efficacy of different treatments against litchi fruit borer during the year 2019**

#### 4.7.12 Cumulative efficacy of different treatments against infested litchi fruits during the year 2018 and 2019

The mean values on number of fruit borer larvae obtained after all the three sprayings during 2018 and 2019 for all the treatments were presented combinedly in **Table 4.28 and Fig. 4.22**. The mean values obtained for both the years after all three sprayings were further analysed to obtain the pooled mean population of infested fruits for the year 2018 and 2019.

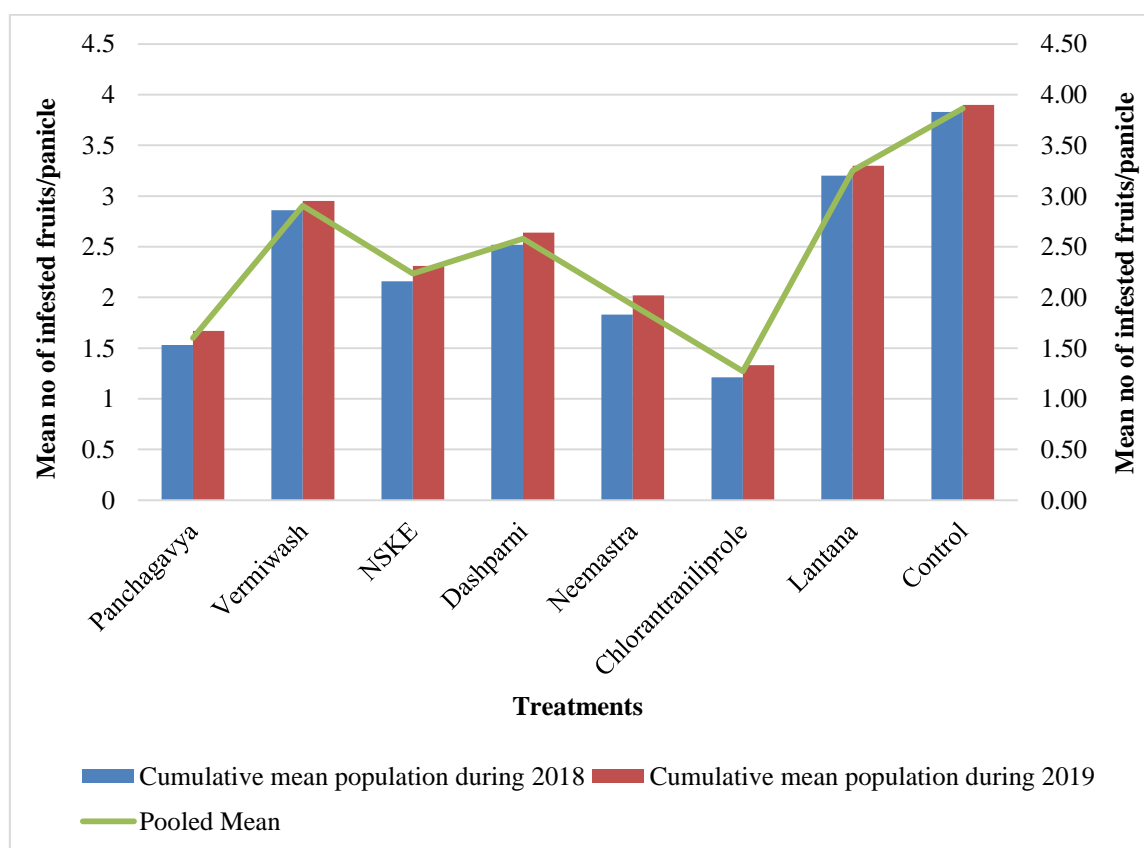
#### 4.7.13 Observations on cumulative mean population of infested fruits during the year 2018

The mean number of infested fruit, after three spraying, during 2018 varied from 1.33-3.90 larvae/panicle with minimum and maximum number of infested fruit in chlorantraniliprole and control plants, respectively. Panchagavya was found most

effective amongst treatments with 1.67 infested fruit/panicle, followed by neemastra (2.02/panicle), NSKE (2.31/panicle), dashparni (2.64/panicle), Vermiwash (2.95/panicle), and lantana (3.30/panicle) as compared to 3.90/panicle in control plant, respectively.

#### 4.7.14 Observations on cumulative mean population of infested fruits during the year 2019

After all the three sprayings during 2019, the mean number of infested fruit/panicle varied from 1.21-3.83/panicle with minimum (1.21/panicle) and maximum (3.83/panicle) number infested fruit in chlorantraniliprole and control plants, respectively. Panchagavya was found most effective amongst the treatments with mean number of infested fruit, 1.53/panicle, followed by neemastra (1.83/panicle), NSKE (2.16/panicle), dashparni (2.52/panicle) vermiwash (2.86/panicle) and lantana (3.20/panicle).



**Fig 4.22: Efficacy of different treatments against litchi fruit borer during the year 2018 and 2019**

**Table 4.28: Cumulative efficacy of natural formulations against litchi fruit borer during 2018 and 2019 at Pantnagar, Uttarakhand**

| TREATMENTS          | CONC. /DOSE | Mean no. of infested fruits/panicle after different sprayings during 2018 |                  |                |                 | Mean no. of infested fruits/panicle after different sprayings during 2019 |                       |                       |                 | Pooled Mean     |
|---------------------|-------------|---|------------------|----------------|-----------------|---|-----------------------|-----------------------|-----------------|-----------------|
|                     |             | 1st Spray   | 2nd Spray        | 3rd Spray      | Cumulative mean | 1 <sup>st</sup> Spray   | 2 <sup>nd</sup> Spray | 3 <sup>rd</sup> Spray | Cumulative Mean |                 |
| Panchgavya          | 3%          | 1.72<br>(1.65)  | 1.54<br>( 1.59)  | 1.76<br>(1.66) | 1.67<br>(1.63)  | 1.63<br>(1.57)  | 1.35<br>(1.53)        | 1.63<br>(1.62)        | 1.54<br>(1.58)  | 1.61<br>(1.60)  |
| Vermiwash           | 50%         | 3.11<br>(2.03)  | 2.74<br>( 1.93)  | 3.00<br>(2.00) | 2.95<br>(1.99)  | 2.98<br>(1.97)  | 2.64<br>(1.91)        | 2.96<br>(1.99)        | 2.86<br>(1.95)  | 2.90<br>(1.97)  |
| NSKE                | 5%          | 2.36<br>(1.83)  | 2.18<br>( 1.78)  | 2.41<br>(1.85) | 2.31<br>(1.82)  | 2.28<br>(1.76)  | 1.96<br>(1.72)        | 2.25<br>(1.8)         | 2.16<br>(1.76)  | 2.23<br>(1.79)  |
| Dashparni           | 3%          | 2.82<br>(1.95)  | 2.35<br>( 1.83)  | 2.75<br>(1.94) | 2.64<br>(1.91)  | 2.68<br>(1.92)  | 2.3<br>(1.81)         | 2.58<br>(1.89)        | 2.52<br>(1.87)  | 2.26<br>(1.89)  |
| Neemastra           | 3%          | 2.07<br>(1.75)  | 1.85<br>( 1.69)  | 2.14<br>(1.78) | 2.02<br>(1.74)  | 1.96<br>(1.72)  | 1.67<br>(1.63)        | 1.88<br>(1.69)        | 1.83<br>(1.68)  | 1.92<br>(1.71)  |
| chlorantraniliprole | 18.5% SC    | 1.29<br>(1.51)  | 1.22<br>( 1.49)  | 1.47<br>(1.57) | 1.33<br>(1.52)  | 1.21<br>(1.48)  | 1.08<br>(1.44)        | 1.35<br>(1.53)        | 1.21<br>(1.48)  | 1.27<br>(1.50)  |
| Lantana             | 5%          | 3.53<br>(2.13)  | 3.06<br>( 2.01)  | 3.32<br>(2.08) | 3.30<br>(2.07)  | 3.39<br>(2.1)   | 3.02<br>(2.01)        | 3.21<br>(2.05)        | 3.20<br>(2.05)  | 3.25<br>(2.06)  |
| Untreated control   | --          | 3.93<br>(2.22)  | 3.77<br>( 2.19)  | 4.00<br>(2.24) | 3.90<br>(2.22)  | 3.83<br>(2.2)   | 3.74<br>(2.18)        | 3.93<br>(2.22)        | 3.83<br>(2.20)  | 3.86<br>(2.21)  |
| C.D.(p=0.05)        |             | 0.33<br>(0.09)  | 0.53<br>( 0.15)  | 0.34<br>(0.1)  | 0.40<br>(0.11)  | 0.42<br>(0.12)  | 0.55<br>(0.16)        | 0.59<br>(0.17)        | 0.52<br>(0.15)  | 0.46<br>(0.13)  |
| SE(m)               |             | 0.11<br>(0.04)  | 0.18<br>( 0.06)  | 0.12<br>(0.04) | 0.14<br>(0.05)  | 0.15<br>(0.04)  | 0.19<br>(0.06)        | 0.2<br>(0.06)         | 0.18<br>(0.05)  | 0.16<br>(0.05)  |
| C.V. (%)            |             | 8.64<br>(3.25)  | 15.59<br>( 5.63) | 8.67<br>(3.22) | 10.97<br>(4.03) | 11.41<br>(4.23)   | 16.91<br>(6.02)       | 16.27<br>(6.17)       | 14.86<br>(5.47) | 12.91<br>(4.75) |

\*Values in the parentheses are square root transformed values

#### 4.7.15 Observation on pooled mean population of infested fruits during the year 2018 and 2019

The cumulative mean population of infested fruits by litchi fruit borer obtained during both the years were analysed to obtain the pooled mean population during both of the years. The values obtained on mean no of infested fruits clearly revealed that the minimum number of infested fruits (1.27/panicle) and maximum (3.86/panicle) infested fruits were recorded in chlorantraniliprole and control plants, respectively. Panchagavya was found most effective against fruit borer amongst different natural formulation and botanicals, with the least number of infested fruits (1.61/panicle) followed by neemastra (1.92/panicle), NSKE (2.23/panicle), dashparni (2.26/panicle), vermiwash (2.90/panicle) and lantana (3.25/panicle).

The combined efficacy of different plant extract viz. neem, garlic and custard apple along with vermiwash produced from different animal dungs and municipal wastes were studied and found effective against *Helicoverpa armigera* in pigeonpea (Mishra *et al.*, 2014). Similarly, vermiwash @50% concentration was found effective against insect pest complex of Tomato (Sayyad, 2017). (Alam *et al.*, 2019) recorded the efficacy of chlorantraniliprole 9.3% +lambda cyhalothrin 4.6 % 150 ZC against infested fruits in West Bengal. (Upadhyay *et al.*, 2020) also reported the efficacy of chlorantraniliprole 18.5 SC and flubendiamide 39.35%SC against infested fruits. (Kumar *et al.*,2014) studied different bio-rational approaches for managing infested fruits and litchi mite under sub-tropical condition. Amongst different treatment, use of trichogramma card @ 50000eggs/ha along with nimbecidine 5% was found most effective against infested fruits. (Srivastava *et al.*, 2021) recommended the application of two sprays with panchgavya (30 ml/l) both at the clove stage and at the color break stage, and two sprays with biodynamic pesticide (50ml/l) mixed with cow urine, cow dung, chopped neem leaves/calotropis (madar) are decomposed in water, which should be done at aril (pulp) development stage and two weeks before expected fruit harvest in order to prevent infested fruits infestations. Sreekanth and Ramana (2020) found the efficacy different indigenous formulations viz. Agniastra, neemastra and bramhastra against different pod borers of pigeonpea. (Kasmara *et al.*, 2018) recorded the

effectiveness of *Lantana camara* nano extract against *Spodoptera litura*. **Ranjan et al. (2019)** found the effectiveness of NSKE 4% against infested fruits causing only 9.50% fruit damage to the crop. (**Suneel Kumar et al., 2020**) recorded the efficacy of NSKE @5% and neemastra @20% against leaf hopper, semilopper and capsule borer of castor.



*Summary  
and  
Conclusions*



The present experiment entitled “Studies on plant volatile mediating orientation behavior of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulation for its management” was carried out with different objectives to understand the orientation adult moth with respect to different plant volatiles through biochemical analysis and olfactometer studies. Biochemical analysis of different plant parts of litchi were studied to understand the biochemical basis of attraction of litchi fruit borer to different plant parts of litchi for feeding and oviposition. Moreover, the chemical changes in leaves due to the infestation of litchi mite were also studied through biochemical analysis of healthy leaves and mite infested leaves. Field studies on efficacy of different natural formulations, botanicals as well as insecticides for management of litchi fruit borer were also studied. Under laboratory condition, the olfactory behaviour of litchi fruit borer moth to different plant parts of litchi were also recorded through olfactometer studies. In addition to that, the deterrence of different natural formulation and botanicals by adult moth of litchi fruit borer were also studied through olfactometer studies under laboratory condition. The diversity of insect pest and natural enemies on litchi at Pantnagar during both the years under study were also reported. The population dynamics of different insect pest and natural enemies and their correlation with different weather parameters were also studied.

### **5.1 Diversity of insect fauna and their associated natural enemies on litchi at Pantnagar, Uttarakhand.**

Careful monitoring of litchi plant during various developmental stages were carried out to understand the diversity of different insect pest, their mode of feeding, population dynamics and preferred stage of host. A close watch on the diversity of natural enemies associated with different insect pest of litchi were also reported and documented in the present study. A total number of 16 insect pest and 1 mite; infesting different plant parts of litchi during various developmental stages of the plant were recorded. Whereas, 13 different natural enemies associated with different insect pest of

litchi were reported. Amongst the insect pest reported during the present study, eight insects belonged to the order hemiptera, 5 to lepidoptera, 2 to coleoptera, 1 to thysanoptera and litchi mite to the order acarina. However, 5 natural enemies belonged the order hymenoptera, two each from diptera and hemiptera order and one each from coleoptera, neuroptera and araneae were present. The insect pests recorded were categorized as major and minor on the basis of their incidence and extent of damage caused by them to the plant. Litchi fruit borer, litchi bug and leaf roller had a close association with the crop and can be categorized as “major pest” of litchi. However, the remaining pest can be considered as minor pest.

## **5.2 Population dynamics of major insect pests and their associated natural enemies on litchi during 2018 and 2019 at Horticulture Research Centre (HRC), Patharchatta, Pantnagar**

The mean population of insect pest and natural enemies with respect to the meteorological standard weeks (MSW) of 2018 and 2019 were recorded during the present experiment. In the year 2018, First appearance of litchi fruit borer damage was recorded during 10<sup>th</sup> MSW and continued till 28<sup>th</sup> MSW. Peak infestation of fruit borer (25.0 infested fruits/panicle) was recorded during 23<sup>rd</sup> MSW and least infestation (4.50 infested fruits/plant) was recorded during 27<sup>th</sup> MSW. The presence of litchi leaf roller was observed throughout the year on the litchi plant. The highest and least population of litchi fruit borer was recorded during 1<sup>st</sup> and 44<sup>th</sup> MSW with 5.00 and 38.12 rolled leaves/Panicle, respectively. Litchi bug; one among the major pest seen infesting to the crop was reported during 10<sup>th</sup> to 27<sup>th</sup> MSW. The lowest population of litchi bug i.e., 0.08 bugs/panicle was reported during 27<sup>th</sup> MSW. However, highest population i.e., 3.00 bugs/plant was reported during 21<sup>st</sup> MSW.

Amongst the natural enemies, Spiders were found associated with different insect pest throughout the year. Lady bird beetles were also reported in two phases on the crop. The beetle population was absent from 19<sup>th</sup> to 41<sup>st</sup> MSW. Green lace wing bugs were found absent on the crop from 21<sup>st</sup> to 34<sup>th</sup> MSW. Assasian bug was present throughout the year except from 27<sup>th</sup> to 34<sup>th</sup> MSW. Similarly, black ants were also observed on the litchi panicle throughout the year except 33<sup>rd</sup> to 46<sup>th</sup> MSW. However, presence of red ants on the litchi panicle were reported from 7<sup>th</sup> to 26<sup>th</sup> MSW. Braconid

wasps were absent from 26<sup>th</sup> to 36<sup>th</sup> MSW. Cotesia wasps were observed on the trap from 8<sup>th</sup> to 21<sup>st</sup> MSW and 37<sup>th</sup> - 43<sup>rd</sup> MSW. Rove beetles were present from 10<sup>th</sup> to 27<sup>th</sup> MSW. Tachnid flies and syrphid flies were also observed throughout the period of study except 23<sup>rd</sup>-39<sup>th</sup> MSW and 23<sup>rd</sup> to 48<sup>th</sup> MSW respectively. Eucanthecona bugs were present almost throughout the year except 43<sup>rd</sup> to 46<sup>th</sup> MSW.

During the year 2019, Litchi fruit borer damage to the fruits were recorded from 13<sup>th</sup> MSW to 26<sup>th</sup> MSW. Maximum no of infested fruits, 41.00/panicle were reported during 21<sup>st</sup> MSW. However, lowest number of infested fruits (3.00/panicle) were reported during 26<sup>th</sup> MSW. Leaf roller infestation was measured indirectly through number of rolled leaves/panicle. Rolled leaves were observed throughout the year. The lowest number of rolled leaves was during 3<sup>rd</sup> MSW while maximum leaf rolled was during 44<sup>th</sup> MSW. Litchi bug infestation was reported from 7<sup>th</sup> to 29<sup>th</sup> MSW. Highest and lowest population was recorded in 23<sup>rd</sup> (2.94) and 29<sup>th</sup> (0.05) MSW respectively.

Among the natural enemies, Assasian bug population recorded in two phases. First phase was from 2<sup>nd</sup> MSW to 31<sup>st</sup> MSW and the second phase lasted from 39<sup>th</sup> to 51<sup>st</sup> MSW. Black ant infestation was recorded during (1-33) and (45-51) MSW. The infestation of braconid wasp observed in two phases. The first phase of attack was reported from 4<sup>th</sup> MSW to 28<sup>th</sup> MSW. Reappearance of braconid wasp was reported from 39<sup>th</sup> MSW to 51<sup>st</sup> MSW. Cotesia wasp infestation occurred in several phases. First phase lasted from 3<sup>rd</sup> to 24<sup>th</sup> MSW while the 2<sup>nd</sup> and 3<sup>rd</sup> phase was recorded during (39-46) and (50-52) MSW respectively. Eucanthecona bug were reported at the starting *i.e.*, 3<sup>rd</sup> -30<sup>th</sup> MSW as well as end *i.e.*, 38<sup>th</sup> to 44<sup>th</sup> MSW of the year. Ichneumonid wasps were present throughout the year except during (26-49) MSW. It reached its peak during 21<sup>st</sup> MSW while lowest population was recorded during 30<sup>th</sup> MSW. The infestation of green lacewing recorded during (1-25) and (38-52) MSW. Red ant population was observed for the first-time during 4<sup>th</sup> MSW and it continued till 30<sup>th</sup> MSW. Two different phases of lady bird beetle infestation were recorded. First phases infestation was from (1-21) and second phase infestation was from (40-52) MSW. Rove beetle infestation was recorded during (7-29) MSW. It reached its peak at 17 MSW and lowest at 25 MSW. Syrphid fly was first recorded at 4<sup>th</sup> MSW and it continued till 26<sup>th</sup> MSW. Spider was observed throughout the year. It reached its peak during 22<sup>nd</sup> MSW

while lowest was during 45<sup>th</sup> MSW. Tachinid fly was recorded throughout the year except during (25-42) MSW.

### **5.3 Correlation of insect pests and their associated natural enemies on litchi with weather parameters during crop season 2018 and 2019 at Pantnagar, Uttarakhand**

The findings from multiple liner regression analysis of different weather parameters with population of litchi fruit borer shows that; the insect population is influenced by a combination of maximum temperature, maximum relative humidity, and wind velocity, with positive coefficients indicating that an increase in the values of these independent variables is associated with an increase in the population of litchi fruit borer.

The study during 2018 analyzed the population dynamics of different insect pests affecting litchi trees and identified the key environmental factors that influence their population. The analysis revealed that wind velocity, maximum temperature, maximum relative humidity, evaporation, sunshine hours, and wind velocity all play a significant role in the population dynamics of these insect pests. Positive coefficients for most of these variables suggest that an increase in their values leads to an increase in the population of the insect pest, except for evaporation in the case of leaf roller, where a negative coefficient indicates that a decrease in evaporation leads to a decrease in pest population. Overall, the models developed in this study explain a substantial portion of the variation in the population of the different insect pests, ranging from 62% to 77%. These findings can help guide pest management strategies and inform decisions related to litchi fruit production.

During 2019 the statistical analysis of various factors influencing the population dynamics of different pests on litchi fruit trees showed varying degrees of significance. While some independent variables such as wind velocity, evaporation, maximum temperature, and maximum relative humidity had a significant impact on certain pests, others like sunshine hours and rainfall showed significant effects on different pests. However, some pests like the litchi fruit borer and litchi mite were not significantly affected by any of the independent variables considered. Overall, the models captured varying amounts of the variation observed in the population of pests, with R-squared

values ranging from 0.44 to 0.91. The findings suggest that multiple factors influence the population dynamics of pests on litchi fruit trees, and the impact of these factors varies depending on the pest species.

#### **5.4. To analyse volatiles compounds from different litchi plant parts, including tender shoots, flowers, immature fruit, and mature fruit**

A list of the different chemical compounds and their percentages in the volatile emissions of different litchi tissues were obtained through biochemical analysis. The analysis revealed that terpenes, alcohols, and esters were the main chemical compounds present in the volatiles emitted from various litchi tissues, with terpenes comprising 21%, alcohols comprising 3%, and esters comprising 2%.

#### **5.5 Comparative analysis of volatiles compounds in normal leaves and mite infested leaves of litchi plant**

The biochemical analysis of methanolic extracts from normal and mite-infested leaves indicated the presence of 41 phytochemicals in normal leaves and 42 in mite infested leaves. The biochemical analysis identified a diverse range of chemical compounds in the methanolic extracts of both normal and mite-infested leaves. These compounds included sesquiterpenes, terpenes, esters, antioxidants, steroids, vitamins, and fatty acids, among others. These results suggest that the leaves contain a variety of biologically active compounds that may play a role in the plant defence against mite infestation.

#### **5.6 To study the olfactory response of male and female adult of litchi fruit borer to different litchi plant parts viz. tender shoots, flowers, mature and immature fruits**

Five arm olfactometer was used to investigate the taxis behavior of adult litchi fruit borer insects towards different tissues of litchi trees. In five arm olfactometer four host plant tissues solutions namely litchi flower, litchi tender shoot, litchi mature fruit, and litchi immature fruit and water was subjected. The mean orientation of the male and female towards different host tissue solution was observed in 1hr, 2hr and 3hr intervals. Study showed that there were differences in the taxes behaviour of female and male adult litchi fruit borer adults towards different tissues of the litchi tree, specifically female litchi fruit borer adults were found to exhibit a stronger preference for the host tissues compared to the male adults

### **5.7. To study the impact of plant and animal based natural formulations on the olfactory response of litchi fruit borer adults**

The study found that chlorantraniliprole 18.5%SC treated gauze was the most effective in repelling litchi fruit borers, while vermiwash 50% was the least effective. Other treatments, such as panchgavya 3% and nemastra 3%, also showed significant repellent activity. These results suggest that these treatments may be useful in controlling litchi fruit borers, but further research is needed to determine their effectiveness in field conditions.

### **5.8. Efficacy of different natural formulations and botanicals against fruit borer of litchi during the year 2018 and 2019**

The mean number of infested fruit, after three spraying, during 2018 varied from 1.33-3.90 fruits /panicle with minimum and maximum number of infested fruit in chlorantraniliprole and control plants, respectively. Panchagavya was found most effective amongst treatments with 1.67 infested fruit/panicle, followed by nemastra (2.02/panicle), NSKE (2.31/panicle), dashparni (2.64/panicle), Vermiwash (2.95/panicle), and lantana (3.30/panicle) as compared to 3.90/panicle in control plant, respectively.

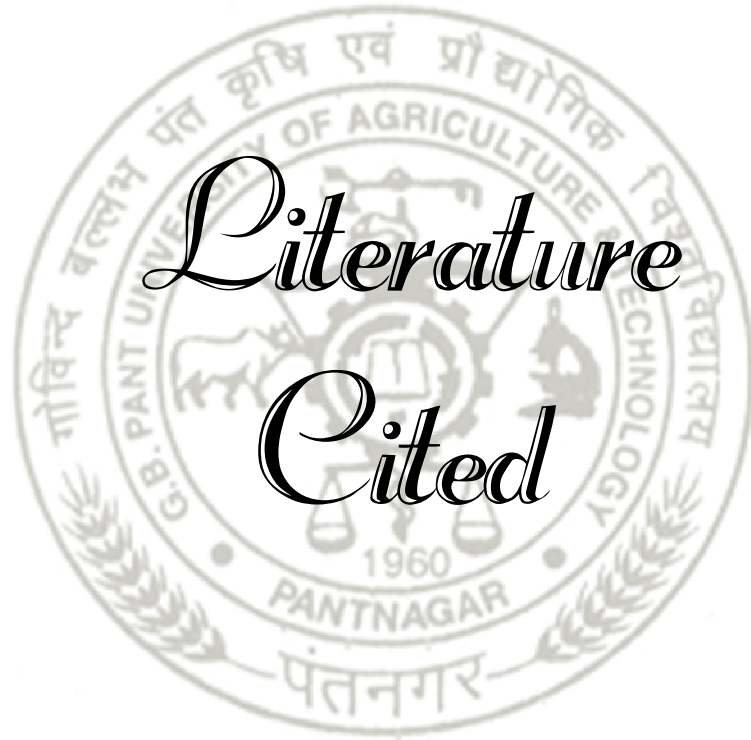
After all the three sprayings during 2019, the mean number of infested fruit/panicle varied from 1.21-3.83/panicle with minimum (1.21/panicle) and maximum (3.83/panicle) number infested fruit in chlorantraniliprole and control plants, respectively. Panchagavya was found most effective amongst the treatments with mean number of infested fruit, 1.53/panicle, followed by nemastra (1.83/panicle), NSKE (2.16/panicle), dashparni (2.52/panicle) vermiwash (2.86/panicle) and lantana (3.20/panicle).

The cumulative mean population of infested fruits by litchi fruit borer obtained during both the years were analysed to obtain the pooled mean population during both of the years. The values obtained on mean no of infested fruits clearly revealed that the minimum number of infested fruits (1.27/panicle) and maximum (3.86/panicle) infested fruits were recorded in chlorantraniliprole and control plants, respectively. Panchagavya was found most effective against fruit borer amongst different natural formulation and botanicals, with the least number of infested fruits (1.61/panicle)

followed by neemastra (1.92/panicle), NSKE (2.23/panicle), dashparni (2.26/panicle), vermiwash (2.90/panicle) and lantana (3.25/panicle).

### **Conclusion**

Litchi fruit borer was found as one among the major devastating insect pest attacking to the litchi plant and causing significant fruit damage and yield loss. The biochemical analysis of different plant parts clearly established the attraction of litchi fruit borer towards the mature fruits and the olfactometer studies under laboratory condition confirmed the same. Since the problem of pesticide residue is more in case of fruit crops, the alternative management of insect pest through various natural formulation is the need of the hour. For the management of litchi fruit borer, several natural formulations derived from various plants and animals were also evaluated. Amongst them panchagavya was found most effective in managing the pest under field condition. Under laboratory condition, panchagavya showed maximum deterrence to the litchi fruit borer adult. It showed no negative impact towards natural enemies and non-target organisms. Therefore, it can be easily incorporated into various IPM modules along with other management practices for management of fruit borer on litchi. Use of panchagavya and other natural formulations for management of litchi fruit borer should promoted among small scale farmers for its efficacy against the pest, readily availability of raw materials, easy method of preparation, cost-effectiveness and eco-friendliness. However, further studies need to be carried out to understand the exact mode of action of these natural formulations against different insect pest to improve its efficacy and applicability.



## LITERATURE CITED

---

- Aboubakar, S.D., Bokonon, G.A.H., Dannon, E. A., Imorou, N., Agui, B., Cusumano, A., Srinivasan, R., Pittendrigh, B. R., Volkoff, A. N. and Tamò, M. 2019.** Volatiles from *Maruca vitrata* (Lepidoptera, Crambidae) host plants influence olfactory responses of the parasitoid *Therophilus javanus* (Hymenoptera, Braconidae, Agathidinae). *Biol. Control.*, 130:104-109.
- Afify, A., Horlacher, B., Roller, J. and Galizia, C. G. 2014.** Different repellents for *Aedes aegypti* against blood-feeding and oviposition. *PLoS One.*, 9(7): 103-165.
- Agut, B., Pastor, V., Jaques, J. A. and Flors, V. 2018.** Can plant defence mechanisms provide new approaches for the sustainable control of the Two-Spotted Spider Mite *Tetranychus urticae*? *Int. J. Mol. Sci.*, 19(2): 614.
- Alam, M. M. 1959.** The litchi Erineum mite and its control. *Indian J Agric Sci.*, 29(3):205-208
- Alam, M. M. 1962.** Population studies on the two-spotted spider mite *Tetranychusurticae* Koch on bean plants. *Pak. J. Sci.*, 14(1): 50-58.
- Alam, M. M. and Wadud, M. A. 1963.** Studies on the litchi mite, *Eriophyes litchii* (Keifer) (Acarina: Eriophyidae). II. Seasonal population changes, age incidence of infestation and effects of infestation on leaf growth and yield of litchi trees. *Pak. J. Sci.*, 15(3): 117-128.
- Alam, S. N., Choudhary, A. K. and Gupta, A. K. 2019.** Efficacy of chlorantraniliprole 9.3%+ lambda cyhalothrin 4.6% 150 ZC against infested fruits of guava, mango and litchi in West Bengal. *Pestology.*, 43(2): 15-19.
- Ali, K., Azam, M., Khan, M. A. and Siddiqui, W. 2016.** L-cysteine application delays senescence and preserves antioxidative properties in litchi fruit during storage. *J. Food Sci. Technol.*, 53(4):1974-1982.
- Amaral, M. R., de Lima, M. A. C. and de Morais, E. G. F. 2020.** Population dynamics of *Aceria litchii* (Acari: Eriophyidae) in different lychee varieties. *Exp. Appl. Acarol.*, 80(3): 377-392.

- Anderson, P. and Anton, S. 2014.** The use of multiple sensory modalities in learning and searching behavior. *Insects.*, 5(2): 313-338.
- Anupunt, P. and Sukhvibul, N. 2005.** Constraints to litchi (*Litchi chinensis* Sonn.) production in Thailand. *Acta Hortic.*, 665: 261-269
- Baidoo, P. and Adam, J. 2012.** The effects of extracts of *Lantana camara* (L.) and *Azadirachta indica* (A. Juss) on the population dynamics of *Plutella xylostella*, *Brevicoryne brassicae* and *Hellula undalis* on cabbage. *Sustain. Agric. Res.*, 1:378-385.
- Balandrin, M. F., Klocke, J. A., Wurtele, E. S. and Bollinger, W. H. 1985.** Natural plant chemicals: sources of industrial and medicinal materials. *Science.*, 228(4704): 1154-1160.
- Ballabeni, P., Bacher, S. and Schmid, H. P. 2001.** Influence of host plant and food availability on oviposition and survival in a monophagous butterfly. *Oecologia.*, 128(1): 104-111.
- Bennett, R. N. and Wallsgrove, R. M. 1994.** Secondary metabolites in plant defence mechanisms. *New Phytol.*, 127(4): 617-633.
- Bhatia, R. and Gupta, R. K. 2003.** *Conopomorpha cramerella* infesting litchi in Himachal Pradesh. *Indian J. Hortic.*, 60(4): 357-360.
- Bhatia, R., Singh, R. and Lal, M. 2000.** Borer incidence on litchi in Himachal Pradesh. *Indian J. Hortic.*, 57(2), 125-127.
- Bijewar, N., Awasthi, O. P., Singh, A. K. and Dubey, R. B. 2018.** Field efficacy of plant leaf extracts, cow urine and their combinations against pigeon pea pod borer complex. *J. Pharmacogn. Phytochem.*, 7(2): 320-324.
- Boopathi, T., Singh, S. B., Manju, T., Ramakrishna, Y., Akoijam, R. S., Chowdhury, S., Singh, N. H. and Ngachan, S. V. 2015.** Development of Temporal Modeling for Forecasting and Prediction of the Incidence of Lychee, *Tessaratomia papillosa* (Hemiptera: Tessaratomidae), Using Time-Series (ARIMA) Analysis. *J. Insect Sci.*, 15(1): 55 .

- Boopathi, T., Pathak, K. A., Ramakrishna, Y. and Verma, A. K. 2011.** Effect of weather factors on the population dynamics of litchi stink bug, *Tessaratoma papillosa* (Drury). *PMHE.*,17(2): 69-74.
- Bhullar, M. B., Heikal, H. M., Kaur, P. and Kaur, R. 2021.** Efficacy of natural products and biorationals against two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) infesting brinjal (*Solanum melongena* L.) under protected cultivation. *Int. J. Acarol.* 47(8): 677-683.
- Bijewar, A. K., Chouragade, V. and Das, S. 2018.** Field efficacy of plant leaf extracts, cow urine and in combination against pod borer complex in pigeonpea (*Cajanus cajan* (L) Millsp.). *J. Entomol. Zool. Stud.*, 6(5): 342-347.
- Boavida, C. and Neuenschwander, P. 1995.** Influence of host plant on the mango mealybug, *Rastrococcus invadens*. *Entomol. Exp. Appl.* 76(2): 179-188.
- Boopathi, T., Pathak, K., Ramakrishna, Y. and Verma, A. K. 2011.** Effect of weather factors on the population dynamics of litchi stink bug, *Tessaratoma papillosa* (Drury). *Pest Manage. Hort. Ecosyst.*, 17(2): 69-74.
- Boopathi, T., Singh, S. B., Manju, T., Ramakrishna, Y., Akoijam, R. S., Chowdhury, S., Singh, N. H. and Ngachan, S. V. 2015.** Development of Temporal Modeling for Forecasting and Prediction of the Incidence of Lychee, *Tessaratoma papillosa* (Hemiptera: Tessaratomidae), Using Time-Series (ARIMA) Analysis. *J. Insect Sci.*, 15(1): 55.
- Bradley, G. A. 1986.** Studies on the biology and control of the litchi fruit borer and litchi stem borer, *Conopomorpha sinensis* Bradley, in Northern Thailand. In Proceedings of the FAO-ICLARM conference on integrated agriculture-aquaculture farming systems for sustainable production in the tropics, pp. 145-154.
- Bruce, T. J. and Pickett, J. A. 2011.** Perception of plant volatile blends by herbivorous insects--finding the right mix. *Phytochem.*, 72(13): 1605-1611.
- Bruce, T. J., Wadhams, L. J. and Woodcock, C. M. 2005.** Insect host location: a volatile situation. *Trends Plant Sci.*, 10(6): 269-274.
- Butani, D. 1977.** Pest of litchi in india and their control. *Fruits.*, 32(4): 269-273.

- Byrappa, A., Kumar, N. and Divya, M. 2012.** Impact of biopesticides application on pod borer complex in organically grown field bean ecosystem. *J. Biopest.*, 5(2): 148.
- Cao, Y., Li, C., Yang, H., Li, J., Li, S., Wang, Y. and Gao, Y. 2019.** Laboratory and field investigation on the orientation of *Frankliniella occidentalis* (Thysanoptera: Thripidae) to more suitable host plants driven by volatiles and component analysis of volatiles. *Pest Manag Sci.*, 75(3): 598-606.
- Cárdenas, P. D., Vidal, L., Chica, E., Luján, H. M., Andrade, T. Y. and González, C. A. 2019.** Triterpenoids with phytotoxic and insecticidal activities from *Pouteria sapota*. *Phytochemistry*, 161:35-42.
- Chandrashekharaiyah, M., Sannaveerappanavar, V., Chakravarthy, A. and Verghese, A. 2013.** Biological activity of select plant and indigenous extracts against diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) and cowpea aphid, *Aphis craccivora* Koch (Hemiptera: Aphididae). *Current Biotica*, 7(3): 134-144.
- Chang, K. P. 1970.** A study of *Anoplophoramacularia*, a serious insect pest of litchis. *TAQ.*, 6(3): 133-143.
- Chakraborty, P. and Samanta, G. 2005 .** Incidence of insect pests on litchi in West Bengal. *J. Interaca.*, 9(4): 537-541.
- Chauhan, R. and Singh, A. (2015).** Field evaluation of vermiwash and neem parts for their potential to manage *Earias vittella* incidence in okra. *J. Appl. Nat. Sci.* 7(1): 372-375.
- Charak, R., Wani, A. A., Khan, M. A., Wani, A. H. and Padder, B. A. 2020.** Seasonal incidence of litchi leaf roller, *Platyepala aprobola* (Meyer) and its correlation with abiotic factors. *J. Entomol. Res.*, 44(3): 515-518.
- Choudhary, S., Rahman, A. and Singh, R. 1989.** Infestation of Litchi trees by *Aceria litchi* Keifer, a mite originating from West Bengal. *Indian J. Agric. Sci.*, 59(9): 609-611.
- Chen, J., Huang, Q., Yuan, Y., Wang, L., Deng, X. and Zhang, Z. 2019.** Comparative metabolomics analysis of pericarp browning of four litchi cultivars. *Food Chem.*, 289: 162-170.

- Chen, Y., Wang, R., Fan, X., Zhang, J. and Cui, J. 2010.** Olfactory responses of female and male *Cydia molesta* (Lepidoptera: Tortricidae) to volatiles emitted by apple trees at different phenological stages. *J. Econ. Entomol.*, 103(5): 1629-1636.
- Chen, Y., Chen, C., Xie, L., Tang, J., Xie, J. and Wang, M. 2011.** Prediction of the occurrence of *Conopomorpha sinensis* Bradley by degree-day model. *JJ. South China Agric. Univ.*, 32(2): 37-41.
- Chyau, C. C., Tsai, S. Y., Wu, C. M. and Mau, J. L. 2003.** Volatile components of Litchi (*Litchi chinensis* Sonn.) pulp. *Food Chem.*, 80(3): 387-392.
- Croteau, R., Kutchan, T. M. and Lewis, N. G. 2000.** Natural products (secondary metabolites). *BMBP.*, 24: 1250-1265.
- Cunningham, J. P., Zalucki, M. P. and West, S. A. 2001.** Learning, odour preference and flower foraging in moths. *J. Exp. Biol.*, 204(4): 585-593.
- Dalui, A. K. and Sarkar, A. 2021.** Management of litchi fruit borer (*Conopomorpha sinensis* Bradley) by entomopathogenic nematode and gamma irradiation in stored fruits. *J. Appl. Hort.*, 23(2): 212-21
- Das, A., Layek, J., Ramkrushna, G. and Babu, S. 2018.** Integrated organic farming system in North East India. *Con. Agri advancing food security in changing climate*, pp. 1-30.
- Da Silva, R. C., De Oliveira, C. M., Santana, R. F. and Da Costa, J. G. 2015.** Oviposition deterrent activity of (E)-caryophyllene and  $\alpha$ -humulene against *Aedes aegypti* (Diptera: Culicidae). *J. Med. Entomol.*, 52(5): 872-876.
- De Azevedo, L. H., Maeda, E. Y., Inomoto, M. M. and De Moraes, G. J. 2014.** A method to estimate the population level of *Aceria litchii* (Prostigmata: Eriophyidae) and a study of the population dynamics of this species and its predators on litchi trees in southern Brazil. *J. Econ. Entomol.*, 107(1): 361-367.
- Del Socorro, A. P., Gregg, P. C. and Landolt, P. J. 2010.** Aromatic compounds, monoterpenes, sesquiterpenes and hydrocarbons of the larval frass of the Macadamia nut borer, *Cryptophlebia ombrodelta* (Lepidoptera: Tortricidae) and their potential as kairomones for parasitoids. *J. Chem. Ecol.*, 36(12):1335-1346

- Eisenring, M., Von Dahl, C. C. and Brunner, F. (2018).** Herbivore-induced changes in cotton metabolome depend on herbivore type and plant development stage. *Plant Signal Behav.*, 13(9): e1509654.
- Faiola, C. and Taipale, D. 2020.** Impact of insect herbivory on plant stress volatile emissions from trees: A synthesis of quantitative measurements and recommendations for future research. *Atmos. Environ.* 5: 100-110.
- Fang, Y. L., Li, J. G., Li, Y. L. and Liu, X. C. 2011.** Volatile flavor components of litchi flower. *Food Sci.*, 32(14): 275-279.
- Feng, J., Chen, Y., Fu, X., Wu, J., Xiao, W. and Chen, J. 2015.** Effect of 5-aminolevulinic acid on fruit coloration and quality of litchi (*Litchi chinensis* Sonn.). *JJ. Agric. Food Chem.*, 63(18): 4514-4521.
- Feng, S., Huang, M., Crane, J. and Wang, Y. 2017.** Characterization of key aroma-active compounds in lychee ( *Litchi chinensis* Sonn.). *J. Food Drug Anal.*, 26:10-20
- Fryer, M. J. 1993.** The antioxidant effects of thylakoid vitamin E (alpha-tocopherol). *Plant Cell Environ.*, 16(2): 327-336
- Gazola, A. C., Castro, E. M., Demarco, D., Costa, A. C., de Souza, L. M., Rodrigues, F. A. and Vieira, P. C. 2019.** Secondary metabolites in cassava cultivars infested or not with the mealybug *Phenacoccus manihoti*. *J. Agric. Food Chem.*, 67(11): 3309-3317.
- Geervliet, J., Posthumus, M., Vet, L. and Dicke, M. 1997.** Comparative Analysis of Headspace Volatiles from Different Caterpillar-Infested or Uninfested Food Plants of *Pieris* Species. *J. Chem. Ecol.*, 23:102-120.
- Gill, S. 1992.** Litchi cultivation in Punjab. *Ind. Hort.* (2):37-38.
- Guangquan, L., Guangyuan, R. and Yuliang, C. 1999.** Chemical constituents of the pericarp of litchi (*Litchi chinensis* Sonn.). *J. Agric. Food Chem.*, 47(4):1329-1331.
- Gunpal, D. and Patni, V. 2022.** International Journal of Botany Studies Comparative analysis of volatile compounds in normal leaves and mite induced leaf galls of *Litchi chinensis* Sonn. *Plant Cell Environ.*, (12):67-75.

- Gupta, M. 2007.** Management of gram pod borer, *Helicoverpa armigera* (Hubner) in chickpea with biorationals. *J. Food Drug Anal.*, (16):766-780.
- Gupta, R. K., Singh, J., Singh, B. and Sood, S. K. 2014.** Incidence and intensity of Indarbela sp. infesting fruit trees in Himachal Pradesh. *J. Appl. Nat. Sci.*, 6(2): 496-499.
- Hameed, S., Sharma, D. and Agarwal, M. 1992.** Integrated pest management in litchi. Proceedings of National Seminar on Recent Development in Litchi production . *Ind. Hort.* 76(3):37-38.
- Hameed, S., Ahmad, S. and Beg, M. A. 1992.** Seasonal incidence of litchi *Erineum mite* and its control in India. *Int. J. Trop. Insect Sci.*, 13(2): 229-234.
- Hameed, S. and Ahmad, S. 1999.** Seasonal incidence of the leaf roller, *Dasyneura ismael* (Meyrick), on litchi trees in northern India. *Int. J. Pest Manage.*, 45(3): 189-192.
- Hameed, M., Ashraf, M. and Razaq, M. 2001.** Evaluation of certain insecticides against Indarbela spp., a pest of fruit trees. *J. Agric. Soc. Sci.*, 89(6)169-170.
- Hazarika, S. 1951.** The ecology and control of the house-mite (*Dermatophagoides desapteronyssinus* (Trouessart)). *J Hyg (Lond.)*, 49(2): 186-200.
- He, D. 2001.** Investigation and control of litchi fruit borer (*Conopomorpha sinensis* Bradley). *Guangdong Agric. Sci.*, 98 (5): 50-51
- Huang, X., Chen, H. and Tumlinson, J. H. 2012.** A non-floral source of caryophyllene in a plant-herbivore system. *Funct. Ecol.*, 26(1): 162-169.
- Hung, N. Q., Trung, T. D. and Son, L. V. 2006.** Survey of Litchi (*Litchi chinensis* Sonn.) pests in Ha Tinh province. Proceedings of the International Workshop on Litchi Production and Marketing., 29(5): 475-480.
- Hwang, S. Y. and Hsieh, F. S. 1989.** Bionomics of the Gracillariid, *Conopomorpha cramerella* Snellen, an Important Pest of Litchi Trees in Taiwan. *J. Taiwan Agric. Res. Inst.*, 38(4): 367-376.
- Huang, X. S., Li, C. H. and Qiu, X. F. 1990.** Biological characteristics of *Aceria litchii* Keifer, the causative mite of litchi erinose in Guangdong Province. *J. South China Agric. Univ.*, 11(4): 77-81.

- Ingber, D. A., Christensen, S. A., Alborn, H. T. and Hiltbold, I. 2021.** Detecting the Conspecific: Herbivory-Induced Olfactory Cues in the Fall Armyworm (Lepidoptera: Noctuidae). *Metabolites.*, 11(9): 583.
- Jang, E. B., Chang, H. T. and Light, D. M. 1997.** Attraction of female oriental fruit flies to fresh mature leaves of *Panax ginseng*. *J. Chem. Ecol.*, 23(4): 947-955.
- Jiang, X. L., Zhang, L. W. and Zhang, Y. J. 2011.** Behavioral responses of *Chilo suppressalis* (Lepidoptera: Pyralidae) to volatiles from rice plants at different growth stages. *Environ. Entomol.*, 40(1): 107-113.
- Jiang, Y., Zhang, J., Li, D., Li, L., Li, S., Li, W. and Liang, Y. 2021.** Polyphenol metabolite differences in litchi fruit cultivars revealed by targeted metabonomics. *Food Res. Int.*, 147(8) 110:120.
- Johnston, J. W., Hunter, D. M. and Reid, M. S. 1980.** Volatile components of lychee fruit. *J. Agric. Food Chem.*, 28(3): 666-668.
- Karar, H., Arif, J., Hameed, A., Ali, A., Hussain, M., Shah, F. H. and Saghir, A. 2013.** Effect of cardinal directions and weather factors on population dynamics of mango mealybug, *Drosicha mangiferae* (Green)(Margarodidae: Homoptera) on Chaunsa cultivar of mango. *Pak. J. Zool.*, 45(6):677-685.
- Karimzadeh, J. and Rabiei, A. 2020.** Larvicidal and Oviposition Deterrent Effects of the Jimson weed (*Datura stramonium*) extracts on the Diamondback Moth, *Plutella xylostella* . *J. Agric. Sci. Technol.*, 22(5): 1279-1293.
- Karkar, D., Korat, D. and Dabhi, M. 2014.** Evaluation of cow urine and vermiwash against insect pests of brinjal. *Karnataka J. Agric. Sci.*, 27(4): 528-530.
- Karmakar, A., Mitra, P., Koner, A., Das, S. and Barik, A. 2020.** Fruit Volatiles of Creeping Cucumber (*Solena amplexicaulis*) Attract a Generalist Insect Herbivore. *J. Chem. Ecol.*, 46(3):275-287.
- Kasmara, L., Rahayu, M. and Lestari, W. 2018).** *Lantana camara* nanoextracts as *Spodoptera litura* (F.) larvae toxic agents. *HAYATI J. Biosci.*, 25(4):183-188.
- Kaupp, U. B. 2010.** Olfactory signalling in vertebrates and insects: differences and commonalities. *Nat. Rev. Neurosci.*, 11(3): 188-200.

- Khurana, R. L. and Gupta, S. K. 1972.** Host plants of some important insect pests of Punjab. *Indian J. Agric. Sci.*, 34(3): 247-251.
- Kilari, E. K. and Putta, S. 2016.** Biological and Phytopharmacological Descriptions of *Litchi Chinensis*. *Pharmacogn. Rev.*, 10(19): 60-65.
- Krieger, J. and Breer, H. 1999.** Olfactory reception and olfactory communication by insects. *Cell Tissue Res.*, 297(3): 1-16.
- Krishnan, A. 2020.** Panchagavya combination against *Spodoptera litura*. *J. Biopestic.*, 12(2):149-152.
- Krishnamurthi, N. 1967.** Some observations on the biology of *Erineum mite*, *Aceria litchii* (Keifer) (Eriophyidae: Acarina) and its control. *J. Bombay Nat. Hist.*, 64(1): 52-57.
- Kulkarni, H. L., Swaminathan, R. and Rahalkar, G. W. 1967.** Life history of the leaf-folder, *Nephantisserinopa Meyrick* (Pyralidae: Lepidoptera). *JBNHS.*, 64(2): 255-260.
- Kumar, R., Verghese, A. and Singh, S. 2007.** Pest management in litchi orchards. *IPMHE.*, 12(2): 383-398).
- Kumar, A., Gupta, R. and Dubey, A. K. 2011.** Assessment of fruit borer (*Conopomorpha cramerella*) and its natural enemies on litchi. *Indian J. Agric. Sci.*, 81(11): 1054-1057.
- Kumar, R., Choudhary, A., Verma, H. N. and Singh, B. 2008.** Seasonal abundance and correlation studies of litchi bug, *Tessaratomya javanica* (Thunberg) on litchi. *Indian J. Hort.*, 65(3): 344-348.
- Kumar, J. and Lall, B. S. 1984.** Incidence of some pests of litchi fruits and their relationship with the fruit age. *Indian J. Hort.*, 41(4): 264-268.
- Kumar, V., Sharma, R. and Singh, B. 2014.** Bio-rational approach for management of fruit borer and litchi mite under sub-tropical condition. *J. Entomol. Zool. Stud.*, 2(6): 109-112.
- Lall, B.S. and Rahman, M.M. 1975.** Occurrence of *Erineum mite* (*Eriophyes litchii* Keifer) on *Litchi chinensis* Sonn. *Curr. Sci.*, pp. 467-468.

- Lall, B. S. and Mallik, A. K. 1976.** Studies on the incidence and bionomics of some insect pests of litchi (*Litchi chinensis* Sonn.) in West Bengal. *J. Agric. Sci. Soc. North East India.*, 9(2): 140-146.
- Lall, B. S. and Sharma, N. N. 1976.** Studies on the control of cacao moth, *Acrocercops cramerella* Snellen, a pest of litchi foliage and fruit. *Indian J. Agric. Sci.*, 46(4): 165-167.
- Lall, B. S. and Sharma, N. N. 1978.** Studies on the biology and control of cacao moth, *Acrocercops cramerella* Snellen, a pest of litchi fruits. *Indian J. Entomol.*, 40(4): 406-411.
- Lal, N., Marboh, E., Gupta, A., Kumar, A., Anal, A. D. and Nath, V. 2019.** Variation in leaf phenol content during flowering in litchi (*Litchi chinensis* Sonn.). *Indian J. Agric. Sci.*, 76(4): 560-567.
- Langenheim, J. H. 1994.** Higher plant terpenoids: a phytocentric overview of their ecological roles. *J. Chem. Ecol.*, 20(6): 1223-1280.
- Li, P., Chen, B., Yizhi, D., Yao, Q., Xu, S., Chen, K. and Chen, G. 2014.** Effects of Temperature on Emergence Dynamics of *Conopomorpha sinensis* (Lepidoptera: Gracillariidae). *Fla. Entomol.*, 97(7): 1093-1097.
- Li, H., Liang, Q., Li, S., Zhang, Z. and Xu, X. 2012.** Isolation and characterization of litchi pericarp procyanidins and investigation of their antioxidant activities. *J. Agric. Food Chem.*, 60(16): 4102-4108.
- Lorenz, L. M., Keane, A., Moore, J. D., Munk, C. J., Seeholzer, L., Mseka, A., Simfukwe, E., Ligamba, J., Turner, E. L. and Biswaro, L. R. 2013.** Taxis assays measure directional movement of mosquitoes to olfactory cues. *Parasit. Vectors.*, 6(1): 1-12.
- Ma, L., Feng, C., Chen, M., Lin, H., Lu, W. and Xu, J. 2015.** Characterization of volatile components in litchi (*Litchi chinensis* Sonn.) 'Guanyinlü' fruit during postharvest storage. *Molecules.*, 20(5): 9448-9463
- Mahattanatawee, K., Goodner, K. L., Baldwin, E. A. and Pitaksutheepong, C. 2007.** Identification of volatiles in litchi (*Litchi chinensis* Sonn.) cultivars grown in Florida. *J. Agric. Food Chem.*, 55(22): 9382-9389.

- Maiti, P. K. and Sahoo, A. K. 1991.** Biology of rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) on deep-water rice. *IJE.*, 53(2): 219-225.
- Matharu, K. and Chahil, G. 2013.** Role of Neem based botanical pesticides in organic agriculture. *Popular Kheti.*, 1(4): 178-179.
- McIndoo, N. 1926.** An insect olfactometer. *J. Econ. Entomol.*, 19(3): 545-571.
- Menger, D. J., van Loon, J. J. and Takken, W. 2014.** Assessing the efficacy of candidate mosquito repellents against the background of an attractive source that mimics a human host. *Med. Vet. Entomol.*, 28(4): 407-413.
- Menzel, C. M. 2002.** Litchi Erinose mite, *Aceria litchii* (Keifer), a significant pest of litchi (*Litchi chinensis* Sonn) grown in semi-humid tropical regions at higher elevations, often in Asia. *Exp. Appl. Acarol.*, 28(1-4), 161-174.
- Menzel, C. M. and Waite, G. K. 2005.** The litchi crop in Asia and the Pacific. *Acta Hort.*, 45(665): 35-44.
- Mishra, P., Singh, P., Singh, G. and Singh, V. K. 2020.**  $\beta$ -Sitosterol: a phytocomponent of *Tecomella neriifolia* (L.) bark extract with insect growth regulatory activity against *Helicoverpa armigera*. *Toxin Rev.*, 56(6):788-795.
- Mishra, S., Kumar, P., Malik, A. and Satya, S. 2014.** In vitro assessment of the combined efficacy of plant extracts and vermiwash against *Helicoverpa armigera* in pigeonpea. *J. Entomol. Zool. Stud.*, 2(3): 190-194.
- Mishra, R. N. 1980.** Studies on the occurrence and control of Erineum mite, *Aceria litchii* (Keifer) on litchi, *Litchi chinensis* Sonn. in Bihar. *Indian J. Agric. Sci.*, 50(8): 615-619.
- Morralo, R. B. 1986.** Botanical insecticides against the diamondback moth. *J. Entomol. Zool. Stud.*, 52(3): 90-102.
- Morya, K., Pillai, S. and Patel, P. 2010.** Effect of powdered leaves of *Lantana camara*, *Clerodendrum inerme* and Citrus limon on the rice moth, *Corcyra cephalonica*. *Bull. Insectol.*, 63(2): 183-189.
- Nair, K. K. C. and Sahoo, A. K. 2006.** Occurrence of *Conopomorpha cramerella* in litchi and its management. *Indian J. Plant Prot.*, 34(1): 82-85.

- Newton, R. C. and Crause, J. C. 1990.** Ecology of the litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae), in South Africa. *J. Entomol. Soc. South Afr.*, 53(2): 261-274.
- Nonomura, A. M., Kojima, M., Takebayashi, Y., Suzuki, T., Chonan, R., Hasegawa, Y. and Sakakibara, H. 2020.** Alpha-Methyl-mannofuranoside functions as a glycoregulator in plants. *PNAS.*, 117(38): 23789-23796.
- Nusra, M. S. F., Udukala, D. N., Amarasinghe, L. D. and Paranagama, P. A. 2021.** Volatiles from host plant brinjal attract the brinjal Fruit and Shoot Borer *Leucinodes orbonalis* Guenee. *J. Asia-Pac. Entomol.*, 24(3): 695-703.
- Ong, P. K. C. and Acree, T. E. 1998.** Gas Chromatography/Olfactory Analysis of Lychee (*Litchi chinensis* Sonn.). *J. Agric. Food Chem.*, 46(6): 2282-2286.
- Pazhanisamy, M. and Krishnan, A. 2019.** Efficacy of botanical extracts and panchagavya against bhendi shoot and fruit borer, *Earias vittella* (Fab.). *J. Biol. Control.*, 33(12): 372-377.
- Pazhanisamy, L. and Krishnan, K. 2019.** Comparative efficacy of botanicals, bio-agents and synthetic insecticides against okra fruit borers under in vitro conditions. *J. Pharmacogn. Phytochem.*, 8(5): 2435-2438.
- Perez, H. M., Alonso, V. M., Vacas, S., Gallego, C., Pons, C., Arbona, V., Rambla, J. L., Navarro L, V., Granell, A. and Urbaneja, A. 2021.** Plant exposure to herbivore-induced plant volatiles: a sustainable approach through eliciting plant defenses. *J. Pest Sci.*, 94(4): 1221-1235.
- Prakash, A. R. J. 1997.** *Botanical pesticides in agriculture.* Lewis Publ., 78(87): 677-680.
- Prasad, R. and Singh, B. 1981.** Occurrence of litchi mite, *Aceria litchi* (Keifer) on litchi in Bihar. *Indian J. Entomol.*, 43(1): 70-72.
- Rai, P.S. and Bhandary, K.R. 1973.** Occurrence of *Xyleborus fornicatus* Eichhoff (Coleoptera: Scolytidae) on litchi (*Litchi chinensis* Sonn.) in India. *Curr. Sci.*, 42(10) :20-30.

- Rahman, V. J. and Babu, A. 2021.** Herbivore-induced plant volatiles from red spider mite, *Oligonychus coffeae* infested tea plants as attractant cues for the predatory mite, *Neoseiulus longispinosus*. *Materials Today: Proc.*, 41(5):613-617.
- Ram, R. and Pathak, R. 2016.** Organic Approaches for sustainable production of horticultural crops: A review. *Prog. Hort.*, 48(1): 1.
- Ramachandran, R., Plimmer, J. R. and Cohen, A. C. 1990.** Electrophysiological responses of male and female beet armyworms (Lepidoptera: Noctuidae) . *Environ. Entomol.*,19(1):210-216.
- Ranjan, R. and Mukherjee, U. 2008.** Influence of weather factors on the incidence of litchi shoot and fruit borer, *Conopomorpha cramerella* Snellen (Lepidoptera: Gracillaridae) in Bihar. *Hort. Ecosyst.*, 14(2): 177-180.
- Ranjan, R. and Ray, R. 2015.** Effect of abiotic factors on the incidence of litchi mite, *Aceria litchii* Keifer. *Pest Manag. Hort. Ecosyst.*, 21(2): 225-227.
- Ranjan, R., Chaudhary, M. and Choudhary, R. 2019.** Efficacy of neem based insecticides against fruit borer in brinjal. *J. Pharmacogn. Phytochem.*, 8(3): 2453-2456.
- Ravisankar, N. and Gangaiah, B. 2016.** Organic Farming: Scope and strategy for Andaman & Nicobar Islands. *Prog. Hort.*, 9(12): 30-32.
- Ray, R. and Mukherjee, U. 2012.** Effect of abiotic factors on the incidence of litchi leaf roller, *Dudua aprobola* Meyrick (Lepidoptera: Tortricidae) in Bihar. *Pest Manag. Hort. Ecosyst.*, 18(2): 210-212.
- Reddy, G. V. P., Tabone, E. and Guerrero, A. (2002).** Interactions of diamondback moth, host plant and natural enemies: A tritrophic system influenced by plant volatiles. *Entomol. Exp. Appl.* 104(2-3): 271-278.
- Renjana, R. and Thoppi, M. 2013.** Chemical composition and antimicrobial activity of the essential oil from leaves of *Pogostemon heyneanus* Benth. *J. Essent. Oil Bear. Plants.*, 16(3): 296-301
- Revadi, S., Lebreton, S., Witzgall, P., Anfora, G., Dekker, T. and Becher, P. G. 2015.** Functional anatomy and physiology of olfaction in the European grapevine moth, *Lobesia botrana*. *J. Chem. Ecol.*, 41(6):547-560.

- Rice, P. J. and Coats, J. R. 1994.** Insecticidal properties of monoterpenoid derivatives to the house fly (Diptera: Muscidae) and red flour beetle (Coleoptera: Tenebrionidae). *Pestic. Sci.* 41(3): 195-202.
- Rodriguez, S. D., Drake, L. L., Price, D. P., Hammond, J. I. and Hansen, I. A. 2015.** The efficacy of some commercially available insect repellents for *Aedes aegypti* (Diptera: Culicidae) and *Aedes albopictus* (Diptera: Culicidae). *J. Insect Sci.*, 15(1) :140-145.
- Rosmana, A., Prijono, D. and Adnan, A. 2010.** Fruit borers attacking litchi and their control in Indonesia. *Acta Hortic.*,14 (863): 511-516.
- Sarkar, S., Kundu, S. S. and Ghorai, D. 2014.** Validation of ancient liquid organics - Panchagavya and Kunapajala as plant growth promoters. *Indian Journal of Traditional Knowledge*, 13(6): 398-403.
- Sayyad, F. J. 2017.** Insect pest management through vermicomposting. *J. Curr. Microbiol. Appl. Sci.*, 6(7): 3113-3120.
- Scheirs, J. and De Bruyn, L. 2002.** Integrating pre and postzygotic events: a review of pollen-mediated gene flow from a plant evolutionary perspective. *Aust. J. Bot.*, 50(1): 5-21.
- Schulte, E. 2007.** Litchi pests in Asia. *Chron. Hortic.*, 47(1): 12-19.
- Schuster, M. F. and Starks, K. J. 1974.** Olfactory responses of the greenbug, *Schizaphis graminum*, to a host plant and other plant odors. *J. Chem. Ecol.*, 1(3): 273-281.
- Schulte, M. J., Martin, K. and Sauerborn, J. 2006.** Effects of *Azadirachtin* injection in litchi trees (*Litchi chinensis* Sonn.) on the litchi stink bug (*Tessaratoma papillosa* Drury) in northern Thailand. *J. Pest Sci.*, 79(4): 241-250.
- Sharma, K. D. and Agarwal, R. A. 1988.** Biology and management of *Acrocercops cramerella* Snellen, infesting litchi in Bihar. *IJH.*, 45(1-2): 102-105.
- Sharma, O. P. and Kumar, M. 1986.** Bark-eating caterpillar: a serious pest of citrus in India. *Int. J. Pest Manage.*, 32(3): 238-242.

- Sharma, V. K. 1985.** Pests of litchi and their management in Bihar. *Indian J. Agric. Sci.*, 55(10): 605-608.
- Shivaraju, C., Kumar, C. A., Sudhirkumar, S. and Thippaiah, M. 2011.** Efficacy of indigenous materials and new insecticide molecules against *Maruca testulalis* (Hubner) on blackgram. *Int. J. Plant Prot.*, 4(1): 214-216.
- Sen, N. L., Rahman, M. M. and Ghosh, S. K. 1965.** Survey of plant parasitic nematodes associated with some fruit trees in West Bengal. *Indian J. Nematol.*, 1(2): 123-129.
- Singh, D. 1971.** Life-history and bionomics of *Mylocerus discolor* Boh. and *M. undecimpustulatus undatus* Marshall (Coleoptera: Curculionidae). *Indian J. Entomol.*, 33(4):361-375.
- Singh, D., Verma, A. N. and Agarwal, R. A. K. 2001.** Insect and mite pests of litchi and their management. *Fruits.*, 56(4): 237-250.
- Singh, J. 1971a.** Studies on the leaf roller, *Desmiamaculalis* Guenee (Lepidoptera: Pyralidae) infesting guava in Punjab. *PFJ.*, 31(1-2): 40-45.
- Singh, M.P. 1971.** *Mylocerus discolor* Boh and *Mylocerus undecimpustulatus* Fst. (Curculionidae: Coleoptera) as pests of litchi (*Litchi chinensis*). *Indian J. Entomol.*, 33(5): 221-225.
- Singh, S., Chakraborty, S. and Poddar, P. 1987.** Occurrence of the red spider mite, *Oligonychus indicus* (Hirst) (Acarina: Tetranychidae) on tea in Darjeeling and Terai. *Plant Protection Bulletin.*, 39(2): 9-14.
- Singh, R., Mohapatra, P. K. and Mohanty, M. 2002.** Incidence of *Aceria litchi* (Keifer) (Eriophyidae: Acari) on litchi (*Litchi chinensis* Sonn.) in Orissa. *J. Appl. Hortic.*, 4(1): 39-42.
- Singh, R., Singh, K. P., Dhiman, R. C. and Gaur, S. N. 1997.** Influence of weather variables on the abundance of different developmental stages of house dust mites in dust from the homes of asthmatic children in Delhi. *Int. J. Biometeorol.*, 41(3): 125-128.

- Song, C., Ma, L., Zhao, J., Xue, Z., Yan, X. and Hao, C. 2022.** Electrophysiological and Behavioral Responses of *Plutella xylostella* (Lepidoptera: Plutellidae) to Volatiles from a Non-host Plant, Geranium, *Pelargonium × hortorum* (Geraniaceae). *J. Agric. Food Chem.*, 70(20): 5982-5992.
- Sreekanth, M. P. and Ramana, J. V. 2020.** Management of pod borers of pigeonpea using indigenous formulations. *Legume Res.*, 43(6), 899-903.
- Srivastava, K., Patel, R., Gupta, A. K. and Sharma, D. 2020.** Scenario of Insect Pests on Litchi: Management Options. *Inno. Pest. Manag. Approaches 21st Century* ., 7(2): 461-480).
- Srivastava, M., Kumar, S., Kumar, S. and Chaudhary, S. 2016.** Insect pests of litchi and their management. In *Sustainable Pest Management in Date Palm: CSEC.*, 4: (367-384).
- Srivastava, M., Pandey, V., Mishra, A. and Mishra, R. 2021.** Sustainable management of fruit borer infestation in pomegranate through Panchgavya and biodynamic preparations. *Org. Agric.*, 11(3): 491-499.
- Storey, R. I. and Rogers, D. J. 1980.** Insect pests of litchis (*Litchi chinensis* Sonn.) in northern Queensland. *Aust. J. Exp. Agric. Anim. Husb.*, 20(104): 115-119.
- Sulistyowati, E., Osman, M., & Yusof, S. 1995.** Survey of cocoa pod borer (CPB), *Conopomorpha cramerella* (Snellen), infestation on cocoa in Malaysia, Indonesia and the Philippines. *Planter.*, 71(828): 493-499.
- Sundaramurthy, V. T. and Basu, A. K. 1989.** Behaviour of insect management system under stress and outbreak situation in the polycrop cotton agrosystem. In *Proceedings of National Seminar on Futuristic Approaches for Cotton Improvement* Hisar, India: CCS Haryana Agricultural University. (p. 62).
- Suneel Kumar, S., Dhaka, R. S. and Singh, S. 2020.** Efficacy of neem seed kernel extract and neem oil against insect pests of castor (*Ricinus communis* L.). *Indian J. Entomol.*, 82(4): 794-797.
- Sushma, K. M. and Tabassum, B. 2022.** Phytochemical profiling and in vitro insecticidal activity of *Betula utilis* D. Don bark extracts against *Aedes aegypti* mosquito larvae. *Ind. Crops Prod.*, 171(1): 114-296.

- Takabayashi, J., Dicke, M. and Posthumus, M. A. 1994.** Volatile herbivore-induced terpenoids in plant-mite interactions: Variation caused by biotic and abiotic factors. *J. Chem. Ecol.*, 20(6): 1329-1354.
- Thakur, M. L. and Sharma, R. C. 1990.** Seasonal incidence of some eriophyoid mites on apple in Himachal Pradesh. *IJPP.*, 18(2): 192-195.
- Thakur, R. S. 1991.** Prevalence of litchi mite, *Aceria litchi* Keifer in some litchi-growing districts of Bihar. *Indian J. Entomol.*, 53(4): 756-759.
- Thakur, S. and Sood, A. (2019).** Lethal and inhibitory activities of natural products and biopesticide formulations against *Tetranychus urticae* Koch (Acarina: Tetranychidae). *Int. J. Acarol.*, 45(1):1-10.
- Tsang, Y. F. and Liang, W. H. 2007.** Trap efficacy of oriental fruit fly (Diptera: Tephritidae) and guava fruit moth (Lepidoptera: Tortricidae) in litchi orchard in Taiwan. *Plant Prot. Bull.*, 49(2): 117-127.
- Turlings, T. C. J., Tumlinson, J. H. and Lewis, W. J. (2004).** Exploitation of herbivore-induced plant odors by host-seeking parasitic wasps. *Sci.*, 285(5433): 895-898.
- Upadhyay, R. K., Singh, A. K., Singh, S. K. and Singh, V. K. 2020.** Efficacy of newer insecticides against fruit borer, *Helicoverpa armigera* (Hub.) on tomato. *Int. J. Chem. Stud.*, 8(2): 4342-4344.
- Upadhyay, S. K., Aryal, S., Bhusal, B., & Chaudhary, B. 2020.** Evaluation of Insecticides for the Management of Litchi Fruit and Shoot Borer. *J. Nepal Agric. Res. Counc.*, 6:(1) 85-91.
- Verma, K. K. and Khurana, R. L. 1974.** On the biology of *Indarbelatetraonis* Moore and *Indarbelaquadrinotata* Walker (Lepidoptera: Zygaenidae) and their control *Indian J. Agric. Sci.*, 44(1): 46-52.
- Villiers, E.A. and Mathee, W.A. 1973.** The occurrence of bark-borers on litchi and other fruit trees. *Citrus Subtrop. Fruit J.*,19(4): 20-23.
- Waite, G. K. 2005.** Litchi pests and their management in Australia. *Crop Protect.*, 24(3): 279-289.

- Waite, G. K., Rikard-Bell, C. and Mayer, D. G. 1992.** Litchi (*Litchi chinensis* Sonn.) Growing in Australia: An Assessment of Cultivar Performance, Postharvest Quality and Pests and Diseases. *Aust. J. Exp. Agric.*, 32(2): 239-248.
- Waite, G.K. and Hwang, J.S. 2002.** Pests of litchi and longan. *Economic Importance, Natural Enemies and Control. Trop. Fruit Pests Pollinators Biol.*, 21(3):331-359.
- Wang, G., Zhang, J., Hu, L. and Dong, J. 2007.** Electrophysiological and behavioral responses of *Spodoptera litura* to volatiles from tea plant, *Camellia sinensis*. *J. Chem. Ecol.*, 33(1): 121-130.
- Wang, Y., Li, X., Yang, Z., & Wang, R. 2010.** Spatial distribution of *Tessaratomia papillosa* (Hemiptera: Tessaratomidae) and its natural enemies in jujube trees. *J. Insect Sci.*, 10(1): 1-14.
- War, A. R., Paulraj, M. G., Ahmad, T., Buhroo, A. A., Hussain, B., Ignacimuthu, S. and Sharma, H. C. 2013.** Mechanisms of plant defense against insect herbivores. *Plant Signal Behav.*, 8(10): e24222.
- Wen, S. and Liou, M. R. 2008.** Management of six insect pests associated with litchi fruit in Taiwan. *Plant Prot., Bull.*, 50(4): 451-461.
- Wen-Hung, L. and Liou-Tsung, L. 2008.** Diversity and abundance of insects in litchi orchard ecosystem. *J. Asia-Pac. Entomol.*, 11(3): 141-147.
- Wu, J., Zhang, Q., Yang, R. and Zhang, Z. 2009.** Composition of the volatile components in *litchi chinensis* sonn. Fruit from different regions and cultivars. *Molecules.*, 14(12): 5060-5072.
- Wu, W., Lan, W. and Liu, Y. 1991.** Phytoseiid mites of lychee from China and their value for application. *Natural Enemies of Insects.*, 13(2): 82-91.
- Xu, G., Xiang, X., Guo, M., Li, X., Turlings, T. C. J. and Zhang, Z. 2008.** Trade-offs between oviposition site selection and mate-finding in the cotton bollworm *Helicoverpa armigera*: female signalling and male attraction. *Anim. Behav.*, 76(5): 1739-1746.

- Yang, L., Hu, X. P., Allan, S. A., Alborn, H. T. and Bernier, U. R. 2019.** Electrophysiological and Behavioral Responses of the Kudzu Bug, *Megacopta cribraria* (Hemiptera: Plataspidae), to Volatile Compounds from Kudzu and Soybean Plants. *J. Agric. Food Chem.*, 67(15): 4177-4183.
- Yankanchi, S. R. and Patil, S. R. 2009.** Field efficacy of plant extracts on larval populations of *Plutella xylostella* L. and *Helicoverpa armigera* Hub. and their impact on cabbage infestation. *J. Biopest.*, 2(1): 32-36.
- Yao, C. T. and Liu, Y. C. 1990a.** Studies on the fruit borer of litchi in China. *J. Fruit Sci.* 7(2): 111-116.
- Yao, C. T. and Liu, Y. C. 1990b.** Studies on litchi fruit borers in Taiwan. *Chin. J. Entomol.*, 10(1): 59-68.
- Yao, R. Y. and Liu, L. J. 1990.** Two species of Gracillariidae injurious to litchi in China (Lepidoptera: Gracillariidae). *Acta Entomol. Sin.*, 33(3): 352-354.
- Yao, X., Zhang, T., Liu, Y. and Zhao, Y. 2021.** Litchi: Phytochemistry, health benefits and potential risks. *J. Agric. Food Chem.* 69(17): 4813-4825
- Yao, Y. and Liu, Y. 1990a.** Two new species of the genus *Conopomorpha* Bradley from China (Lepidoptera: Gracillariidae). *Acta Entomol. Sin.*, 33(4): 508-512.
- Yao, Y. and Liu, Y. 1990b.** A study on the genus *Conopomorpha* Bradley from Taiwan (Lepidoptera: Gracillariidae). *Plant Prot. Bull.*, 32(4): 417-422.
- Yin, X. Q., Chen, J. J., Chen, H., Liao, B. Q. and Guan, X. 2009.** Control of litchi stem borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae), in southern China. *Int. J. Pest Manage.*, 55(4): 301-305.
- Yongjun, W., & Fushun, C. 1994.** Effect of plant volatiles on feeding preference of beet armyworm, *Spodoptera exigua*. *Entomol. Sin.*, 1(1): 25-34.
- You-Minsheng, Liang Guangwen and Wang Xinquan. 2005.** Biodiversity conservation and sustainable use of important insect resources in China. *J. Insect Sci.*, 5(1): 1-9.

**Zhang, Q. H., Schlyter, F., Birgersson, G. and Löfstedt, C. 2012.** Olfactory and behavioral response of female and male *Plodia interpunctella* to cocoa husk volatiles. *J. Chem. Ecol.*, 38(2): 210-219.

**Zhao, M., Guo, M., Lu, X., Zhu, J., Zhang, Y. and Ma, C. 2021.** Comprehensive Analysis of Aroma Compounds in Apples from Shaanxi Province by HS-SPME/GC-MS. *Food Anal. Methods.*, 14(1): 182-192.

**Zul, A. M. 2020.** Cocoa Fruit Borer (*Conomoporpha cramerella*) infestation on cocoa trees: An overview of integrated pest management strategies. *Int. J. Agric. For. Plant.* 5(2), 79-90.

## CURRICULUM VITÆ

**Name** : Anjali Nautiyal **Phone No.** : 7055202581  
**Mailing Address** : Nautiyal House, Gujrada mansingh, Sahastradhara road, Dehradun, Uttarakhand Pin-248001 **Permanent Address** : Nautiyal House, Gujrada mansingh, Sahastradhara road, Dehradun, Uttarakhand Pin-248001  
**E-mail** : anjaliento@gmail.com

**Career Objective:** My ultimate career objective is to embark on a thrilling and fulfilling journey in academia or industry, relentlessly pushing the boundaries of knowledge and understanding in my field. Driven by a desire to make a tangible impact on the world, I aspire to become a distinguished leader in my area of research, celebrated for my pioneering contributions to the development of cutting-edge solutions that tackle pressing real-world challenges.

### Educational Qualification:

| S.No. | Examination passed        | Institution   | Year | Percentage/CGPA |
|-------|---------------------------|---|------|-----------------|
| 1.    | PhD, (Entomology)         | G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand | 2023 | 75.46%          |
| 2.    | M.Sc. (Entomology)        | G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand | 2016 | 70%             |
| 3.    | B.Sc. ZBC & Biotechnology | Sardar Bhagwan Singh University   | 2013 | 73.09%          |
| 4.    | Intermediate              | Kendriya Vidyalaya, Nagaland (CBSE)   | 2010 | 69.04%          |
| 5.    | High School               | Kendriya Vidyalaya, Mizoram (CBSE)  | 2008 | 67.04%          |

- **Specialization: Major:** Anjali Nautiyal **Minor:** Plant Pathology
- **Thesis Title:** Studies on plant volatile mediating orientation behaviour of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulations for its management
- **Publications:**

#### Paper published/accepted from thesis:

- Anjali Nautiyal, P. S. (2022). Bio-efficacy of different plant and animal based natural formulations against litchi fruit borer, *conopomorpha sinensis* under field conditions of tarai region, Uttarakhand. *Journal of Experimental Zoology, India*, 25(2), 1965-1969.
- Nautiyal,A.,& Kaul,R.(2022).RNAi technology and its application-review. *Int. J. Adv. Res.* 10(10), 1344-1347.

### **Papers communicated from thesis:**

- Anjali Nautiyal, P. S. (2022). Bio-efficacy of different plant and animal based natural formulations against litchi fruit borer, *conopomorpha sinensis* under field conditions of tarai region, Uttarakhand. *Journal of Experimental Zoology, India*, 25(2), 1965-1969.
- Nautiyal, A. and Kaul, R.(2022).RNAi technology and its application-review. *Int. J. Adv. Res.* 10(10), 1344-1347.
- **Conference Attended:**
  - Best poster presentation award for “Evaluation of different modules for management of whitefly in tomato” in national seminar on Entrepreneurship and innovation in agriculture for socio-Economic Framers organized by National agriculture higher education project (ICAR), Swami keshwanand Rajasthan Agriculture university, Bikaner from March 12-13, 2019
  - Best oral presentation for “Bio-efficacy of plant and animal based natural formulations against litchi fruit borer under field conditions” of tarai region, Uttarakhand in International conference on recent advances and innovations in biological and applied sciences(RAIBAS-2022) at SGT University ,Gurugram,Haryana,India.
  - Poster presentation for “Population dynamics of major insect on litchi during 2018 and 2019 at HRC Patharchatta” in International conference on Global approaches and allies sciences for sustainability, food security and livelihood organized by Samagra vikas evam paryavaran samiti, Prayagraj, Uttar Pradesh, India.
  - Oral Presentation on Studies on efficacy of different pest management modules against insect pest complex of tomato organized by 15th Uttarakhand state science and technology congress.
  - Poster presentation on pollination efficacy of insect pollinators in litchi.National symposium on innovations in horticulture : Production to consumption at G.B. Pant University of Agriculture and Technology, Pant Nagar, Uttarakhand, India on September 14-15,2017
  - Participated in international webinar on “engineering interventions in plant health management” organized by plant health engineering division of National institute of plant health management Hyderabad, India on 27th and 28th July 2020

- Participated in National Webinar On “Challenges, Opportunities and Future of Agri and Allied Research and Education: Post Covid Era” Organized by All India Agricultural Students Association (Registered under Societies Registration act 1860) on 30th – 31st May, 2020
  - Participated in National Webinar on "Management of Biotic and Abiotic Stresses in Protected Agriculture" organized by Centre of Advanced Agricultural Science & Technology on Protected Agriculture and Natural Farming, CSKHPKV, Palampur, under the aegis of World Bank & Indian Council of Agricultural Research (ICAR), New Delhi jointly funded NAHEP project held on 22-09-2020 to 24-09-2020.
  - Participated in webinar on “Desert locust management: current status and future strategies” by Division of entomology ICAR-Indian Agriculture research institute, New Delhi, India
- 
- **Awards/ Honors/ Achievements:**
    1. Rank state rank 2<sup>nd</sup> in National science Olympiad
    2. Best poster presentation award (2)
    3. Best oral presentation (1)

Place: Pantnagar

Date: March, 2023

  
(Anjali Nautiyal)

**Name** : Anjali Nautiyal **Id. No.** : 45819  
**Sem. & Year of Admission:** 2<sup>nd</sup>, 2016-17 **Degree** : Ph. D  
**Major** : Entomology **Deptt.** : Entomology  
**Minor** : Plant Pathology  
**Thesis Title** : “Studies on plant volatile mediating orientation behavior of adult litchi fruit borer, *Conopomorpha sinensis* Bradley and evaluation of plant and animal derived natural formulation for its management”  
**No. of pages** : 156 **Advisor** : Dr. Poonam Srivastava

### **ABSTRACT**

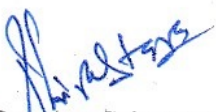
Litchi fruit borer is one among the major devastating pest of litchi causing fruit damage and yield loss. The present experiment was carried out to study the orientation behavior of adult litchi fruit borer toward different plant volatiles through olfactory studies. The biochemical analysis of different plant parts was carried out to find out the volatiles along with its concentration present in different parts of litchi plant. Field efficacy of different natural formulations against litchi fruit borer were also studied. Laboratory analysis of deterrence of these formulations to adult fruit borer moth was also studied through olfactometer studies. The diversity of different insect pest and natural enemies during the period of study was also recorded. The population dynamics of insect pest in relation with different weather parameters was also established.


A total no of 16 insect pest, one mite and 13 natural enemies were reported during the course of study. Amongst them, litchi fruit borer, litchi bug and leaf roller were found in close association with the plant and were categorized as “major pest; causing significant damage and yield loss to the plant. The findings from multiple liner regression analysis of different weather parameters with population of litchi fruit borer showed that; the insect population is influenced by a combination of maximum temperature, maximum relative humidity, and wind velocity, with positive coefficients indicating that an increase in the values of these independent variables is associated with an increase in the population of litchi fruit borer.

The biochemical analysis of different litchi plant parts revealed that revealed that terpenes, alcohols, and esters were the main chemical compounds present in the volatiles emitted from various litchi tissues, with terpenes comprising 21%, alcohols comprising 3%, and esters comprising 2%. The biochemical analysis of methanolic extracts from normal and mite-infested leaves indicated the presence of 41 phytochemicals in normal leaves and 42 in mite infested leaves.

The preference of fruit borer moth towards different plant parts were studied through olfactometer studies and it was found that there were differences in the taxes behaviour of female and male adult litchi fruit borer adults towards different tissues of the litchi tree, specifically female litchi fruit borer adults were found to exhibit a stronger preference for the host tissues compared to the male adults.

Efficacy of different botanicals and natural formulations against litchi fruit borer were studied under field condition for both the years. Laboratory studies on olfactory behavior of adult moth towards these formulations were also studied through olfactometer. Amongst the treatments, panchagavya and lantana was found most and least effective against litchi fruit borer, respectively. Similar findings were also recorded under laboratory condition. Panchagavya showed maximum repellent against the adult moth of fruit borer. Whereas, vermiwash showed the least repellent activity.

  
(Poonam Srivastava)  
Advisor

  
(Anjali Nautiyal)  
Authoress

नाम : अंजलि नौटियाल परिचयांक : 45819  
सत्र और प्रवेश का वर्ष: द्वितीय, 2016-17 उपाधि : पीएचडी  
प्रमुख विषय : कीट विज्ञान विभाग : कीट विज्ञान  
गौण विषय : पादप रोग विज्ञान  
शीर्षक : "वयस्क लीची फल छेदक, कोनोपोमोर्फा सिनेसिस ब्रेडली के पौधे वाष्पशील मध्यस्थता अभिविन्यास व्यवहार पर अध्ययन और इसके प्रबंधन के लिए पौधे और पशु व्युत्पन्न प्राकृतिक सूत्रीकरण का मूल्यांकन"  
पृष्ठ संख्या : 156 सलाहकार : डॉ. पूनम श्रीवास्तव

## सारांश

लीची फल छेदक लीची के प्रमुख विनाशकारी कीटों में से एक है जो फलों और उपज को नुकसान पहुंचाता है। विभिन्न पौधों के वाष्पशील की ओर वयस्क लीची फल छेदक के उन्मुखीकरण व्यवहार का अध्ययन करने के लिए घ्राण अध्ययन का प्रयोग किया गया था। लीची के पौधे के विभिन्न भागों में मौजूद वाष्पशील पदार्थों के साथ-साथ इसकी सांद्रता का पता लगाने के लिए विभिन्न पौधों के हिस्सों का जैव रासायनिक विश्लेषण किया गया था। लीची फल छेदक के खिलाफ विभिन्न प्राकृतिक योगों की क्षेत्र प्रभावकारिता का भी अध्ययन किया गया। घ्राणमापी अध्ययन के माध्यम से वयस्क फल छेदक कीट के लिए इन योगों के निवारण के प्रयोगशाला विश्लेषण का भी अध्ययन किया गया। अध्ययन की अवधि के दौरान विभिन्न कीट-पीड़कों और प्राकृतिक शत्रुओं की विविधता भी दर्ज की गई। विभिन्न मौसम प्राचलों के संबंध में कीट पीड़कों की समष्टि गतिकी भी स्थापित की गई।

अध्ययन के दौरान कुल 16 कीट पीड़क, एक माइट और 13 प्राकृतिक शत्रु पाए गए। उनमें से, लीची फल छेदक, लीची बग और लीफ रोलर पौधे के साथ निकट संबंध में पाए गए और उन्हें "प्रमुख कीट" के रूप में वर्गीकृत किया गया; जिससे पौधे को काफी नुकसान और उपज का नुकसान होता है। लीची फल छेदक की आबादी के साथ विभिन्न मौसम मापदंडों के बहु लाइनर प्रतिगमन विश्लेषण के निष्कर्षों से पता चला है कि; कीट आबादी अधिकतम तापमान, अधिकतम सापेक्ष आर्द्रता और हवा के वेग के संयोजन से प्रभावित होती है, सकारात्मक गुणांक के साथ यह दर्शाता है कि इन स्वतंत्र चर के मूल्यों में वृद्धि लीची फल छेदक की आबादी में वृद्धि के साथ जुड़ी हुई है।

विभिन्न लीची संयंत्र भागों के जैव रासायनिक विश्लेषण विश्लेषण से पता चला है कि टेरपेन, अल्कोहल और एस्टर विभिन्न लीची के ऊतकों से निकलने वाले वाष्पशील में मौजूद मुख्य रासायनिक यौगिक थे, जिसमें टेरपेन 21%, अल्कोहल 3% और एस्टर 2% शामिल थे। सामान्य और माइट-संक्रमित पत्तियों से मेथनॉलिक अर्क के जीसी-एमएस विश्लेषण ने सामान्य पत्तियों में 41 फाइटोकेमिकल्स और माइट संक्रमित पत्तियों में 42 की उपस्थिति का संकेत दिया।

विभिन्न पौधों के हिस्सों के प्रति फल छेदक कीट की वरीयता का अध्ययन ओलफैक्टोमीटर अध्ययनों के माध्यम से किया गया था और यह पाया गया कि लीची के पेड़ के विभिन्न ऊतकों के प्रति मादा और पुरुष वयस्क लीची फल छेदक वयस्कों के कर व्यवहार में अंतर थे, विशेष रूप से मादा लीची फल छेदक वयस्क। पुरुष वयस्कों की तुलना में मेजबान ऊतकों के लिए एक मजबूत वरीयता प्रदर्शित करने के लिए पाए गए।

लीची फल छेदक के खिलाफ विभिन्न वनस्पति विज्ञान और प्राकृतिक योगों की प्रभावकारिता का दोनों वर्षों के लिए क्षेत्र की स्थिति के तहत अध्ययन किया गया। इन योगों के प्रति वयस्क कीट के घ्राण व्यवहार पर प्रयोगशाला अध्ययनों का भी घ्राणमापी के माध्यम से अध्ययन किया गया। उपचारों में पंचगव्य और लैंटाना क्रमशः लीची फल छेदक के विरुद्ध सबसे अधिक और सबसे कम प्रभावी पाए गए। इसी तरह के निष्कर्ष प्रयोगशाला की स्थिति में भी दर्ज किए गए थे। पंचगव्य ने फल छेदक के वयस्क पतंगे के खिलाफ अधिकतम विकर्षक दिखाया। जबकि, वर्मीवाश ने सबसे कम विकर्षक गतिविधि दिखाई।

  
(पूनम श्रीवास्तव)  
सलाहकार

  
(अंजलि नौटियाल)  
लेखिका