STUDIES ON FRUIT FLY DIVERSITY AND THEIR MANAGEMENT ON IMPORTANT FRUIT CROPS OF JAMMU SUB -TROPICS

By

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IN

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Ph.D

STUDIES ON FRUIT FLY DIVERSITY AND THEIR MANAGEMENT ON IMPORTANT FRUIT CROPS OF JAMMU SUB -TROPICS

GAURAV BHAGAT

2023

CERTIFICATE - I

This is to certify that the thesis entitled **"Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy,** in **Entomology** to the Faculty of **Agriculture**, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the University. Further, the level of minor similarities has been declared after checking the manuscript with **URKUND** software provided by the University.

The work has been carried out by **Mr. Gaurav Bhagat,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

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(Major Advisor)

Place: Jammu
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CERTIFICATE-II

We, the members of Advisory Committee of **Mr. Gaurav Bhagat**, Registration No. **J-16-D-274-A,** a candidate for the degree of **Doctor of Philosophy** in the subject of **Entomology** have gone through the manuscript of thesis entitled **"Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics"**and recommendthat it may be submitted by the student in partial fulfillment of the requirements for the degree.

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This is to certify that the thesis entitled **"Studies on fruit fly diversity and their management on important fruit crops of Jammu sub-tropics''**, submitted by **Mr. Gaurav Bhagat,** Registration No. **J-16-D-274-A**, to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in **Entomology,** was examined and approved by the advisory committee and external examiner(s) on **28-10-2022.**

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Gaurav

Dated: 30-1-2023 **Gaurav Bhagat**

ABSTRACT

Title of Thesis	:	**Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics**
Name of the Student	:	Gaurav Bhagat
Registration No.	:	J-16-D-274-A
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The thesis embodies the results of experimentation made on diversity of fruit flies in Jammu Sub-tropics, population dynamics and management of fruit fly in mango, guava and peach followed by refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) against major fruit flies on the mentioned fruit crops carried out during cropping seasons of 2019 and 2020. The diversity pattern of fruit flies revealed the presence of different species of *Bactocera*, *Dacus* and *Carpomyia* fruit flies at the experimental orchards. The experimental orchards at FSR, Chatha had highest diversity of fruit flies in terms of species richness and species abundance as compared to experimental orchards at Raya and Miran Sahib, during both the years. The computed Sorenson's evenness coefficient (CC) indicated that all the three communities under study had a bit of overlap or similarity in terms of fruit fly species diversity. The studies on population dynamics of fruit flies revealed the presence of fruit flies from 8^{th} to 50^{th} standard weeks at all the experimental sites during both the years. The fruit fly population had a positive correlation with minimum and maximum temperature, non-significant positive correlation with evening relative humidity and rainfall but negative correlation with morning relative humidity at Raya and FSR. However, at Miransahib, fruit fly population had a non-significant positive correlation with maximum temperature and morning relative humidity and significant positive correlation with minimum temperature, evening relative humidity and rainfall. For evaluating the MAT and BAT techniques in different fruit orchards, the population of fruit flies commenced from February and lasted till December wherein, Methyl eugenol+malathion was statistically superior over all other treatments. The refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) in the orchards of mango, guava and peach revealed that the highest trap catches were recorded in commercially available green valley fruit fly traps followed by another commercially available traps (PCI) and the least trap catches were recorded in cue-lure+absorbent plastic on all the three fruit crops during both the years of experimentation.

Keyword: Diversity, Population dynamics, Mango, Guava, Peach, Male Annihilation technique, Bait Attractant Technique, Methyl eugenol, Malathion

Signature of Major Advisor **Signature of Student**

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Introduction

CHAPTER-I

INTRODUCTION

The Union Territory of Jammu and Kashmir (32-36°N, 73-80°E) has diverse agro-climatic conditions that have encouraged the cultivation of quality fruits and vegetables production ranging from subtropical to intermediate and temperate areas. This UT is known as the bowl of horticultural crops wherein, horticulture is the backbone of economy with a yearly turnover of Rs 6000 crores, contributing about 7% to the Gross Domestic Product. Horticulture is considered as thrust area by our UT. Currently, it provides direct and indirect employment to about 33.00 lakh people and most of them earn their livelihood from this sector (Anon., 2016)

The area under horticulture crops grew by 2.6% per annum and annual production increased by 4.8% over the last decade in India. During 2017-18, production of horticulture crops was 311.71 million tonnes from an area of 25.43 million hectares, while in Jammu and Kashmir production of horticulture crops was 3.6 million tonnes from an area of 0.44 million hectares **(**Anon., 2018). During 2018–19, the area of 331538 ha and the production of 2415421 MT under horticulture in Jammu and Kashmir contributed about 2.20% to the overall production to India. However, Jammu region contributes 37.07 % fruit production including fresh and dry fruits in UT of Jammu and Kashmir (Ahmad *et al*., 2021). Presently, an area of 1.18 lakh ha is under fruit cultivation in Jammu province with an annual production of 1.87 lakh MT (Anon., 2018).

Among the fruit crops, mango and guava have a prominent position in sub-tropical regions of Indian sub-continent and world, while peach thrives well and extensively grown in sub-tropics as well in temperate region. Mango belongs to the family Anacardiaceae and is known as the king of fruits whereas guava belongs to family Myrtaceae and better known as poor man’s apple. The production of these crops is severely threatened by the insect pest infestation which reduce the fruit quality as well as quantity which indirectly keeps the global trade of horticultural crops at stake. Among the insect-pests, fruit flies of the family Tephritidae are the most destructive pests of fruits and vegetables around the world and pose a significant risk to horticulture in India. Fruit flies are considered as one of the most damaging agricultural pests around the globe which causes huge threats to horticultural crops, both fruits and vegetables (Hasyim *et al*., 2008; Clarke *et al*., 2011 and Hendrichs *et al*., 2015). The genera *Bactrocera* poses the greatest risk to horticultural crops, especially to the fruit and vegetable growing states. The extensive damage and wide host range of fruit fly is a matter of serious concern to the diversification of horticulture as well as exports and cost a heavy toll to the horticultural producers. Globally, around 4000 fruit fly species belonging to family Tephritidae are present; however, only 350 species are economically important (Anon., 2011). Tephritid fruit flies cause 90 to 100 % yield loss in fruits and vegetables depending upon several factors such as area, season, variety, and their population (Sapkota *et al*., 2010). Fruit flies caused direct loss in the form of yield and indirect loss such as reduction in trade and export prospect (Sharma *et al*., 2015).

Most fruit and vegetable crops in India suffer from attack by fruit fly belonging to the genus *Bactocera* (Diptera: Tephritidae) and losses may be up to the tune of 100 per cent, if not regulated in time. They attack almost all fruit crops along with the wild ones and many vegetable crops. Furthermore, they are regarded as serious quarantine pests impeding access for many commodities to markets within India and overseas (Abdullah *et al*. 2007, Kapoor *et al*., 1980; Ndiaye *et al*., 2008; Verghese *et al*., 2012 and Ekesi *et al*., 2016).

In Indian subcontinent, there are more than 200 known species of fruit flies. However, hardly more than ten species are considered to be the serious pests of fruits and vegetables. Most of these species are polyphagous, having high rate of fecundity and ability to quickly spread over a wide area that makes them real and challenging threat for fruit and vegetable growers (Saeed *et al*., 2022).

From an economic point of view, many species of fruit flies that infest various kinds of fruits and vegetables such as *Bactrocera zonata* (Saunders), *Bactrocera dorsalis* (Hendel), *Bactrocera correcta* (Bezzi) and *Bactrocera cucurbitae* (Coquillett), *Bactrocera tau* (Walker) are the most important ones in India. *B. dorsalis* is a major fruit fly pest, especially on mango, affecting local and export markets wherein, crop loss due to *B. dorsalis* varies with season and region. According to an estimate the loss to mango in an unsprayed situation varied from 2.5 to 59.0 % depending on the variety (Verghese *et* *al*., 2002). About 80 species of insect pests are recorded on guava (*Psidium guajava* L.) (Tandon and Verghese, 1987; Haseeb and Sharma, 2002) and a huge economical loss amounting to 2558 and 26902 million rupees has been recorded due to fruit fly infestation (Sharma *et al*., 2011). The *B. zonata* is a serious and polyphagous insect pest of fruit crops in many parts of the world and widely distributed in several regions of India (Rai *et al*., 2008 and Choudhary *et al*., 2018). In case of severe infestation, fruit fly may cause fruit damage up to 50 to 80 per cent. The population dynamics, distribution, and species diversity of fruit flies on sub-tropical fruit crops in Jammu region was earlier portrayed by Rai *et al*. (2008), while on cucurbits in Kashmir valley, it was highlighted by Ganie *et al*., 2013. The ber fruit fly (*Carpomyia vesuviana*) may cause 90-100 per cent damage to ber fruits (Kapoor, 1993).

Despite of IPM promotion and adoption of IPM policy by several governments, farmers are still relying on chemical pesticides as a single method of control which leads to several impacts like residues in food stuff and contamination of natural resources and disturbance in ecological equilibrium. In order to limit such problems, there is a need to adopt integrated pest management to control fruit flies on fruit crops in tropical, sub-tropical and temperate areas for sustainable crop production. IPM or Integrated Pest Management is an approach that has been recently utilized for fruit fly management around the world. The installation of traps around the perimeter of the crop can also prevent fruit fly invasion which not only shows the promising results but also are ecofriendly (Epsky *et al.,* 2014). Toxic baits are also considered the good means to mitigate the fruit fly population (Navarro-Llopis *et al.,* 2013 and Hafsi *et al.,* 2015). The efficacy of crop protection methods with system's sustainability coupled with right decision on right time may facilitate in developing quantitative information in reducing the crop losses and their management for better integrated pest management. The existing techniques should further be refined as low cost and slow-release techniques which may be easily adopted by the farming community. Chemical attractants such as methyl eugenol and cue lure are very useful and standardized technique for surveying, monitoring and controlling fruit flies. Exploration and utilization of an effective and locally available biological control agent may also be blended in IPM programme to suppress the fruit fly population (Verghese, 2001; Soumya *et al.,* 2013 and Harbi *et al.,* 2019). Male annihilation technique (MAT), Bait Application Technique (BAT) and Sterile Insect Technique (SIT) are already validated techniques to control fruit flies throughout the world (Stonehouse *et al.*, 2002; Jessup *et al.*, 2007; Singh and Sharma, 2011; Rull *et al.*, 2012 and Patel *et al.*, 2020). These methods are relatively safer to the environment and proved to be ecologically sound. Certain other methods such as safe chemical control, cultural control and combinations of safe insecticides and available plant products may also be promising strategy for the fruit fly suppression.

The present study was carried out to gather more realistic information on diversity of fruit fly, seasonal population dynamics, evaluation of different techniques and refinement of existing MAT and BAT techniques against fruit flies infesting mango, guava and peach which is an important pre-requisite in decision making and devising the better integrated pest management to suppress the fruit fly population and their damage on crop plants. Besides these, the inputs like low-cost mineral bottle traps, locally available botanicals preparations may become a good driver in providing job opportunities to rural family for making the local traps to earn extra remuneration which eventually leads to uplift their socio-economic conditions.

In view of the economic importance of horticultural crops cultivation in Jammu and the losses caused by the fruit flies, it becomes imperative to keep continuous vigil on the population dynamics of fruit flies and their status coupled with identification of promising natural enemies for management studies in devising an effective integrated pest management against dreaded fruit flies. Therefore, the present investigation is being carried out the studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics. Keeping the above facts in mind, the economic importance of the fruit crops and the magnitude of the damage caused by fruit flies, the present study is proposed with the following objectives-

1. To study the diversity of fruit flies in Jammu Sub-tropics
2. To study the population dynamics of fruit fly in mango, guava and peach
3. Evaluation of different techniques for the management of fruit fly on mango, guava and peach
4. Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies

Chapter-II

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

This chapter deals with the work done in the past emphasizing on the objectives decided for the present investigation. The major thrust has been given to the integrated approach to mitigate the fruit fly damage. Tephritid fruit flies are recognized worldwide as the most important threat to horticulture (Ekesi and Mohamed, 2011). With about 4,500 species, Tephritidae is one of the largest families of order Diptera and about 325 species are known to occur in the Indian subcontinent. Of which, 243 species in 79 genera under four subfamilies, namely Dacinae, Phytalmiinae, Tephritinae and Tryptinae are from India alone (David and Ramani, 2011). India represents and shares about 5 per cent of known tephritid fauna of the world. In the family Tephritidae, the subfamily Dacinae has a maximum number of economically important species and the tribe Dacini with the genus, *Bactrocera* is occurring more abundantly in India. From an economic point of view, *Bactrocera dorsalis* (Hendel), *B. zonata* (Saunders), *B. correcta* (Bezzi) and *B. caryeae* (Kapoor) are important (Verghese *et al.*, 2002), whereas *Dacus cucurbitae* was found infesting the vegetables and fruit crops (Kapoor, 2005) in India. According to an estimate by Mumford (2001), India being the world's largest producer of tropical and sub-tropical fruits, suffers of Rs.29,460 million losses due to fruit flies. Fruit flies have polyphagous feeding habit and thus they have their remarkable importancein causing tremendous losses in agriculture and horticulture sector. Efforts were made to cite some important and pertinent references on species diversity, population dynamics, evaluation of different MAT and BAT techniques and refinement of different combination treatments on mango, guava and peach fruits against fruit flies have been compiled under different sub-headings as follows-

2.1 Survey on diversity of fruit flies

The important fruit flies belong to family Tephritidae and include some economically important species belonging to genera *Anastrepha*, *Rhagoletis, Bactrocera* and *Ceratitis.* There are two genera under Dacinae *viz.*, *Bactrocera* and *Dacus.* Three species of *Bactrocera* viz., *B. dorsalis*, *B. zonata* and *B. diversa* are important pests of mango, guava and stone fruits (Bhalla and Pawar, 1977) while as per Butani (1979) the fruit flies are insect pests of economic importance globally. The fruit fly species, *Bactrocera dorsalis*, also called as oriental fruit fly, belongs to Oriental region and is an important insect pest of various fruit crops in Japan, China, Taiwan and India. In India, the knowledge of Tephritidae fruit flies is mostly derived from the monograph of Bezzi published in 1913 (Kapoor *et al.*, 1980). Kapoor and his associates have carried out tremendous work on fruit flies of Tephritidae family from 1960s to 1990s. Different fruit fly species are responsible for causing damage to different parts of plants like flower heads, seeds, leaves and fruits (White and Elson-Harris, 1992 and Thompson, 1998).

Drew and Hancock (1994) studied on fruit fly complex of Asia and reported that fifty-two species are placed in the *B. dorsalis* complex in Asia, eight of which are considered of economic importance. Moreover, they revised twelve species and described forty new species. Further, keys were developed by them on the number of fruit fly species within a complex, their host plants, recorded attractants, location of type specimens and geographic distribution. Lectotypes were designated for *B. dorsalis* (Hendel), *B. mangiferae* (Cotes) (a synonym of *B. zonata* and *B. pedestris* (Bezzi).

Ovruski *et al.* (2000) discussed the diversity of fruit fly (Diptera: Tephritidae) parasitoids (Hymenoptera) of the Neotropics. They focussed on distribution patterns and the taxonomic status of all known Anastrepha parasitoids, its guilds, parasitoid assemblage size and fly host profiles. Further, they stressed on most pressing needs related to fruit fly biological control (classical, augmentative, and conservation modalities) in areas of the Neotropics where fruit fly populations severely restrict the development of commercial fruit growing.

In India, Dacinae fruit fly species attacks mango and causes serious loss ranging from 5-80% (Verghese *et al.*, 2002). In 2005, Agarwal and Sueyoshi published catalogue of Indian fruit flies, listing 243 species in 79 genera. *B. cucurbitae* and *B. tau* on cucurbits (Sood and Nath, 1999) in Himachal Pradesh.

Drew and Raghu (2002) documented above twenty-one species of fruit flies from Western Ghats of India. Among the recorded species, eight were considered as the new records. The noval recorded species were: *Bactrocera apiconigroscutella B. amarambalensis, B. neoarecae, B. neonigrotibialis, B. paraosbeckiae, B. paraverbascifoliae, B. penecorrecta, B. pseudoversicolor, B. (Daculus) yercaudiae, B.*

(Sinodacus) binoyi. Information is given on location of type specimens, host plants, attractant records and geographic distributions for the species that are described in detail. A full list and key to the species of the genus *Bactrocera* Macquart recorded from the Indian subcontinent are presented. Whereas, Verghese and Jayanthi (2001) in earlier studies have also documented bait trap catches of *B. dorsalis* and *B. correcta* where methyl eugenol was used as a bait.

Kapoor (2002) reported that about two hundred species of fruit flies are known from India. Out of these, only 35 to 40 species were directly or indirectly associated with their host plants. Major pest species belong to the subfamily Dacinae and genus *Bactrocera*; e.g. *B. cucurbitae*, *B. dorsalis* and *B. zonata*. *B. cucurbitae* was a major pest of almost all cucurbits and damages up to 70% of these fruits. It often competes with *Dacusciliatus, B. scutellaris* and *B. tau*. *D. ciliatus* sometimes dominates *B. cucurbitae* in round gourds (tinda) and squash melons (*Citrullus lanatus* var. *fistulossus*). *B. dorsalis* occurs in a complex of at least four species; of these only the true *D. dorsalis* is of greatest importance. *B. zonata* has now surpassed *D. dorsalis* in many mango growing areas. It is believed to occur in a complex of two to three species. Both, *B. zonata* and *B. dorsalis* compete strongly with *B. correcta* in guava in some important fruit-growing areas in India, which sometimes becomes a major threat. Other fruit fly species are currently confined to the Andaman and Nicobar Islands, and their entry into mainland India need to be very carefully monitored.

Muraji and Nakahara (2002) revealed that fruit flies, *Bactrocera* species in particular, have their origin in tropical Asia, Australia and some regions of South Pacific. However, some species are also found in Africa and warm areas of Eurasia. These are mainly polyphagous pests, having widespread distribution, wide climatic adaptation, high reproductive potential, high mobility and cause losses in fruit and vegetable crops.

Verghese *et al.* (2002) visualized about 200 different fruit fly species in India which constitutes only 5 per cent of the global population of Tephritid flies.Highest number of fruit fly species come under sub family Dacinae. The genus *Bactrocera* lies under sub-tribe Dacini has economic importance in our country. *Bactrocera* species *viz.*, *B. dorsalis, B. correcta, B. cucurbitae* and *B. zonata* are important crop pests. *B. cucurbitae* mainly is restricted to cucurbits whereas the other three species are important pests of fruit crops. *B. dorsalis* is a serious pest on mango inflicting severe crop losses and also causes reduced trade and the loss caused due to this pest varies with season.

Madhura and Viraktamath (2003) documented five *Bactrocera* species *viz*., *B. affinis, B. zonata, B. dorsalis, B. correcta* and *B. verbascifoliae*. The attractiveness of these species was reported for traps baited with methyl eugenol at Bangalore. The ber fruit fly, *Carpomyia vesuviana* Costa (Diptera: Tephritidae) is the most destructive pest of *Ziziphus* spp. in its area of distribution including Bangladesh, China, Georgia, India, Indian Ocean Islands, Iran, Mauritius, Oman, Pakistan, Southern Europe, Turkmenistan, Turkey, and Uzbekistan (Farrar *et al.*, 2004; Vadivelu, 2014).

Sardana *et al.* (2005) showed that agricultural problems are aggravated due to fruit fly infestation and nine species in particular *viz*., melon fly, *B. cucurbitae*; oriental fruit fly, *B. dorsalis*; peach fruit fly, *B. zonata*; pumpkin fly, *B. tau*; guava fruit fly, *B. correcta*; lesser pumpkin fly, *Dacus ciliatus*; ber fly, *Carpomyia vesuviana* and seed fly, *Acanthiophilus helianthi* are major and economically important in India and caused annual estimated losses to the tune of 855.40 million dollar. Among these the melon fly, *B. cucurbitae* is a polyphagous fruit fly that attacks more than 125 plant species, mostly belonging to the Cucurbitaceae and Solanaceae and include some species of significant agricultural interest (Dhillon *et al.*, 2005 and Pinero *et al.*, 2006).

Prabhakar *et al.* (2012) recorded 13 species of Dacine fruit flies from North-Western Himalaya of India of which 4 species were new records from the Himachal Pradesh region. Most of these species have economic importance as pests of horticultural crops in different countries of the world.

Singh (2012) reported that oriental peach and ber fruit flies (*Bactrocera dorsalis, B. zonata* and *Carpomyia vesuvinana*, respectively) are the major damaging pests in horticultural ecosystems in Punjab. An integrated pest management with use of PAU fruit fly trap (@ 16 traps per acre) achieved best control across a wide range of crops. He further recorded *Biosteres longicaudatus* Ashmead as egg and pupal parasitoid of fruit flies.

Leblanc *et al.* (2013) conducted a survey on various Dacinae fruit flies in Bangladesh and revealed that thirteen species of *Bactrocera* and one species of *Dacus* were collected during field surveys in Bangladesh, including eight new country records, for a total of fifteen species confirmed to occur in the country. Color variation in Bangladesh *B. dorsalis* is similar to that observed in *B. invadens* in Africa and Sri Lanka.

Ukey *et al.* (2013) worked on the diversity in terms of species composition of fruit flies in the family Tephritidae on guava orchards of Maharashtra. The collected specimen of fruit flies was identified with the help of taxonomical keys. The highest population of *B. dorsalis* was trapped to methyl eugenol traps installed in guava orchard and lowest population of fruit fly, *B. verbascifoliae* was trapped due to the less prevalence of this species in the guava orchards of Ahmednagar district while in cue lure traps, only one species *B. cucurbitae* was noticed throughout the year. The fruit fly species, *B. zonata* and *B. correcta* were also observed in the fruit fly methyl eugenol trap.

Barr *et al.* (2014) studied genetic diversity of *Bactrocera dorsalis* on the Big Island using DNA sequencing. The Hawaiian set was compared to DNA sequence of 165 fruit flies between 2006 and 2012. The results indicated that no geographic association was found between Hawaiian and non-Hawaiian haplotypes in Los Angeles. Hence, it was concluded that in California, independent and multiple introductions were noticed from different sources.

Bhagat (2014) recorded fruit fly fauna of Jammu and Kashmir, India, and showed 48 species of fruit flies, belonging to 21 genera under families Drosophilidae (subfamily Drosophilinae) and Tephritidae (subfamily Dacinae, Tephritinae, and Trypetinae), occurring in diverse areas and localities of Jammu and Kashmir Himalayan region. The fruit fly species are responsible for causing immense damage to tropical and temperate fruits and vegetables grown in this region. The crops attacked in Jammu region include ber, citrus, guava, mango, and phalsa whereas, Kashmir region include apple, cherry, pomegranate, walnut, and members of Cucurbitaceae crops.

Rizk *et al.* (2014) studied thirteen species of the available fruit and vegetables for choice as preference under the laboratory conditions. The data indicated that guava fruit was the most preferable host according to an ascending sorted list of attraction percentages based on the number of flies attracted to guava. Lemon, zucchini, grapefruit and plum fruits were the least attractiveness, whereas cantaloupe, apple and pear were found to be the highly preferable fruits. The rest of examined fruits, such as peach, fig, mango, orange and cucumber, had a moderate preferable level. This wide range of response may be attributed to the large number of volatile substances that emanate from fruit inducing insect responses.

Badii *et al.* (2015) conducted an experiment to work out the host range and species diversity of various fruit flies in Ghana between October 2011 and September 2013. They collected samples of desired fruits from 80 host plants, both cultivated as well as wild. Then the plants were incubated to check the emergence of fruit flies. They found out that out of 80 plants, 65 plant species revealed the emergence of fruit flies. Infestation by *B. invadens* was higher in the cultivated fruits; *Ceratitis cosyra* dominated in most wild fruits. Cucurbitaceae were mainly infested by three species of *Dacus* and *Bactrocera cucurbitae*, a specialized cucurbit feeder. Among the commercial fruit species, the highest infestations were observed in mango, tomato, sweet pepper and watermelon, whereas marula plum, soursop, tropical almond, sycamore fig, African peach, shea nut, persimmon, icacina and albarillo dominated the wild host flora. The widespread availability of host plants and the incidence of diverse fly species in the ecology call for particular attention to their impact on commercial fruits and the development of sustainable management strategies against these economically important pests in Ghana.

Gautam *et al.* (2015) developed a manual wherein, they revealed important Asian fruit flies of economic importance and their management with focus on their identification on morphology of an adult fruit fly and distinguishing characters of order Diptera (Family:Tephritidae), methods of survey, sampling, collection and mounting procedures; biosystematics of *Bactrocera dorsalis* complex. They also revised the taxonomic characters of important fruit flies; biology and ecology of fruit flies in citrus; documentation through illustrations for development of illustrated diagnostic keys and key to the pest specie.

Adhikari and Joshi (2016) recorded the presence of fruit fly in *Citrus sinensis* in orchards of Nepal. They made a fruit fly surveillance during 2014-15 and revealed six species of *Bactrocera* flies, namely *Bactrocera minax* (Enderlein), *B. cucurbitae* Coquillett, *B. dorsalis* (Hendel), *B. zonata* (Saunders), *B. tau* Walker and *B. scutellaris* (Bezzi), and one species of *Dacus longicornis* Wiedeman. Except *B. minax*, other fruit flies were collected in male lure traps, while *B. minax* fruit flies were also reared to adults from infested sweet oranges. Each species of fruit flies has been morphologically identified up to species level for field identification purpose. *D. longicornis* is reported for the first time from Nepal.

Laskar *et al.* (2016) visualized diversity of various fruit flies (Family: Tephritidae) in West Bengal. They documented nine fruit flies of Tephritidae family which were collected by using traps (cue lure and methyl eugenol traps). A total of six fruit fly species *viz.*, *Bactrocera diversa, B. cucurbitae, B. tau, B. caudata, B. nigrotibialis* and *Dacus longicornis* by installing cue lure traps in cucurbits. In guava orchards of West Bengal, Methyl eugenol traps were used to trap four fruit fly species namely *Bactrocera* *zonata*, *B. dorsalis*, *B. correcta* and *B. versicolor*. Three fruit fly species viz., *B. dorsalis*, *B. zonata* and *B. versicolor* were recovered from fallen mango fruits at West Bengal. Again, after rearing from infested fallen and harvested guava fruits in Cooch Behar district (West Bengal), five species of tephritid fruit flies, viz., *B. dorsalis* (Hendel), *B. zonata* (Saunders), *B. versicolor* (Bezzi), *B. caudate* (Fabricius), and *B. nigrotibialis* (Perkins), were obtained. Moreover, 31.67 per cent, 36.33 per cent and 45.67 per cent of mango, guava and citrus fruits were infested by fruit flies in Northwest Bengal, respectively.

Nair *et al.* (2018) identified the Dacine fruit fly species present in Tripura, N.E. India. Para-pheromone traps (cue-lure and methyl-eugenol) and food bait traps were used to catch the Dacine fruit flies. Twenty species of Dacine fruit flies have been recorded form this North-Eastern state of India. Among these, 11 species are new records for the state and 6 species, namely *Bactrocera nigrifacia*, *B. rubigina*, *B. tuberculata*, *B. bogorensis*, *B. vulta and B. apicalis*) are new records for India. The taxonomic keys and coloured photographs for identification of these fruit flies were provided.

Rodríguez-Rodríguez *et al.* (2018) studied the fruit fly species diversity and population dynamics in the municipalities of Tetipac and Atoyac de Alvarez, Guerrero, Mexico. Fruit flies (Diptera: Tephritidae) are the most important limiting factor due to the direct damage caused to fruit crops such as mango, sweet citrus, guava, and some Sapotaceae species. Eleven fruit fly species were detected: *Anastrepha ludens* (Loew), *A. striata* Schiner, *A. obliqua* (Macquart), A. serpentina (Wiedemann), *A. spatulata* Stone, *A. bicolor* (Stone), *A. dentata* (Stone), *A. chiclayae* Greene, *Toxotrypana curvicauda* Gerstaecker, *Rhagoletis ramosae* Hernandez-Ortiz, and *Zonosemata cocoyoc* Bush (all Diptera: Tephritidae). In Tetipac, they recorded the greatest abundance of fruit flies (S = 10) and also the highest values for the Shannon-Wiener (H') diversity index and Simpson (λ) index (H' = 1.30; λ = 0.68). Total fruit fly abundance was 1,546 individuals (Tetipac 1,085; Atoyac de Alvarez 461). The main peak populations of fruit flies were recorded from February to October, coinciding with the phenological stages of fruiting, ripening, and harvesting of fruits of each area. The host range of the most predominant fruit fly species was confirmed by recording flies emerging from fruit. *Anastrepha obliqua* was detected in mango and jobo (Anacardiaceae) collected in Tetipac and mango from Atoyac de Alvarez. The fruit fly parasitoid, *Diachasmimorpha longicaudata* (Ashmead)

(Hymenoptera: Braconidae) was recorded only in Tetipac emerging from fruit flies infesting mango, guava and jobo.

Akbar *et al.* (2019) reported that the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) infested apple, apricot, nectarine, pear, peach and quince fruits from the Kashmir valley. Infestation to quince plants (*Cydonia oblonga*) constitutes a new global host record and to apple perhaps only the fifth known field infestation to be reported. The host suitability of the species on apple and quince was confirmed with harvested fruits, under cage rearing experiments. In field orchards, the fruit fly infestation for stated crops revealed a cumulative incidence and severity percentages of 17.33% and 6.44% respectively. All the specimens collected across different crops showed consistent morphological characters and were identified as one species. However, in light of the economic importance of the species, morphological studies were also integrated with molecular analysis for accurate identification of the species. The morphological characters and sequence results of amplified product of ITS1 and COX1 gene confirmed occurrence of single fruit fly species as *B. dorsalis*.

Irsad and Haseeb (2019) worked out species diversity of fruit flies belonging to Dacinae group in guava from 2017-2018 at Uttar Pradesh. Methyl eugenol traps were installed in the field to trap adults of fruit flies during the crop growing season. Three species of fruit flies recorded were, *Bactrocera correcta, B. dorsalis* and *B. zonata*. In general, proportionately higher population of *B. zonata* was recorded form various places surveyed. There was not much difference in species composition in different places. However, on an average, population differences were noticed in different areas. Number of adult fly emergence from the infested guava fruits collected from different places was proportionately in the range of 21.00-69.85 %, 21.06-49.80 % and 20.12 %-43.65 % for *B. zonata*, *B. dorsalis* and *B. correcta*, respectively.

Luciano Brasil *et al.* (2019) determined the richness of fruit fly species and their associations with their host fruits in a conservation unit from midwestern Brazil. Thirty-nine plant species from 29 plant families were collected. Twelve fruit species were hosts to fruit fly larvae. The survey resulted in the recovery of 1,476 larvae and 968 adult fruit flies. Among the adults, 878 were Tephritidae and 90 Lonchaidae. Nine species from the genus *Anastrepha* (Diptera: Tephritidae) and 3 from *Neosilba* (Diptera: Lonchaeidae) were obtained.

Tabasum *et al.* (2019) determined the species diversity of different fruit flies and longevity of pheromone lures in guava orchard at Fruit Research Station Sangareddy. They conducted experiment with 8 treatments and 3 replications in randomized block design. Initially all the traps were loaded with pheromone lure which was later changed from the traps at 30, 35, 40, 45, 50, 55 and 60 days interval, respectively. They identified three species of fruit flies *viz*., *Bactrocera correcta, B. zonata* and *Gastrozona fasciventris* from the collected samples. The number of fruit fly catches were highest in T1 *i.e*., when the lure was changed at 30 days interval, with lowest number of damaged fruits and highest number of healthy fruits against the tree without traps *i.e*., in Control (T8). When the weather parameters were correlated with number of fruit fly catches and age of the lure it was observed that there was positive correlation existed with maximum and minimum temperature, morning and evening relative humidity however, there was no correlation with rainfall and negative correlation with wind velocity. They further observed that the longevity of pheromone in the traps was lasted for 30 days.

Thangraj *et al.* (2019) investigated the diversity of fruit fly by using mitochondrial cytochrome oxidase I and II (cox1 and cox2), the genetic analysis of *B. dorsalis* from eight locations of major fruit growing areas in western parts of Tamil Nadu. Genetic diversity indices viz., haplotype number, diversity of haplotypes and diversity of nucleotides and the average number of nucleotide differences between sequences (k) of the populations revealed that *Bactrocera dorsalis* has a high level of genetic diversity with distinct genetic structure. Further, they stressed that this information will be useful to devise an area-wide management programme for this destructive pest.

Vignesh *et al.* (2020) showed the fruit fly species diversity, distribution pattern with its varietal preference of fruit flies in mango ecosystem by using methyl eugenol based parapheromone traps during 2017-18 at Tamil Nadu Agricultural University, Tiruchirappalli. The major diversity of species registered in mango ecosystem is viz., *Bactrocera caryeae* (Kapoor), *B. dorsalis* (Hendel) and *B. correcta* (Bezzi). The activity of fruit fly is maximum in the month of August and September with the mean catch ranges from 27.00 to 57.00 flies/ trap/week.

Hudiwaku *et al.* (2021) reported the diversity and species composition of fruit flies (Diptera: Tephritidae) in Lombok Island, Indonesia. The research was carried out on two habitat types, *i.e*., tropical rainforest and orchard, with each habitat type consisted of three different sites spread across Lombok Island as replication. A sampling of fruit flies was conducted using parapheromone traps from March to June 2020. Twenty-two species and 210, 267 individual fruit flies were collected from all locations during the study period. The most dominant species were *Bactrocera carambolae, B. limbifera, Zeugodacus caudatus*, and *B. dorsalis*. Based on the ANOVA, habitat types significantly affected the abundance but not the species richness of fruit flies. The visualization results obtained from the NMDS ordination indicated a difference in the species composition of fruit flies between the two habitats. They concluded that habitat types are an essential factor in shaping the community of fruit flies in Lombok Island.

2.2. Population Dynamics of fruit flies on Mango, guava and peach

In the beginning of 1900, methyl eugenol was being used for attracting fruit flies (Howlett 1912) and the effectiveness of methyl eugenol against *B. dorsalis* has been well reported. Apart from these, cue-lure, protein hydrolysate and trimedlure are the most commonly used attractants for monitoring as well as the management of fruit fly populations.

Narayanan and Batra (1960) recorded the highest fruit fly population in guava from July to September whereas, Qureshi *et al* (1975) while studying the population fluctuations and dispersal patterns of *B. zonata* in two orchards of guava demonstrated that the monthly mean catches of males in traps baited with a mixture of methyl eugenol and Naled were at their lowest in January-February and increased gradually to reach a peak in March-May. Populations declined in June-July but increased again in August, reaching another peak in September.

Prasad and Bagle (1978) recorded highest fruit fly population in guava from March to April with second peak population from August to September. However, Belavadi (1979) recorded March to May and September to November as two peak periods for fruit fly population in guava orchards of Dharwad.

Bagle and Prasad (1983) studied the population dynamics of *Dacus dorsalis* in mango orchards in Karnataka from July 1975 to December 1978 by weekly counts of males caught in traps with 100 ml of an emulsion containing 0.1% methyl eugenol and 0.25% malathion. The population was greatest during March, April, May and June with average monthly catches per trap of 1268, 270, 416 and 487 flies, respectively. The lowest catches were made in January, August and December, with average monthly catches per trap of 42, 71 and 72 flies, respectively. Increasing trends in the population were observed in February (average 194 males/trap) and September (172 males/trap). A significant positive correlation was observed between weekly catch and maximum temperature, while negative correlations were observed between weekly catch and relative humidity, rainfall and wind velocity.

Shukla and Prasad (1985) recorded distinct population peaks of *B. dorsalis* in March-April, May-June and September-October and maximum activity coincided with ripening of guava and mango fruits. Trap catches were significantly correlated with maximum and minimum temperatures, mean temperature and maximum relative humidity whereas, Fletcher (1989) showed that temperature plays a vital role in development, survival and reproduction of tephritid species and other insects.

Rana *et al.* (1992) demonstrated that abiotic factors played an important role in the regulation of *B. correcta* population. Mean maximum and minimum temperature, day degree, morning relative humidity and rainfall had positive impact while sunshine hours had negative effect on *B. correcta* population. The infestation of *B. zonata* varied with the temperature and relative humidity and more infestation was found at 26-30°C and 70-75 per cent, respectively.

Hedstrom (1993) determined the seasonal variation in abundance of the fruit flies *Anastrepha striata, A. obliqua* and *Ceratitis capitata* by monitoring adults in food-baited standard McPhail traps, during 14–28-months at seven sites in Costa Rica. Population fluctuations were evaluated with respect to phenology of host trees and rainfall. The peak number of fruit flies captured was significantly correlated with the fruiting peaks of their major hosts. There was no direct relationship between rainfall and variation in number of flies trapped, except for *C. capitata,* which was more abundant in drier habitats and periods of less precipitation. The duration of the adult emergence period declined as temperatures rose.

Agarwal *et al.* (1995) worked out the mean number of fruit flies namely *B. dorsalis* and *B. zonata* in traps in the months of April and August during 1997. The results revealed the population of *B. dorsalis* and *B. zonata* to be 39.94 and 134.92 fruit flies/trap/week, respectively. Further, they also reported that there existed a positive correlation of *B. dorsalis* population with mean temperature. Fruit fly population counts were low in the winter months from December to February which was thought to be caused by low temperature (below 20°C). Following the warmer season, the flies rebuilt their population throughout the rest of the year. However, Aluja *et al.* (1996) did not find any relationship between rainfall and fruit fly trap captures in mango orchards in Mexico.

Mann (1996) reported the presence of fruit fly (*B. dorsalis*) population round the year in installed fruit fly traps baited with methyl eugenol in mango orchards of Punjab.He recorded least fruit fly population in winter as a result of falling temperature. Moreover, low fruit fly population was also recorded in the month of July. Fruit fly population counts were low in the winter months from December to February which was thought to be caused by low temperature (below 20°C) and during the following warmer season, the flies rebuilt their population throughout the rest of the year. However, low catches in July may be due to the after-effects of high temperatures in June or due to high rainfall.

Singh (1996) revealed that incidence of fruit fly and pupal counts/kg fruit increased as the season and maturity of fruits advanced. The winter crop of guava was totally free but rainy season crop had more than 90 per cent fruit fly damage, however, temperature and rainfall had a positive impact on fruit fly population build-up.

Allwood (1997) focused on the importance of using traps to bring down the fruit fly population. The required information on geographical conditions, host range, population dynamics and abundance must prove vital in cataloguing the fruit fly species dominant in a particular area.

Kumar *et al.* (1997) observed that the population of *B. correcta* in mango was highest in mid-April with 453 fruit flies per trap and in May with 483 flies per trap. Afterwards, the population of fruit flies revealed a steady decline. The pest was highest active from March-June when the crop was in fruiting stage. There existed a positive correlation between fruit flies and mean temperature. On the other hand, fruit fly population had no significant effect due to mean rainfall, relative humidity and sunshine hours.

Makhmoor and Singh (1998) showed that the fruit fly population in guava had a negative correlation with mean temperature but positive correlation with mean rainfall and relative humidity. The peak population of fly was recorded in last week of July and lasted till second week of August and the highest trap catches of 170.66 in the last week of July at Jammu were recorded.

Verghese and Sudhadevi (1998) recorded highest population of B. dorsalis in the month of June in the year 1995. A year later, the highest fruit fly population was recorded in May and August followed by second highest population in the months of September and November. They reported a significant positive correlation of trap catches of *B. dorsalis* with minimum temperature and wind speed.

Agarwal and Kumar (1999) conducted a study on the seasonal population pattern of *Bactrocera zonata*. They reported that highest population of fruit flies existed in second fortnight of June and the lowest fruit fly population existed in fourth week of August.Moreover, fruit fly population had a positive correlation with mean temperature and rainfall whereas a negative correlation existed between fruit fly population and relative humidity. Further, Agarwal *et al.* (1999) reported that in mango, mean number of 39.94 and 134.92 *B. dorsalis* and *B. zonata* existed per trap per week, respectively in the months of April and August while, Jalaluddin *et al.* (1999) reported that there existed three peak populations of fruit flies *viz*., *B. zonata, B. dorsalis* and *B. correcta* in guava. The first highest population was recorded in last week of June followed by second highest population in last week of July and third highest population in last week of August.

Anjum *et al.* (2000) recorded the highest fruit fly population of *B. zonata* during first fortnight of July. The population *B. zonata* was higher than of *B. dorsalis*. They observed that there was a significant positive correlation between the trap catches of *Bactrocera* species and maximum and minimum temperatures. The maximum catch coincided with the ripening period of fruits in Pakistan. However, Chaudhary and Jamal (2000) recorded that during August to October, the fruit fly activity is highest which comes around the maturity time in guava.

Gupta and Bhatia (2000) observed the highest population of fruit flies in third week of June with 357 fruit flies per trap while, minimum population (14.3 flies/trap) was recorded during last week of August. The peak incidence of *B. dorsalis* and *B. zonata* in guava was found in 37^{th} and 39^{th} standard meteorological week, however, the maximum catches of *B. dorsalis* and *B. zonata* in mango orchard were 98.6 to 62.6 fruit flies during 30^{th} and 27^{th}standard weeks in 1992 and 1993, respectively.

Clarke *et al.* (2001) reported that *B. dorsalis* and *B. correcta* exhibited unimodal patterns of population abundance with peak incidence from June to September in guava in Thailand and Peninsular Malaysia.

Jalaluddin *et al*. (2001) studied the population fluctuations of the guava fruit fly, *B. correcta,* in guava orchards in Tamil Nadu from May 1994 to September 1995 using methyl eugenol traps. A distinct population peak, which coincided with the ripening, was recorded from July to August in both years. Abiotic factors played an important role in regulating *B. correcta* population. Data on weekly catch when, correlated with weather parameters showed significant positive correlation with mean maximum temperature (r=0.3314), minimum temperature (r=0.3610), day-degrees (thermal units) (r=0.3692), morning relative humidity (r=0.4369) and rainfall (r=0.2364). Weekly mean sunshine hours had low negative correlation with the catch.

Madhura (2001) reported that in 1998, population of fruit flies on mango were non-significantly correlated with mean maximum temperature and in 1999, negative correlation existed with mean temperature. However, significant positive correlation existed with fruit flies in 2000. Moreover, in 1998 and 2000, negative correlation of fruit flies existed with relative humidity and in 1999, positive correlation with fruit fly population. In 1998, the peak population was observed during 3rdweek of May (315.14 fruit flies/week), however, during 1999, besides a peak in 3rd week of May (282.29 fruit flies/week), another peak was observed in second fortnight of June. The fruit fly population commenced from last week of April in 2000 and the highest population was recorded in third week of May.

Sarada *et al.* (2001) worked out population dynamics of fruit flies in Andhra Pradesh from Feb-July in 2000. They reported that fruit fly population showed an upsurge from beginning of February and continued to increase up to last week of June. The highest fruit fly population was noticed from May to June which coincided with the maturity time of fruit. There existed a positive correlation of fruit flies with mean rainfall and temperature; however, there existed a negative correlation with relative humidity.

Gillani *et al.* (2002) worked out the seasonal fluctuation in fruit fly population in guava and nectarine orchards at NARC, Islamabad, Pakistan, using pheromone traps baited with a mixture of methyl eugenol, sugar and naled. Generally, flies were caught in higher numbers in nectarine orchard than in guava orchard, however, the difference was not statistically significant. The fruit flies were present in the field throughout the year except January. They were caught in the traps in greater numbers from the months of May-August and the highest population was recorded in the month of July in guava as well as nectarine. Three species, *Dacus zonatus, Dacus dorsalis* and *D. cucurbitae* were caught in the traps. *D. zonatus* was the dominant species and its population was significantly higher than other two species. It appears to be a severe pest of these fruits as it was present in the field almost throughout the year and in greater numbers in the warmer half of the year. *D. cucurbitae* was caught in the traps in very small numbers and this species does not seem to be a serious pest of guava and nectarine under Islamabad ecological conditions.

Mahmood *et al.* (2002) investigated the density fluctuation of trapped fruit flies male, *D. zonatus* throughout two consecutive years and effect of abiotic factors on its trapping in peach orchard. Three traps were placed in the peach orchard on 1st September 1995. The trapping of males continued from 8th September to 8th December 1995. During 1996, the trapping continued from 6th September to 22nd November. No male was trapped from mid of December to end January during 1995-96 and end of November to 1st week of March, 1996-97. From February to April, mean number of males caught per trap was very low. The month of May, June and July were found as the period of high trapping during 1996, while the same was observed in the month of June and July during 1997. All abiotic factors contributed significantly towards increasing/decreasing fruit fly catches. Mean maximum and minimum temperature, rainfall had a positive and highly significant correlation with mean number of males per trap. Mean relative humidity was the only factor, which had a negative and significant correlation.

Anonymous (2003) demonstrated that Cue-lure, chemically known as 4-(pacetoxyphenyl)-2-butanone, is widely used to catch *B. cucurbitae* and Queensland fruit fly, *Bactrocera tryoni* (Froggatt). However, the documentation has revealed that about 150 varied fruit fly species belonging to genus *Bactrocera* are attracted to cue-lure.

Singh and Mann (2003) reported that population of *B. dorsalis* was maximum in September, declined in July and lowest in February in methyl eugenol baited traps fixed in peach orchard in Punjab. The population build up was positively correlated with temperature and rainfall. As the season advanced, the attack of *B. dorsalis* also increased during the fruiting period. The activity was higher in the north, west and centre of the field whereas, the southern canopy of the tree had low counts of fruit fly in methyl eugenol baited traps. Though the fly remained active during the whole day but its activity slowed down during noon hours.

Dwivedi *et al.* (2003) showed that the commencement of *Bactrocera dorsalis* was noticed in April with 3 per cent rate of infestation which gradually increased in May (8.2%), June (9.8%) and then slightly declined in July (8.3%) in mango orchard at Kanpur.

Sureshbabu and Viraktamath (2003) reported that *B. zonata* and *B. correcta* in mango were positively correlated with mean temperature at Dharwad and the fruit fly species were positively correlated with mean maximum and minimum temperature at Kumbapur. However, trap captures of *B. zonata* and *B. correcta* in guava were positively correlated with mean temperature and negatively correlated with mean relative humidity. It was observed that the one highest fruit fly population (*B. zonata*) was recorded in 21st week followed by three highest populations of *B. correcta* in 19, 23 and 47 standard meteorological weeks and another three highest populations of *B. dorsalis* in 21, 23 and 46 standard meteorological weeks at mango orchards of Dharwad. At Kumbapur, there existed a positive correlation of *B. zonata* and *B. correcta* with mean temperature and relative humidity (Viraktamath and Sureshbabu 2004). In guava, *B. dorsalis* had one peak (45th standard week) at Dharwad and three peaks (43rd, 45th and 47th standard weeks) at Kumbapur.

Manzar and Srivastava (2004) compared the efficacy of cue-lure and methyl eugenol on *B. cucurbitae* and *B. zonata* infesting bitter gourd and computed the correlation between trap catch and abiotic factors. The results showed that fruit fly population had positive correlation with mean temperature in 2002. However,*B. cucurbitae* had significantly correlation with only maximum temperature during both years. However, the maximum and minimum relative humidity and rainfall were negatively correlated.

Dhillon *et al.* (2005) identified the traits associated with resistance of bitter gourd, *Momordica charantia* and their influence on Melon fruit fly, *Bactrocera cucurbitae* multiplication. The results indicated that fruit infestation percentage had a significant positive correlation with larval density per fruit. Moreover, there was a positive correlation between larval density per fruit and per cent fruit infestation with depth of ribs, diameter of fruit, thickness of flesh, length of fruit. There was a negative correlation with toughness of fruit. Flesh thickness and fruit diameter explained 93.0% of the total variation for fruit fly infestation, and flesh thickness and fruit length explained 76.3% of the variation for larval density/fruit. Moreover, fruit fly infestation and larval density per fruit were positively correlated with moisture content. There was about 97.4 per cent variation in infestation of fruit with moisture, potassium and sugar content. 85.7 per cent variation was noticed for larval density per fruit with moisture, phosphorous, protein and total sugars.

Ravikumar (2005) revealed that a daily average temperature of 18°C was estimated as the threshold temperature for the flies to undertake long-range dispersal.

Three peaks of *B. dorsalis* were recorded in guava orchard in 27, 45 and 48 standard meteorological weeks. However, *B. correcta* population peaked in 27 standard meteorological week in 2004; however there were two peak populations of *B. correcta* in 2005 during 11 and 18 standard weeks. In mango, the peak incidence of *B. correcta*was observed in first fortnight of July but in 2004, population of *B. dorsalis*was highest in 27thand 47th standard meteorological week. However, the highest population of *B. zonata* was recorded in 21st standard meteorological week.

Kannan and Rao (2006) conducted a study on the impact of climatic factors and host plant on the population of fruit flies (*Bactrocera dorsalis*) in mango orchards in Andhra Pradesh.The results revealed highest population of fruit flies in last week of May wherein 6.9 infested fruits were recorded per 20 fruits. Moreover, there existed a positive correlation of fruit flies with mean temperature (maximum and minimum) and negative correlation with mean relative humidity and rainfall.The mango trees that were younger than 15 years were comparatively more resistant to fruit fly damage.

Rajitha and Viraktamath (2006) recorded *Bactrocera dorsalis*, *B. correcta* and *B. zonata* while monitoring the population of fruit flies in a guava orchard in Dharwad, Karnataka, using methyl eugenol traps. The population of *B. dorsalis* peaked during the 30th standard week (SW, 27.16 flies per trap) in 2003 and on the 1st SW (2.03 flies per trap) in 2004. Peak populations of *B. correcta* were observed during the 30th (123.69 flies per trap) and 45th (362.67 flies) SW in 2003. In 2004, no significant peak was observed. The population of *B. zonata* peaked during the 42nd SW (15.19 flies per trap) in 2003, and on the 11th and 12th SW (17.71 flies per trap) in 2004. Based on the total number of fruit flies, population peaks were recorded on the 30th (157.64 flies), 43rd (218.75 flies) and 45th (379.82 flies) SW. Trap catches of *B. dorsalis* were positively correlated with mean temperature, relative humidity. Trap catches of *B. zonata* were significantly and positively correlated with maximum temperature. Trap catches of *B. correcta* had no significant correlation with weather parameters. The effects of weather parameters accounted for 56.70, 12.0 and 53.30% of the trap catches of *B. dorsalis, B. correcta* and *B. zonata*, respectively.

Hasyim *et al.* (2008) conducted an experiment on the population variation of adult fruit fly males (*Bactrocera tau*) and their infestation on passion fruits and their correlation with weather projections in West Sumatra, Indonesia and the results revealed that there existed similar fluctuation in number of males of *B. tau* with highest peak in the month of July.

Rai *et al.* (2008) studied the population dynamics and succession of fruit fly wherein, they revealed that fruit fly occurred throughout (34-52 SW), (25-43 SW), (7-37 SW), (22-03 SW) and (19-25 SW) on ber, guava, mango, citrus and phalsa with their peak population 450.7, 1882.2. 1967.3, 1069.3 and 85.3 adult male fruit fly/trap, respectively. Positive correlation between fruit fly and abiotic factors (temperature, humidity and rainfall) exists, whereas temperature (max. and Min.) ranged between (15-30 °C) showed highly significant impact in comparison to relative humidity on population fluctuations on fruit fly and found significant at both 5 % and 1 %. Temperature below 15°C was found lethal for the growth and development and during this period (December and January) population was very low.

Deepa *et al*. (2009) monitored the *Bactrocera* complex through methyl eugenol traps and revealed that the occurrence of *B. dorsalis, B. zonata, and B. correcta* in relation to abiotic factors throughout the season. In horticulture orchard, the highest trap catches were recorded in last phase of October in case of *B. zonata* wherein trap catches of 32.3 fruit flies were recorded per trap per week. The highest population of *B. correcta* were recorded in second week of December and April wherein trap catches of 30 and 47.6 fruit flies were recorded per trap per week. While *B. dorsalis* peak catch was recorded during fourth week of April with 46.6 fruit flies/trap/week.

Dale and Patel (2010) studied the seasonal fluctuation of fruit flies (*Bactrocera zonata* and *B. dorsalis*) on guava (cultivars Reshmadi and Lucknow-49) in Gujarat, India. Results showed that the highest number of fruit fly populations was observed in September and the lowest in May in the guava orchard. The peak fly population coincided with the fruiting season of guava. The highest number of fruit flies collected was *B. zonata* males (3665) compared with only 357 of *B. dorsalis*. The fruit fly population in the guava orchard had a significant positive correlation with minimum temperature and relative humidity while, Kumar (2011) stated that methyl eugenol attracts males of many *Bactrocera* spp., but not members of the subgenus *Zeugodacus,* which includes *B. cucurbitae, Bactrocera caudate* (Fabricius) and *B. tau*. Cue-lure (e.g. from up to 300 m away) and methyl eugenol (*e.g.* from up to 500 m away) attracts male flies but not the female flies.

Choudhary *et al.* (2012) studied about fruit flies from March to July in mango during 2012 by installing methyl eugenol traps. They recorded three fruit fly species *viz.*, *Bactrocera zonata*, *B. dorsalis* and *B. diversa*. The concluded that among all the collected species, B. zonata was the most predominant on mango in Jharkhand. The highest population index was recorded from Ranchi, Gumla, Lohardaga and Khunti during 2012.

Rai and Shankar (2012) recorded the severe infestation of fruit flies like *Bactrocera dorsalis* and *B. zonata* on Mango, guava and peach fruits in Jammu region. They recorded the *Diachasmimorpha longicaudata* for the first time in Jammu and Kashmir state on ber fruits and subsequently also recovered the parasitoids on guava and mango infested fruits.

Ganie *et al.* (2013) conducted a study of population dynamics of fruit flies and impact of various weather parameters in cucurbits at Srinagar and Budgam districts of Kashmir. They recorded the highest population of fruit flies at Batamaloo and Chadoora districts on different Cucurbitaceae crops (bottle gourd, ridge gourd, bitter gourd and cucumber). There existed significant correlation with mean temperature. In Chadoora, the fruit fly diversity was computed to be 0.51 wherein, *Bactrocera cucurbitae* was most dominant in Srinagar as well as Budgam which was succeeded by *B. dorsalis*and *B. tau*. In Chadoora, *B. scutellaris* was the restricted species. Results of the present investigation may be utilized in developing a sustainable pest management strategy in the agro-ecological system.

Soumya *et al.* (2013) devised the models to predict infestation of *Bactrocera dorsalis* (Hendel) in guava during 2009 and 2010 at Indian Institute of Horticultural Research, Bangalore. Guava is one of the preferred hosts of the fruit fly, *B. dorsalis* (Hendel) wherein, fruit flies cause high risk or loss to the fruits. In both the years, the infestation in second harvest could explain the variability in total infestation to the extent of 86% and 73%, respectively. IPM strategies can be decided from the second harvest infestation, thus obviating loss by > 95% in the subsequent 3-12 harvests.

Kakar *et al.* (2014) determined the level of infestation of fruit flies in various fruits (Peach at Swat and Guava at Kohat) and vegetable (Bitter gourd at Charsada) in Khyber Pakhtunkhwa (KP) during 2010 and 2011.The studies showed that fruit fly infestations gradually gained from mid-April and reached to its peaks in mid-August and September whereas, the fruit fly infestation dropped from the end September to mid-November in Guava orchards. In case of Peach orchards, fruit fly infestation varied during the study periods in both the years (2010 and 2011). There was a steady upsurge in infestation from April and was highest in August. Afterward the insect infestation reduced and was minimum in October. Likewise, the highest infestation rate in Bitter gourd was found in August at Charsada. Afterwards, the infestation decreased and was minimum in November.Thus, fruit fly infestation was reported in all the study orchards and this time period is critical for management of fruit flies.

Mishra *et al.* (2014) concluded that *Bactrocera dorsalis* population showed its peak in 32nd and 35th SW, respectively on mango fruit crop. Correlation between *B. dorsalis* and weather conditions resulted, in a non-significant correlation with maximum temperature while it showed positive significant correlation with minimum temperature, relative humidity and rainfall in both years of the experiment.

Nagaraj *et al.* (2014) studied population dynamics of fruit flies in mango orchard during 2008-2009 at GKVK campus, Bangalore and revealed the presence of *Bactrocera* species namely *B. correcta, B. dorsalis* and *B. zonata* round the year in orchards of mango. Fruit flies had two major peaks during second and third week of July (28th and 29th standard week). The least count of fruit flies was recorded during the fourth week of December (52nd standard week). In 2009 three minor peaks and one major peak was observed during first, second, third and fourth week of April (14th, 15th, 16th and 17th standard week respectively) with the mean trap catches of 32.6, 34.8, 36.2 and 43.2 fruit flies/trap/week, respectively. Mean minimum temperature and mean relative humidity was positively correlated with fruit fly population (*B. dorsalis*). Overall influence of weather parameters on trap catches of *B. dorsalis, B. correcta* and *B. zonata* was to the extent of 45.2, 19.6 and 51.1 per cent, respectively.

Vadivelu (2014) reported that Ber fruit fly, *Carpomyia vesuviana* Costa (Tephritidae: Diptera) is one of the notorious monophagous pests of ber in India, Pakistan and Middle East countries. The fly infest most of the *Ziziphus* species grown in the world and cause the damage internally and in serious case it causes severe yield loss up to 80% or even up to 100% damage. The external temperature, relative humidity and rainfall and soil moisture, soil temperature and soil depth are found to be critical factors for the activity and the adult fly emergence from soil. The favourable temperature for pupal development and adult emergence is 30°C, pupation at 3 to 6 cm depth of soil was ideal for adult emergence. Alternating rainfall ranging from 20 to 40 mm and 62 to 85% relative humidity also promotes fly activity. Prophylactic measures are the essential components for the successful management of *C. vesuviana*. Field sanitation, destruction of wild bushes, collection of infested fruits and summer ploughing to expose the overwintering pupa to hot summer breaks the reproduction cycle of fly. However, synthetic chemicals are presently employed as major tools against fruit fly management. Availability of potential biocontrol agents and botanic pesticides are very limited. Therefore, emphasis has been laid on integrated manner and incorporation of neem-based formulations and biological pesticide, spinosad, bait application, male annihilation technique to manage the *C. vesuviana* in a successful manner.

Devi and Mehta (2015) revealed the population buildup of *Bactrocera* spp. through pheromone traps (Palam trap which are made from wastewater bottles with wooden septa impregnated with cuelure, methyl eugenol, ethanol and dichlorvos) at Palampur. Among all the prevalent species, B. tau was found to be predominant species followed by *B. nigrofemoralis* and *B. scutellaris*. The first trap catches of four species namely *Bactrocera cucurbitae, B. tau*, *B. nigrofemoralis* and *B. scutellaris* commenced from second week of April and was highest in 22nd standard week. The studies revealed that peak activity of fruit flies was coinciding with the maturity of cucumber. Temperature was observed to play a significant role in regulating population dynamics of most of prevailing species as indicated by a positive correlation. Relative humidity and rainfall, however, had a negative correlation thereby indicating negative impact on abundance of fruit fly species.

Pal *et al*. (2015) documented about nine fruit fly species. Among the collected species, the activity of *B. zonata* and *B. affinis* was recorded throughout the season. The activity of *B. correcta*, *B. diversa* and *B. dorsalis* was recorded during kharif and rabi seasons. The activity of *B. cucurbitae* was noticed in all seasons but *B. nigrofemoralis* and *B. caudata* were active during *kharif* and *rabi* seasons, while *B. yercaudiae* was active during *kharif* and *zaid* seasons, were trapped in cuelure (CL) baited traps. The maximum populations of fruit fly species were active during *kharif* season. All the fruit fly species attracted towards ME baited traps had positive correlation with minimum and maximum temperature (°C) except B. *zonata* which had highly significant and positive correlation with above abiotic parameters. *B. caudata* had highly positive correlation with rainfall (mm) during zaid season and *B. cucurbitae* had highly negative correlation with RH (%).

Sharma *et al*. (2015) developed weather-based prediction model for guava fruit fly from 2007-2012 at IARI (New Delhi). They established the relationship of each of the weather parameters with peaks of guava fruit fly, *Bactrocera zonata* trap catches. Peak of fruit fly trap catches exhibited significant correlation with T max, RH1, RH2, RF and BSS of April 1st week and T min of March 3rd week. Weather-based prediction model for guava fruit fly was developed by regressing peaks of fruit fly trap catches on mean values of different weather parameters of aforesaid weeks (R2=0.80). However, by stepwise regression, minimum and maximum temperature and relative humidity were calculated to be relevant.

Stanley *et al.* (2015) studied the seasonal incidence of different fruit flies namely, *Bactrocera dorsalis*, *B. zonata* and *B. diversa* by using methyl eugenol traps in different crop fields of Himalayan Hills.The fruit fly population was correlated with weather parameters (temperature, rainfall, relative humidity). The results of the study revealed the peak fruit fly population from May to October. However, no population existed in the month of January.The most predominant species was *B. zonata* that emerged from March to August. *B. dorsalis* continued to persist till December. There existed a positive correlation of fruit flies with mean temperature.

Draz *et al.* (2016) observed the Peach Fruit Fly (PFF) *Bactrocera zonata* in fruit orchards in different agro-ecosystem in Egypt. Further, they studied the efficiency of Jackson traps baited with methyl eugenol (M.E.) and McPhail traps for male capture during May 2014 to April 2015. The traps were installed in the middle of orchard at an elevation of 2m for efficient male trap catch. The highest trap catches were recorded in autumn season in case of McPhail traps whereas the other three seasonsrecorded similar type of mass traps. There existed a negative correlation of trap catches in McPhail traps with wind directionwhereas trap catches had positive correlation with mean temperature.

Kumar (2016) recorded the incidence of fruit flies from second week of June to August and the peak population was recorded at 32^{nd} standard week (August). The results showed that the highest population was recorded with *B. dorsalis* followed by *B. zonata* and *B. correcta* on guava. He also evaluated three different types of traps *viz*: Sabour trap, Water trap and Nomate trap along with untreated control for the management of fruit flies. Among the traps, Sabour trap performed well as compared to other traps-based reduction of fruit damage both weight and number basis and simultaneously obtained highest yield as compared to others. The highest cost-benefit ratio was obtained with Sabour trap (1:18.71) followed by water trap (1:8.97).

Das *et al.* (2017) studied the species diversity and population dynamics of *B. dorsalis, B. zonata* in three orchards with different mango cultivars Viz., Amrapali (1st orchard), Himsagar (2nd orchard) and Amrapali (3rd orchard) at BCKV, Nadia, West Bengal during April 2013- April 2014. Similarly screen out the mango cultivars namely Amrapali, Ratna, Himsagar and Fajli against mango fruit fly attack. Maximum population of fruit fly (*B. dorsalis* and *B. zonata*) in three orchards was observed in the months April - May 2013 when maximum temperature was 39.55°C. *B. dorsalis* showed a significant positive correlation coefficient with seasonal average maximum temperature (0.187) and minimum temperature, mean relative humidity, rainfall had negative correlation with fruit fly population while as mean temperature and rainfall were positively correlated with *B. zonata* population. However,mean morning and afternoon relative humidity had negative correlation with fruit fly population. The variety Amrapali, Himsagar showed a higher susceptibility to mango fruit flies followed by varieties Ratna and Fajli.

Nair *et al.* (2017) demonstrated the population fluctuation of different fruit flies in many cucurbits. They reported that nine fruit fly species namely *Bactrocera dorsalis*, *B. latifrons, B. diversa, B. hochii, B. caudata, B. cucurbitae, B. tau, B. cilifera and Dacus longicornis* had a close association with different cucurbits and this also proves to be the first record from Tripura, India. *B. hochii* and *B. cilifera* contribute as novel records from India.

Dashavant *et al.* (2018) studied on natural bio agents of *Bactrocera* species in six selected villages of Dharwad with synchronization of mango, guava fruiting and most of the cucurbits grown simultaneously in the area. The results revealed that *Diachasmimorpha longicaudata* (parasitoid of family Braconidae) was the most dominant species among all the natural enemies of fruit flies. The mean per cent parasitism varied from 8.98 to 13.52 in Dharwad district wherein highest per cent parasitism was found in June (14.84%) and lowest per cent parasitism of 8.10 per cent was observed in August and October months. Among the different locations irrespective of months, MARS, Dharwad recorded highest per cent parasitism by *D. longicaudata* species complex (13.52%), and least per cent was noticed in Kelageri (8.98%).

Kumar *et al.* (2018) conducted an experiment to study the population dynamics of different fruit flies using traps (methyl eugenol) at two districts of Uttar Pradesh during

2013. They documented four fruit fly species *viz., B. dorsalis, B. zonata, B. correcta* and *B. diversa* were identified by using methyl eugenol trap on mango orchards. The incidence of fruit flies was correlated with weather data. The maximum and minimum population of B. dorsalis was recorded in the months of August and January on mango orchard both at Saharanpur and Meerut District. Where, the maximum and minimum population of *B. zonata* was recorded in the months of July and January on mango orchard. The population of *B. diversa* and *B. correcta* were very low on mango orchard throughout the year. Only two species of fruit flies viz. *B. dorsalis* was dominant on mango orchard at both locations. The correlation coefficient between population and weather parameter in mango orchard both at Saharanpur and Meerut District showed highly positive correlation with maximum and minimum temperature, relative humidity and rainfall.

Ashoka and Javaregowda (2019) made a study on the presence of natural bio control agents of *Bactrocera* species in mango ecosystem from May to August during 2018. The results indicated that the highest parasitic activity of *Diachasmimorpha longicaudata*, a Braconid parasitoid, was recorded in July succeeded by June.Moreover, the highest parasitic activity of *Diapriids* parasitoid was recorded in the months of July succeeded by August. However, no significant difference was found out within the mean of two parasitoids, when pooled for both the years.

Harbi *et al.* (2019) assessed the influence of medfly-infested (two infestation ages, 1 and 4-d-old) and un-infested fruit species on host preference and efficiency of *Diachasmimorpha longicaudata* by using a multistep assay including olfactory, laboratory and semi-field trials. They found that *D. longicaudata* was significantly more attracted to medfly-infested apples for both infestation ages, with the oldest being the most preferred. *D. longicaudata* exhibited a significant preference among the four fruits tested. The implications of these behavioral responses of *D. longicaudata* to medfly host fruits and infestation age are discussed in relationship to its use in IPM programs in the Mediterranean basin area.

Li *et al.* (2019) studied *Bactrocera tau* for monitoring population dynamics and for direct control of population through field trapping with cuelure (CUE). It was a quarantine pest of international concern and has marked its importance in Asia as well. They collected different fruit fly species out of McPhail traps from 2008 to 2015.A total of 7811 tephritid flies were captured and included *B. tau*, *B. cucurbitae* and *B. scutellata*.

Among them, *B. tau* was the dominant species. It had 3–4 generations a year in north Jiangxi with high generation overlapping. The average number of trapped *B. tau* males did not differ significantly in different years, while the average monthly number showed large variation from June to December. No *B. tau* males were trapped before June in any year. Adult males were present from mid-June to late December, with distinct peaks between late August and mid-October. This fruit fly can withstand below 13℃ as a monthly minimal temperature under field conditions, and adult capture rates were significantly related to monthly minimal temperature and monthly total precipitation. These results can be used to predict the occurrence time and population size of *B. tau* in different seasons, enabling growers and extension personnel to take efficient management measures before they damage the host crops.

Roy *et al.* (2019) determined the intensity of infestation by fruit flies in important fruits of mango in West Bengal. The fruits were collected from different location of Cooch Behar, Alipurduar, Jalpaiguri and plains of Darjeeling district. From each location, altogether one hundred (100) fruits were collected randomly at three times *i.e.*, early, mid and late stage of the crop during 2014 and 2015. During 2014, results showed that highest fruit infestation on mango (16.33%) by fruit flies was recorded from Chilkir hat (26053′N, 89019′E) and lowest (7.33%) infestation was noted from Matigara (26072′N, 88038′E). However, in the next year *i.e*., during 2015, the fruit infestation was recorded higher (15.00%) from Naksalbari (26070′N, 88042′E) and lower (7.33%) was recorded from Pundibari (26041′N, 89038′E). Pooled mean of both the years of study revealed highest average infested fruit (13.67%) at Chilkir hat localities while lowest (7.83%) at Pundibari on number basis. When no control measures were applied, the fruit losses upsurged up to 100 per cent in various agro-ecological zones. The situation was increasingly severest with exotic commercial varieties.

Vediyappan *et al.* (2019) revealed the population magnitude of melon fruit fly, *Bactrocera cucurbitae* (Coq.) in watermelon during November 2018 to January 2019 in three districts of Tamil Nadu using cue-lure traps. Significantly higher mean population was recorded in Dharmapuri (17.57±0.78) followed by Tiruvannamalai (16.14±0.79) and Kanchipuram districts (13.8 ±0.84). Irrespective of the location, highest mean population was found during December while lowest population was observed during last week of January. Negative correlation was obtained between temperature and fruit fly population, while rainfall and relative humidity positively correlated with fruit fly capture in all the three experimental sites. Higher population level observed during December month coincided with peak flowering period of watermelon crop. Results reveal that low temperature and availability of flower, influence population level and hence planting period can be manipulated to escape peak population period of fruit fly.

Vignesh *et al.* (2020) recorded fruit fly species distribution pattern with its varietal preference of fruit flies in mango ecosystem was undertaken by using methyl eugenol based parapheromone traps during 2017-18 at TNAU, Tiruchirappalli. The activity of fruit fly is maximum in the month of August and September with the mean catch ranges from 27.00 to 57.00 flies/ trap/week. The poor activity of fruit flies in mango orchards was registered in the month of November to February with the least trapped population of < 3.0 flies/trap/week. Considering the varietal preference, the prevalence of *B. correcta* both in rumani and PKM 1 varieties is comparatively less when compared with the *B. dorsalis* and *B. caryeae*. The correlation analysis results revealed positive correlation of fruit fly population with mean temperature and negative correlation with mean rainfall and relative humidity.

Choudhary *et al.* (2021) studied the spatial and temporal variations in population abundance and distribution of peach fruit fly, *Bactrocera zonata* in response to climate change-based variations in temperature across India. To examine the likely possibilities of changes in abundance and distribution of *B. zonata*, temperature driven process-based phenology models were linked with climatic data of multiple General Circulation Model (eight models) and climate change scenarios (RCP 2.6, 4.5, 6.0 and 8.5) using the Insect Life Cycle Modeling (ILCYM) software. The risk indices (establishment, generation, and activity index) were mapped and quantified the changes in respect to locations, scenarios, models and times (2050 & 2070). The risk indices results revealed that, 1.73 (0.8–1.0 establishment risk), 14.15 (>16 high abundance) and 59.69% (>8.0 generation per year) area is projected to be highly suitable for *B. zonata* regarding establishment, abundance and generation indices, respectively in India under current climatic conditions. In spite of decreased permanent establishment (Establishment Risk Index >0.6) in future climatic conditions, it is predicted that abundance and generation indices would increase in all the locations of the country. The variation in the results due to use of multiple GCM-scenario combinations suggested that choice of GCM and scenario combinations have impact on future prediction of the species. Overall, results indicate that *B. zonata* would be significant threat to horticultural crops in India. Therefore, present findings are of immensely useful to provide important information to design integrated pest management strategies and phytosanitary measurements for local, regional and national level to restrain the insect pest activity across different layers.

Halder *et al.* (2022) recorded the distribution and abundance of cucurbit fruit fly *Zeugodacus* (*Bactrocera*) *cucurbitae* in relation to weather parameters for six years (2013 to 2018). They revealed the occurrence of cucurbit fruit fly throughout the year with two major peaks during 13 (last week of March) and 46 (third week of November) standard meteorological week (SMW) and the corresponding adult fly caught per trap were 90.33 and 96, respectively. Moreover, the population of fruit flies remained at low during cooler and rainy months of the year being the lowest during the January month in the region. Thus the active periods of the pest were noted from 11 to 24 SMW and 42 to 49 SMW on the region. It is evident that maximum atmospheric temperature had highly significant positive correlation with the fruit fly population during the study period and the correlation co-efficient (r) value was +0.447**. Similar observation was also noted on minimum temperature and the corresponding r-value was +0.035.

Saeed *et al.* (2022) visualized about *Bactrocera zonata* (Peach fruit fly) and *B. cucurbitae* (Melon fruit fly) that they are severe and polyphagous insect pests for various fruits and vegetables in Pakistan and all over the world. The study showed that Sponge Gourd was the preferable host with the mean pupae resurgence of (242.33), followed by Bitter Gourd (78.333) among selected vegetables. At the same time, among fruits, a banana was the preferable host with mean pupae resurgence (204.33), followed by orange (158.33). The pumpkin and apple were the least preferable host for both *B. cucurbitae* and *B. zonata*, with mean pupae resurgence (35.667) and (79.000), respectively. Furthermore, the study showed that Banana was the preferable host for *B. Zonata* among intact and infested fruits, whereas *B. cucurbitaee* showed the most preference to Bitter gourd among intact and infested vegetables showing significantly different results among intact and infested fruits and vegetables. Maximum number of eggs, pupa, female flies, male flies, adult emergence from pupa (flies) and period of pupa of *B. zonata* and *B. cucurbitae* on banana and bitter gourd. While, other fruits and vegetables showed the minimum number of eggs, pupa, female flies, male flies, adult emergence from pupa (flies) and period of the pupa.

2.3 Evaluation of different techniques for the management of fruit fly

Vijaysegaran (1997) discussed that infestation by fruit flies is common and is a major constraint to the production and export of horticultural produce in the tropical Asian region. There are about 20 species of *Bactrocera* of economic importance, some of which belong to species complexes and thus have only been recently described. The new knowledge on the species, their host range and current known distributions, requires countries in the region to re-evaluate the risk of spread of pest species to new areas within tropical Asia. Control methods commonly used include cover sprays of insecticides, spot sprays of protein baits, orchard sanitation and fruit wrapping, and these are aimed primarily at preventing direct damage to fruits or at achieving population suppression in individual orchards. These field control techniques enable production of fruit of sufficient quality to meet the needs of domestic consumption as well as that for export to some countries in Asia and Europe where fruit flies are not quarantine pests. Export to markets where fruit flies are quarantine pests is more complex and is facilitated through additional postharvest disinfestation treatments.

Latif *et al.* (2002) studied the efficacy of bait (Protein hydrolysate and molasses) and dust formulation of carbaryl, with various concentrations against fruit flies infesting muskmelon under semi-arid and water stress area of Dera Ismail Khan (D.I. Khan). Intermittent spray of protein hydrolysate caused least fruit infestation (12%) as compared to molasses (15%). Carbaryl dust (Sevin-10 D) mixed with soil dust at 1.5:15 and 3.0:15 was found statistically at par with bait sprays but significantly deteriorated the efficacy when applied at 1.0:15.

Stonehouse *et al.* (2002) estimated the losses caused by the fruit flies population in protected and un-protected conditions of guava, jujube, melon and mango fields in Pakistan. The results revealed about 29 per cent infestation rate in unprotected fields and 5 per cent infestation rate in fields treated with bait application technique (BAT). There was 44 per cent infestation in unprotected guava fields and 12% in orchards protected by BAT; in jujube, infestation was 16% in unprotected orchards and 4% in those protected by BAT. Fifteen farmer-managed trials found BAT-treated melon fields yielded 37% more than unprotected. In mango, soaked-block male annihilation technique (MAT) was compared with farmer practices of no control: average infestation before harvest was 9% in unprotected plots and 0% in protected mango orchard. Additional to differences in infestation rate, protected melon fields produced 17 per cent higher yields of all fruit, and protected guava orchards had 20 per cent more fruit.

Ravikumar and Viraktamath (2007) conducted a study on fruit flies attraction to various colour of traps in different orchards (mango and guava) at Dharwad in 2005-06. The results revealed that *B. correcta* was maximum attracted to transparent yellow-coloured traps in both guava and mango orchards. However, B. dorsalis showed maximum attractiveness to orange- and green-coloured traps in guava orchards and in mango orchards, they showed highest attraction towards black-coloured traps.In mango orchards, *B. zonata* showed highest attractiveness towards red colour of traps.However, the consolidated picture revealed that in general, yellow-coloured traps had highest attractiveness towards fruit flies in guava whereas, in mango orchards, black colour of the traps was highly effective.

Zur *et al.* (2009) investigated the effect of social interaction on the feeding, longevity and resource management of the Ethiopian fruit fly, *Dacus ciliatus*. Single flies and pairs of flies (of the same or different sexes) were confined to a small arena (the PUB system), in which they measured the amount of liquid food ingested daily by each fly. They further revealed that the individual ingestion was significantly higher in flies maintained in pairs than in flies kept as solitary individuals whereas, the highest intake rates were observed for the female–female pairs. In general, females ingested significantly greater volumes than males. Lipid and protein contents were recorded as the viable sources for enhancing the lives and longevity of solitary individuals. The flies kept as solitary individuals lived significantly longer than those kept in pairs. They further concluded that the resource-management analysis points to a decreased metabolic rate in flies kept as solitary individuals, as compared to paired flies.

Souza-Filho *et al.* (2009) studied the seasonal fluctuation and diversity of fruit flies along with their parasitoids in guava, loquat and peach orchards for two consecutive years (2002 and 2003). Subsequent bagging and un-bagging of fruits *i.e*., guava, peach and loquat was done on weekly basis. At the beginning of fruit development, assay was done in the green fruit stage. When fruits were ripe, they were kept in plastic cups within a laboratory. In order to analyse the population of fruit flies (*Ceratitis capitata*), the McPhail traps which contained torula yeast were placed in study orchards for two consecutive years (2002-2004). *In toto*, five different species of fruit flies belonging to family Tephritidae were reared namely *Anastrepha fraterculus*, *A. bistrigata*, *A.*

sororcula, A. obliqua and *Ceratitis capitata*. From fruit fly pupae, near to ten different parasitoid species were recorded. Among the isolated parasitoids, five parasitoid species were from the family Braconidae. The study, moreover, revealed a seasonal behaviour of *C. capitata* with population density and the highest prevalence was recorded in second half of every year.

Singh and Sharma (2011) reported usefulness of methyl eugenol based mineral water bottle traps in mass trapping of fruit flies, *B. zonata* and *B. dorsalis* on Kinnow in Punjab. They recorded number of adult male fruit flies captured/trap at weekly interval in pear in Punjab. Trap catch ranged from 74.9 to 326.4 flies/trap/week during different years. Trap catch during the year 2006 was recorded to range from 76.3 flies to 326.3 flies from first week of June to last week of July. In 2007, trap catch varied from 78.4 to 300.8 flies while during 2008, the catch range was 70.2 to 352.3 flies. Results showed that the using traps with MAT can reduce the insecticide usage in pear orchards and help in better management of fruit flies, which otherwise was very difficult with insecticides.

Ero and Clarke (2012) identified the cues used by the parasitoid to find suitable hosts, they offered, to free flying wasps, different combinations of three fruit fly species (*B. tryoni, B. cacuminata, B. cucumis*), different life stages of those flies (adults and larvae) and different host plants (*Solanum lycopersicon*, *Solanum mauritianum*, *Cucurbita pepo*). In the laboratory, the wasp will readily oviposit into larvae of all three flies but successfully develops only in *B. tryoni*. *Bactrocera tryoni* commonly infests *S. lycopersicon* (tomato), rarely *S. mauritianum* (wild tobacco) but never *C. pepo* (zucchini). The latter two plant species are common hosts for *B. cacuminata* and *B. cucumis*, respectively. *Diachasmimorpha krausii* is a braconid parasitoid of larval tephritid fruit flies, which feed cryptically within host fruit. At the ovipositor probing stage, the wasp cannot discriminate between hosts that are physiologically suitable or unsuitable for offspring development and must use other cues to locate suitable hosts. herbivore-induced, nonspecific host fruit wound volatiles were the major cue used by foraging *D. krausii*. Although positive orientation to infested host plants is well known from previous studies on opiine braconids, the failure of the wasp to orientate to some plants even when infested with physiologically suitable larvae, and the secondary role played by adult fruit flies in wasp host searching, are newly identified mechanisms that may aid parasitoid host location in environments where both physiologically suitable and unsuitable hosts occur.

Rizk *et al.* (2014) studied about the factors that affect the efficiency of trap catches against *B. zonata* in mango wherein, four types of traps; Bottle trap, Glass McPhail trap, Plastic McPhail trap, and Abdel-Kawi trap baited with different doses of methyl eugenol (ME) were used. The results indicated that Abdel-Kawi trap charged with 0.5 ml ME, it was the most effective trapping system. ME seemed to be with highly attracting effect, but most of the attracted males were found on the outside surface of the trap and on the branches surround the trap. Under these conditions, the females/males ration became 1:171. Thus, the believing tactic that fruit flies populations will decline due to the lack of males in the population available to females for mating seemed to be an erroneous believing. Results proved that PFF males had the highest activity at the dawn period between 5 and 7am. We strongly recommend using the trapping system consists of Abdel-Kawi trap charged with 0.5 ml ME only at dawn period (The first appearance of light in the morning followed by sunrise).

Bhowmik (2017) monitored the incidence and management through mass trapping of fly, at three locations of Nadia districts (Jaguli, Kalyani and Haringhata), WB with methyl eugenol (ME) during 2012 and 2013. Three types of traps (trap- 1: cotton impregnated with ME, trap-2: ME added in water and trap-3: ME mixed with banana and sevin) were used in three orchards of each location. The maximum mean number of fly catch/trap/day was in mango and banana (14.42 and 16.39) in trap-1, mango (14.04 and 11.24) in trap-2 and guava, mango (11.06 and 10.77) in trap-3 during 2012 and 2013, respectively. Trap-1 (13.16 and 15.23 catch/day) was found most effective during 2012 and 2013, respectively. Further he stressed that due to abundant availability and delayed harvesting of mango, guava and banana during season of production, makes them vulnerable to the attack of *Bactrocera dorsalis*. Due to cryptic nature of fly larvae, they mostly remain unaffected by insecticides and the chances of insecticide residues in fruits also increase. Among different control measures used to combat fruit fly infestation, the installation of methyl eugenol traps provides most promising results.

Dias *et al.* (2018) reviewed the research outputs on global trend of fruit fly management through present and past evidence from 1952 to 2017 and the results revealed that about 533 out of 4900 documentations mentioned the population fluctuations of fruit fly with its management. The selected research studies were conducted in 41 countries for 43 fruit fly species of economic importance. Although 46% of the studies were from countries of North America, analysis of the control tactics and studied species showed a wide geographical distribution. Biological control was the most commonly studied control tactic (29%), followed by chemical control (20%), behavioral control, including SIT (18%), and quarantine treatments (17%). Studies on fruit flies continue to be published and provide useful knowledge in the areas of monitoring and control tactics. Further, they analyzed the limitations and prospects for fruit fly management and highlighted the recommendations which will improve future studies.

Maung *et al.* (2019) performed studies on the damage level and population fluctuations of fruit flies *viz*., *Bactrocera dorsalis* in mangoes from 2016 to 2018 in Myanmar’s tropical region. During three years survey, the abundance of oriental fruit flies, *B. dorsalis* on the tropical fruits is 57% among the other fruit flies. Twenty-one species of fruit flies were identified by collecting specimens from both traps and infested fruits. Among them, we found that *B. dorsalis, B. correcta* and *B. cucurbitae* are economically important fruit flies. The percentages of fruit fly infestations are increasing year by year from 2016 to 2018. The highest infestation on the host plant (mangoes) was 78.2±6.5%. *B. dorsalis* populations dynamic when, correlated with metrological data revealed that highest trap caches of fruit flies were recorded in June from 2016-2018, every year. As such, the results opined that B. dorsalis or oriental fruit fly is the dominant fruit fly species and the infestation rate of this pest was recorded to be maximum in tropical region of Myanmar.

Mariadoss *et al.* (2020) studied species diversity of fruit flies damaging the important mango varieties like Banginapalli, Dasheri and Himayat in Ranga Reddy district of Telangana state during 2018 and 2019 (two seasons). The surveillance was conducted using bottle traps with methyl eugenol as attractant. The results revealed that significant population of two species of fruit flies belongs to Genus *Bactrocera* namely, *Bactrocera dorsalis* and *B. zonata* were trapped in all the three varieties. In variety Banginapalli significantly highest number of 190.60 ± 12.51 fruit flies were trapped and followed by 67.20 ± 3.77 in Dashehari and 62.60 ± 5.99 in Himayat variety during 2018. Similarly, significantly higher number of fruit flies were trapped in Banginapalli (90.80 ± 15.81) followed by Dasheri (31.50 ± 4.75) and Himayat varieties (20.20 ± 4.26) during the year 2019. Among the two species, the oriental fruit fly, B. dorsalis was found dominating other species in Banginapalli variety whereas peach fruit fly, *B. zonata* found dominating in Dasheri and Himayat varieties during both years. Timely management through cultural, chemical and use of para pheromone lures as an area wide management strategy can reduce the fruit fly damage in mango.

Patel *et al.* (2020) studied the new protein bait formulations from locally available materials in Mauritius as alternative sources of protein for baits and thereby making baits more affordable and reducing the cost of the fruit fly monitoring and control programs. Locally available waste brewery yeast (WBY) was modified in a digester. The WBY was exposed to different boiling and proteolysis conditions. A two-choice bioassay was conducted and each of the 64 resulting baits were tested against water in a non-competitive situation with two fruit fly species of economic importance: the peach fruit fly, *Bactrocera zonata* and the melon fly, *Zeugodacus cucurbitae*. Three baits, F1, F2, and F3, showed significantly more fly attraction ranging from 0.7 to 1.1 mean fly catches. These baits were used for further testing for optimal concentrations (7.5, 10, 12.5, and 15% v/v) in field cages. With *B. zonata*, bait attractiveness increased significantly with increasing bait concentrations for both male and female flies. With *Z. cucurbitae*, an increase in attraction was observed but attractiveness was not significantly different. Bait concentration (10% v/v) was selected for open field trials using the three preselected baits (F1, F2, and F3). The results of traps baited with modified WBY at 10% v/v were comparable to commercial protein hydrolysate in attracting flies. A 5-year cost-benefit analysis indicated that a net benefit of US dollar 283,558.60 is possible if modified WBY is used instead of imported commercial protein hydrolysate. Thus, modified WBY is a promising cost-effective alternative to the imported costly protein hydrolysate in fruit fly suppression programs for Mauritius.

Singh *et al.* (2020) recorded the presence of fruit fly, *Bactrocera* (*Bactrocera*) *nigrofemoralis* White & Tsuruta first time from the state of Bihar, India. *B. nigrofemoralis* was captured in cuelure (p-acetoxyphenyl 2 butanic) based pheromone traps from Bhagalpur (Sabour) and East Champaran (Motihari) districts of Bihar during 2016-17. It can be a new threat on the horticultural commodities of Bihar in incoming days. The distinguishing character of *B. nigrofemoralis* is all the femora is having dark black shining, costal band of the wing confluent with R2+3 and remaining very narrow around costal margin to end at apex of R4+5 and narrow lateral postsutural vittae reaching to intra-alar seta of the thorax.

2.4 Refinement of MAT (Male Annihilation Technique) and BAT (Bait Annihilation Technique) for fruit fly

Turner *et al.* (1989) investigated the environmental fate of methyl eugenol, naled, and dichlorvos (DDVP) baits through a three-phase study in 1988. During the first phase, Methyl eugenol was found as unmeasurable after day zero except for the 24-hour sample collected 1 m from the bait station on day 1. Naled was not detected. DDVP was found on all sampling days and decreased to less than ngm^{-3} by day 7. Results from the first phase were used to design the second phase. In second phase, Four-hour ambient air samples were collected during the first and fourth applications of bait, at four and six sites, respectively. During application one, methyl eugenol decreased significantly over 0,1 and 5 ($p< 0.00$ 1) and ranged from 323 to 1050 ngm^{-3} on day zero to none detected on day 5. During application four, there was no significant decrease in methyl eugenol: concentration over day 0 to through 4 but the decrease in DDVP concentration at the same site was significant ($p< 0,001$). Lastly, during third phase, Methyl eugenol was found in two samples from site1 and one sample from site 2 whereas, DDVP was found in two samples from site 1.

Aluja *et al.* (1997) designed two papaya groves to test the concepts of trap cropping and border trapping to control *Toxotrypana curvicauda*. Intensive fruit sampling in grove 1 indicated that the degree of fruit infestation decreased as the distance from the native vegetation (source of flies) increased. Rows planted 10 m away from the main block of papaya trees (trap crop) exhibited the greatest degree of puncture damage and larval infestation in both experimental groves. Fruit damage was highest after the rainy season was over and was spatially aggregated. They conclude that designing a papaya grove in such a way that a trap crop consisting of plants located 10 m from the main block of trees (and entirely surrounding it) can reduce fly damage significantly. If pheromone-baited fly traps are hung in these peripheral rows, the trap crop effect can be enhanced, and as a result, damage to the commercial block of trees can be reduced even further.

Makhmoor and Singh (1999) observed that pupal survival was affected by the soil type. The study showed that the pupal mortality of *B. dorsalis* was 96.6, 43.3, 23.3, and 16.6 per cent in clay soil, sandy soil, sandy loam and orchard soil, respectively. The frequency of hoeing also effected the pupal survival. It was also found that hoeing daily, every third day, weekly and no hoeing, respectively caused 80.0, 70.0, 43.0 and 13.3 per cent pupal mortality. The depth of soil also influenced the survival and it was observed that pupal mortality ranged from 13.3-93.3 per cent at 0-15 cm. There was maximum pupal mortality at the surface than at 10 cm depth. Increased irrigation was found to have more pupal mortality.

An area-wide insect control program is a long -term campaign against an insect pest population throughout its entire range with the objective of reducing the insect population to a non-economic status (Lindquist, 2000).

Verghese (2001) stated that host plant resistance in fruits offers the maximum scope for economically viable IPM, as many fruit crops are grown on large scale, even tolerance mechanism can offset pest flareups. Therefore, it was clear that plant resistance could assist fruit fly control not only to limit the insecticide usage but also can be a viable component of IPM.

Jessup *et al.* (2007) highlighted the role of area-wide integrated pest management (AW-IPM) principles such as trapping, trap arrays, border inspections, community awareness programmes as well as the MAT, SIT, BAT and postharvest treatments to maintain fruit fly free areas in Australia.

Mau *et al.* (2007) revealed about HAW-FLYPM or the Hawaii Area Wide Fruit Fly Pest Management programme of suppression of populations of *B. cucurbitae*, *C. capitata* and *B. dorsalis* to levels below economic thresholds by developing and integrating biologically-based pest control technologies into a comprehensive management package. The strategies involved sanitation programmes, use of protein bait, male annihilation techniques, use of male lures, need based augmentative parasitoid releases and sterile insect releases.

Chuang and Hou (2008) conducted a study on attract and kill method of fruit flies by using traps baited with methyl eugenol along with insecticide-neonicotinoid against the male of *B. dorsalis*. In laboratory bioassays, mortality of male flies resulting from the conventional toxicant, naled was 98.3-100 per cent at 24 through 72 hrs after treatment, whereas the neonicotinoid insecticides imidacloprid and acetamiprid caused about 60-80 per cent mortality at 24 through 72 hrs after treatment. In the assays of residual effect, Naled was persistent up to 96 weeks, whereas imidacloprid or acetamiprid was persistent upto 150 weeks, resulting in 38.9 or 61.2 per cent male mortality, respectively. Imidacloprid, in particular, caused a delayed lethal effect on flies. In another experiment, male mortality within 28 weeks from clothianidin was about 80 per cent after exposure for 24 hrs, suggesting a delayed lethal effect similar to those treated with imidacloprid, and mortality was upto 91.8 per cent, when observed 72 hrs after treatment. In field trials, attractiveness was similar between methyl eugenol alone and methyl eugenol incorporated with naled or neonicotinoids, indicating that addition of these insecticides to methyl eugenol in traps was not repellent to B. dorsalis males. Using an improved wick-typed trap with longer attractiveness for simulating field application, addition of imidacloprid or acetamiprid maintained 40.1 or 64.3 per cent male mortality, respectively, when assayed once every 2 weeks from traps placed in orchards for 42 weeks without changing the poison, whereas incorporation with naled resulted in as high as 98.1 per cent after 34 week and about 80 per cent at 42 weeks, indicating that persistence was increased compared with sugarcane fibre board blocks for carrying poison attractants. This study also suggested that neonicotinoid insecticides could be used as an alternative for broad-spectrum insecticides as toxicants in fly traps.

Singh (2008) screened seven guava varieties viz. Lucknow-49, Seedless, Behat Coconut, Red Flesh, Allahabad Safeda, Local and Pear Shaped for their susceptibility to Oriental fruit fly, *Bactrocera dorsalis* (Hendel) infestation at Dhaula Kuan, Distt. Sirmour (H.P.) during 2005-06. Smooth skinned varieties namely Red Flesh, Allahabad Safeda and Local were found to be highly susceptible to the fly attack (Infestation range 64.2 to 80.4%) whereas rough-skinned Pear-Shaped variety was least susceptible (35.1%) as compared to other varieties where the infestation ranged between 45. 7 to 56.5 per cent. Five baits namely fruit pulps of banana, guava and apple along with jaggery (l0% M:V) and jaggery alone @ 250 ml/bait and aqeous extract of Shyamtulsi (Ocimum sanctum var. Krishna) (1g crushed leaves in 4 ml water) @ 370 ml/bait were evaluated for their efficacy in attraction and killing of the fly. Fruit pulps of banana attracted maximum number of flies (23.2/week) followed by guava (18.2) as compared to other baits where the number ranged between 4.8 to 12.0/week. Use of less susceptible varieties and fruit pulps of banana and guava in poison baits have been suggested for better management of the pest.

Piñero *et al.* (2009) conducted a study on the effect of fruit fly bait (GF-120 NF naturalyte) in combination with sanitation programmes to combat the infestation by *Bactrocera dorsalis* in different orchards of *Carica papaya* in Hawaii. The spray was applied in every row by using higher bait quantity, moderate bait application was done in every 5th row and low bait application was carried out every 10th row. The control plots were also kept as check when no bait application was done. The data was recorded on biweekly intervals. The collected data revealed that in control plots, lesser number of target pest was trapped as compared to treated plots. After twelve weeks of spray, the variation in infestation level among different treatments was analyzed. In plots where moderate to high use of bait was done, the infestation level was minimum in papaya fruits as compared to the control plots. The application of baits had no effect on the rate of parasitation by *Fopius arisanus*.

Satarkar *et al.* (2009) conducted a study ondistribution of fruit flies (*Bactrocera* sp.) for two consecutive years (2006-2008) in Goa, India. Three different ecological zones (upland, midland and coastal) were taken into study to analyze various dispersion parameters which were located at a distance of 10km, 25 km and 50 km from Arabian sea coast towards the east with an elevation of 15m, 70m, 100m above mean sea level. The study revealed that various species of fruit fly like *B. correcta, B. affinis, B. dorsalis, B. caryeae, B. zonata* showed strong affinity towards traps baited with methyl eugenol. Moreover, a highly clumped negative pattern of binomial distribution of fruit fly population was revealed.

Singh *et al.* (2009) evaluated the performance of eco-trap, methyl eugenol bait and carbaryl against fruit fly in mango. Maximum number of fruit flies were trapped in treatment (25 trees/eco-trap) followed by 20 trees per eco-trap and 30 trees per eco-trap. In methyl eugenol treatment, the number of fruit flies trapped was 34.74, 42.05 and 28.98 at 5, 10 and 15 days after installation of trap, respectively. Effectiveness of the eco traps was maintained up to 45 days.

The trials in two locations on the island of Hawaii with plastic-matrix formulations of methyl eugenol and cue-lure in traps with or without a toxicant (DDVP) against wild fly populations of *B. dorsalis* and *B. cucurbitae*, respectively indicated that both 5 g disks and 10 g cones of methyl eugenol and 2 g plugs of cue-lure caught flies for >9 months which varied relative to the population fluctuations (Jang, 2011).

Piñero *et al.* (2011) examined the behavioural response of wild female species of *B. dorsalis* or oriental fruit fly; *B. cucurbitae* or melon fruit fly; and *Ceratitis capitata* or Mediterranean fruit fly to Spinosad based GF-120 NF Naturalyte Fruit Fly Bait© formulated to contain either 0, 1 or 2% ammonium acetate. Use of visually attractive yellow bait stations for bait application in the field allowed for proper comparisons among bait formulations. The field results indicated that a significant positive effect of the presence, regardless of amount, of AA in GF-120 for *B. dorsalis* and *B. cucurbitae*.

For *C. capitata*, there was a significant positive linear relationship between the relative amounts of Ammonia-releasing substances (AA) in bait and female response. GF-120 with no AA was significantly more attractive to female C. capitata, but not to female B. dorsalis or *B. cucurbitae*, than the control treatment. Our field cage results indicate that the effects of varying amounts of AA present in GF-120 can be modulated by the physiological stage of the female flies and that the response of female *B. cucurbitae* to GF-120 was consistently greater than that of *B. dorsalis* over the various ages and levels of protein starvation regimes evaluated.

Chandaragi *et al.* (2012) reported that bottle trap was found to have significantly higher trap catch (41.13 fruit flies/trap/week) followed by cylinder trap (29.84 flies/trap/week), when five traps with different designs (bottle trap, cylinder, sphere, PCI trap and open trap) were used to capture fruit flies in mango in Karnataka.

Rull *et al.* (2012) examined the effect of radiation dose and mass rearing history on male mating performance to improve the efficiency of the sterile insect technique applied to eradicate, suppress, and control wild *Anastrepha oblique* (Macquart) (Diptera: Tephritidae) in mango producing areas of Mexico, Field cage tests in which both male and female laboratory flies were irradiated at different doses (0, 40, and 80 Gy) were released with cohorts of wild flies of both sexes, revealing that both mass rearing history and irradiation affected male mating performance. Laboratory males were accepted for copulation by wild females less frequently than wild males. Copulations involving laboratory males were shorter than those involving wild males. Irradiated males mated less frequently with wild females than wild males, and irradiated females appeared to be less able to reject courting males of both origins. High levels of fertility for untreated laboratory females crossed with males irradiated at different doses may reflect problems in mass rearing affecting homogeneity of pupal age before irradiation, and possibly masked a dose effect.

Sharma (2012) tested the efficacy of an improved form of mass trapping method using spinosad as an insecticide in methyl eugenol trap for the control of *Bactrocera* complex on mango, guava, sapota and peach at New Delhi. The catches of fruit fly increase having a maximum capture of 179 flies/trap during 2007 and 14.8 flies/trap in 2010, thus indicating 90 per cent reduction in mean capture/trap in 3 years and 6 months.

Vargas *et al.* (2015) stated that fruit flies have highest economic importance in terms of crop pests around the world and they infest varied groups of fruits and vegetables in areas they are grown.In order to overcome the infestation and damage caused by these pests, various management and eradication programmes have been planned and carried out on a large scale in different parts of the world. The management strategies used against this pest include use of insecticides, use of baits, male attraction techniques, capture and recapture method, sterilization and various other cultural methods. Moreover, a general view of seventy-three *Bactrocera* species given along with control techniques which pose reduced risk to non-target organisms, thereby the use of Integrated pest management strategies to unify various control measures on a single scale for control of this pest.

Singh and Kaur (2016) studied the natural parasitism in mango ecosystem. Further, they experienced that management of fruit flies by using insecticides only is not an easy task due to the reason that all the life stages except adult stage of thus pest are concealed within fruit or soil. That’s why they suggested that the present scenario warrants the need of integrated use of eco-friendly control measures with much more reliance on use of bio-control agents as other methods would cause harm to consumers when fruits are eaten raw and fresh.

Wazir *et al.* (2019) evaluated twelve types of lure traps with different combinations for monitoring the fruit fly population for two seasons *i.e.*, during 2017-2018 and 2018-2019. The studies revealed that, there was a significant difference recorded among all the twelve traps in both seasons. For 2017-2018 season, in commercial traps, Green Victory Methyl Eugenol (ME) fruit fly trap showed the best performance in capturing adult fruit fly population throughout the cropping period with catch of 479.33 fruit flies/trap. However, among innovative traps, low-cost mineral bottle trap (ME + wooden block + spinosad) was found superior with 436.33 fruit flies/trap. Similarly, for 2018-2019 season, in commercial traps, Green Victory methyl eugenol (ME) fruit fly trap showed the best performance in capturing adult fruit fly population throughout the cropping period with catch of 475.00 fruit flies/trap. However, among innovative traps, low- cost mineral bottle trap (ME + wooden block + spinosad) was found superior with 440.00 fruit flies/trap.

Materials and Methods

CHAPTER-III

MATERIALS AND METHODS

The materials employed and methodology adopted during the entire course of investigation to study various objectives viz., study of diversity of fruit flies in Jammu Sub-tropics, population dynamics of fruit flies in mango, guava and peach, evaluation of different techniques for the management of fruit flies on mango, guava and peach and refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies have been portrayed in this chapter.

3.1 General details of the experiments

3.1.1 Location and site of the experimental plots

For studying the diversity, population dynamics and different techniques in suppressing the fruit fly populations and refinement of existing traps for catching fruit flies, the locations were chosen tactfully which were the intensive fruit orchards. Three different locations were selected for the present studies viz, Rainfed Research Sub-station for Sub-tropical Fruits, (RRSSS) Raya which is about 30 km from the Main Campus SKUAST-J, Chatha and situated in Samba district, while Farming System Research (FSR) is situated at the main Campus Chatha. The third location is about 5 km from the main campus which was a government fruit orchard comprising Mango, high density planting of guava and peach (Plate-1 to 3). It was evident that the wherever fruit and vegetable cultivation occurred, fruit flies are the major problems or impediments in growing successful cultivation. The fruits infested with the fruit flies were collected at weekly interval during the cropping season from all sites of each particular location and were brought to laboratory for observing the emergence of natural enemies of fruit flies and recorded the extent of their parasitism.

3.1.2 Study the diversity of fruit flies in Jammu Sub-tropics

Survey was conducted at three different locations of Jammu districts of UT of J&K, India, during 2019 to 2020, to determine species diversity and relative abundance of fruit flies on widely prevalent fruit and vegetable crops ecosystem in Jammu sub-tropics. In each location, three different fruit crops were selected randomly for the fruit flies collection and further identification of different types of fruit flies. Fruit flies were collected from the field on weekly basis by installing the different types of traps such as methyl eugenol, cue lure and protein hydrolysate as an attractant. The observations on number of fruit flies/trap/day and number of fruit flies /trap/week for two consecutive years viz., during 2019 and 2020 were recorded in all the three locations of the experimentation.

3.1.3 Trapping and identification of fruit flies

Fruit fly samples were obtained by trapping using three different types of traps like Green Valley traps, PCI Fruit fly trap and Low-Cost Mineral Bottle Traps. Each trap was added with a different parapheromone attractant, *i.e*., Methyl eugenol (4-allyl-1, 2-dimethoxybenzene-carboxylate) or Cue lure (4-(p-acetoxyphenyl)-2-butanone), protein hydrolysate with a 20 m between them. It is evident from the earlier research that Methyl eugenol or Cue lure, protein hydrolysate are largely being used and essential in monitoring and controlling pest fruit fly species. Moreover, these attractants are necessary for managing pest species through male annihilation techniques and trapping to detect different fruit fly pest populations. The trap was hung on a tree branch at the height of 2.0–2.5 m above ground level. Trapping at each location was carried out 4-5 times at monthly intervals. The attractant was replaced after 1 and half month interval. Trapped fruit flies were collected in plastic containers and brought to the laboratory for identification purposes. Trapping was carried out from March to July during 2019 and 2020. Identification of fruit flies was carried out morphologically using Magnus Stereo Microscope MS24 (Plate-4). Each morphological character of fruit flies was documented using identification key book for tropical fruit flies in Southeast Asia, Indomalaya to Northwest Australia (Drew and Romig, 2013), David and Ramani (2011), Prabhakar *et al*. (2012), David *et al*. (2020) taxonomical keys (Plate-5).

To evaluate differences and changes in fruit fly diversity throughout the sampling period at Jammu, the occurrence and abundance of number of individuals of fruit flies

Plate 1: Experimental view of fruit orchards for assessing diversity, Population dynamics, evaluation of techniques for the management and refinement of MAT and BAT techniques against fruit flies

A) Field view of Guava orchard at FSR, Chatha Farm, SKUAST-Jammu

B) Experimental view of Mango orchard at FSR, Chatha Farm, SKUAST-Jammu

C) Experimental view of Peach orchard at FSR, Chatha Farm, SKUAST-Jammu

Plate 2: Experimental view of fruit orchards at RRSSS, Raya

A) Installing Low cost mineral bottle traps in Guava at RRSSS, Raya

B) Experimental view of Mango orchard at RRSSS, Raya

C) Installing Green valley traps in Mango at RRSSS, Raya

Plate 3: Experimental view of Govt. Orchard, Miran Sahib

A) Installation of Green valley and PCI fruit fly traps at Govt. Guava orchard, Miran Sahib

B) Experimental view of Mango orchard, Miran Sahib

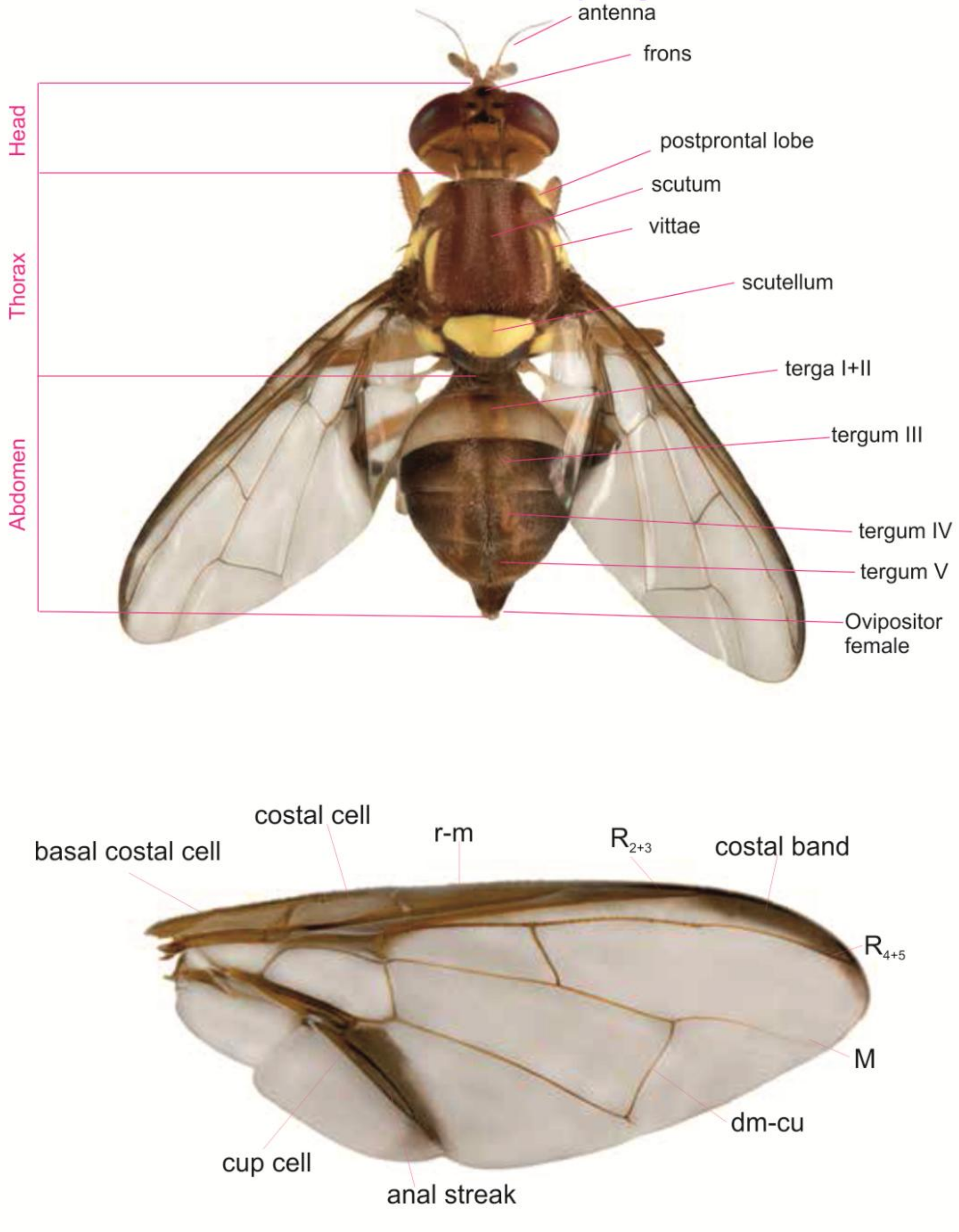
C) Experimental view of Govt. Peach Orchard, Miran Sahib

Plate 4: Diversity study of Fruit flies collected in different types of traps in Jammu Sub-tropics

A) Processing of collected fruit flies for diversity analysis

B) Evaluating the morphological characters of fruit flies for diversity in the laboratory

Plate 5: Identification of fruit flies on the various morphological features



5A & 5B: Hypothetical dorsal view and wing of female fruit fly

and species were catalogued from February-December for calculation of the changes in diversity. Species richness, species diversity and evenness will be computed for both the monthly data and pooled data (Magurran, 1988; Shannon and Wiener, 1949; Simpson, 1949).

3.1.4 Shannon-Wiener diversity:

The Shannon diversity index is calculated by the following equation:

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

Where, P is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations and s is the number of species.

Simpson Index:

$$D = 1/\sum_{i=0}^{n} P_i^2$$

Where, P is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species.

Sorenson's Coefficient (Evenness):

It is a measure of the relative abundance of each species in a habitat. Sorenson's coefficient gives a value between 0 and 1, the closer the value is to 1, the more the communities have in common. Sorenson's Coefficient will be calculated using the following formula:

$$CC = \frac{2C}{S1+S2}$$

Where, C is the number of species the two communities have in common, S1 is the total number of species found in community 1, and S2 is the total number of species found in community 2.

3.1.5 Record of the fruit flies

Besides the experimental crops like mango, guava and peach, some other crops like vegetables, flowers and other wild fruit plants were also selected for installation of different types of traps for collecting various types of fruit flies during the course of investigation in Jammu Sub-tropics.

3.2 Study the population dynamics of fruit flies on mango, guava and peach

The studies on the population dynamics of fruit flies on mango, guava and peach in relation to abiotic factors were carried out at three locations *i.e*., RRSSS, Raya; Farming System Research (FSR) SKUAST-J Chatha and Miran Sahib during 2018-19 and 2019-2020, respectively. The observations on fruit flies were taken at weekly interval on mango, guava and peach plantation. Four plants were selected for installation of different MAT and BAT applications from each location for recording observations and marked with labels. The observations were recorded for fruit flies (*Bactrocera* spp.), by segregated and counted all fruit flies trapped in different MAT and BAT traps.

The studies were carried out at all three locations selected for the present research during 2019 and 2020. For this study, wooden blocks treated with methyl eugenol, and malathion in the ratio of (3:1) and Methyl eugenol of Green Valley traps were installed for monitoring the fruit fly population dynamics. The methyl eugenol treated wooden blocks were tied through a wire in used Mineral bottles containing a circular hole was cut open to facilitate the entry of fruit fly. The population of trapped flies was recorded at weekly intervals throughout the cropping season on different fruit crops. The effect of various abiotic factors on fruit fly population, independently or jointly was determined by using statistical technique particularly by simple correlation and regression analysis.

The daily meteorological observations on temperature (maximum, minimum), relative humidity (maximum, minimum) and rainfall were collected and converted into weekly mean which were used as independent parameters for their effect on the fruit fly population. Then, the fruit fly population dynamics was correlated with abiotic factors and linear regression analysis was calculated. The meteorological observations were obtained from the Agrometeorology section at the SKUAST-Chatha of this University.

3.3 Evaluation of different techniques for the management of fruit fly in mango, guava and peach

In Male Annihilation Technique (MAT), the different attractants like Cue lure, Protein hydrolyzate, Methyl Eugenol (ME) were used for trapping of male fruit fly population on mango, guava and peach. Whereas, in Bait attractant Technique (BAT), Fish meal, Mashed banana, female biased technique with some food additives and oils were utilized for attracting the fruit flies for lure and kill method. All the MAT and BAT techniques were standardized in all three fruit orchards during both the years of study.

The weekly collected fruit fly populations in different types of MAT and BAT techniques were counted in all the three replications separately throughout the cropping season on three different fruit crop orchards. Thereafter, a monthly data was computed which comprised the mean of all the four weeks coming in the respective month. Moreover, the monthly fruit flies trap catches data were subjected to transformation using log (x+1) to homogenize representation of data for statistical analysis. Thereafter, the statistical analysis (Tukey test) was carried out for the transformed values in SPSS20 software to draw the statistical inferences.

3.4 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies

To manage fruit flies, different treatments regarding BAT and MAT techniques were taken into study and the treatments were replicated thrice. The treatments were described as under-

Treatments	**Details**
T1	Cue- lure + wooden block
T2	Cue- lure+ absorbent plastic
T3	Protein hydrolyzate + wooden block
T4	Protein hydrolyzate + absorbent plastic
T5	Mineral bottle traps (ME+ wooden block+ malathion)
T6	Mineral bottle traps (ME+ absorbent plastic + spinosad)
T7	Fish meal + diazinon
T8	Mashed banana +malathion

T9	Commercially available traps green valley fruit fly traps
T10	Commercially available traps PCI

3.4.1 Observations and Statistical analysis

Regular monitoring through the weekly collections of fruit flies in different treatments were made and data were collected to ascertain the efficacy of refinements in MAT and BAT techniques. Thereafter, a monthly data was computed which comprised the mean of all the four weeks coming in the respective month. The original trap catches in different treatments were subjected to the transformation by using the formulae Log (X+0.5), wherein X denoted the original trap catches value. Further, the transformed values were analyzed statistically for the Tukey HSD test by using SPSS-20 pack to draw valuable inferences.

Results

CHAPTER-IV

RESULTS

In the present investigation an effort was made to understand the diversity of fruit flies in Jammu Sub-tropics, population dynamics of fruit fly in mango, guava and peach, evaluation of different techniques for the management of fruit fly on mango, guava and peach and refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) against major fruit flies on selected fruit crops viz. mango, guava and peach, respectively. The results obtained are presented under following sub-heads:

4.1 Study the diversity of fruit flies in Jammu Sub-tropics

4.1.1 Survey on diversity of fruit flies in Jammu Sub-tropics

A survey was conducted under the present investigation for the consecutive two years *i.e.*, 2019 and 2020 for assessing the faunistic diversity of fruit flies on cultivated fruits and vegetable crops and their interaction for food sources on other wild host plants in different ecosystem of Jammu sub-tropics. For the true representation of Jammu sub-tropics, three different locations with intensive cultivation of fruit crops *i.e.*, RHRSS, Raya; FSR, Chatha and Govt. Orchard, Miran Sahib were selected for the present investigation. Each location was further categorized with different host plants such as mango, Guava and peach orchards into sub-locations for collecting and recording the existing fruit fly diversity in Jammu sub-tropics.

The collected fruit flies were brought to the laboratory for the further identification based on the keys adopted from various authentic and peer reviewed published research papers. The keys were developed for the identification of fruit flies species which are summarized as follows-

Pictorial Keys of Fruit Flies

1. Abdomen oval or elongate.......... 2
……………………………………………………………………………………(**Genus *Bactrocera***)

- Abdomen petiolate and elongate……………….......................... ……………….......................... 11
.... (**Genus *Dacus***)

2 (1). Lateral and medial postsutural yellow vittae present 3

- Lateral postsutural yellow vittae present, medial postsutural yellow vittae absent 6

3 (2). Scutum black 4

- Scutum mostly red brown .... …………..5

4 (3). Scutellum yellow without an apical black spot .... **Bactrocera (*Hemigymnodacus*) *diversa* (Coquillett)**

- Scutellum yellow with an apical black spot ....***Bactrocera*** **(*Zeugodacus*)** ***scutellaris*** **(Bezzi)**

5 (3). Fore wings with cubital streak and costal band with a distinct large spot in wing apex ………….. ***Bactrocera*** **(*Zeugodacus*)** ***tau*** **(Walker)**

- Fore wings with infuscation on dm-cu crossveins in addition to cubital streak and costal band with a distinct large spot in wing apex .... ***Bactrocera*** **(*Zeugodacus*)** ***cucurbitae*** **(Coquillett)**

6 (2). Scutum base colour red brown 7

- Scutum base colour black 8

7 (6). Fore wings with costal band but either discontinuous or with vey narrow part distal to apex R_{2+3} before expanding into a spot in wing apex ....…………………………………………..***Bactrocera*** **(*Bactrocera*)** ***zonata*** **(Saunders)**

8(6) Fore wings with costal band but either discontinuous or with an extremely narrow section distal to apex R_{2+3} before expanding into a spot in wing apex ....………………………………………..***Bactrocera*** **(*Bactrocera*)** ***correcta*** **(Bezzi)**

- Wings with continuous costal band confluent with R_{2+3} 9

9 (8). All femora with dark black marking ....***Bactrocera (Bactrocera) nigrofemoralis*** **White & Tsuruta**

- All femora entirely fulvous 10

10 (9) Costal band confluent with R_{2+3} not expanding into a distinct spot in wing apex .... ……………***Bactrocera*** **(*Bactrocera*)** ***dorsalis*** **(Hendel)**

- Costal band confluent with R_{2+3} expanding into a small spot in wing apex ....***Bactrocera*** **(*Bactrocera*)** ***latifrons*** **(Hendel)**

12**.** Ocellarseta small and rudimentary; scutum fulvous with black spots laterally; scutellum with four black spots ……… ………………………………………***Carpomyia vesuviana*** **Costa**

- Ocellar seta absent; scutal colour variable, anatergite with fine erect hairs .13

4.1.2 Diversity of fruit flies at Rainfed Research Sub-Station for Sub-Tropical Fruits, Raya during 2019

During 2019, a total of five (05) fruit fly species were recorded at study orchards in Raya (Table 1). The perusal of data depicted the plant-insect interaction and the

Table 1: Diversity of fruit flies at Raya orchard locations in Jammu Sub-tropics during 2019

Raya	Species of fruit fly	n	P=n/N	Pi	lnPi	Pi * lnPi	Pi^2	Shannon Index (H)	Simpson diversity Index (D)
1	*B.dorsalis*	98	98/217	0.4516	-0.7949	-0.3590	0.2039	**1.2812**	**3.0409**
2	*B. zonata*	70	70/217	0.3225	-1.1314	-0.3649	0.1041		
3	*B. tau*	16	16/217	0.0737	-2.6073	-0.1922	0.0054		
4	*B. correcta*	26	26/217	0.1198	-2.1218	-0.2542	0.0144		
5	*C. vesubiana*	7	7/217	0.0322	-3.4339	-0.1107	0.0010		
	N=	**217**	**-**	**-**	**-10.0894**	**-1.2812**	**0.3288**		

utilization and infestation of planted crop products by fruit fly species. In the area under study, four species of *Bactocera* viz., *Bactocera dorsalis*, *B. zonata*, B. tau and *B. correcta* and one species of *C. vesuviana* were recorded. A total of 217 fruit fly individuals were recorded wherein, 98 individuals of *B. dorsalis*, 70 individuals of *B. zonata*, 16 individuals of *B. tau*, 26 individuals of *B. correcta* and 7 individuals of *C. vesuviana* were noticed. Species diversity (richness and abundance) of the fruit flies was, therefore, measured which indicated the distribution pattern of fruit flies in the orchards. Species diversity measured by Shannon Weiner's index showed a value of H = 1.2812 which indicated somewhat higher magnitude of diversity of fruit flies in the mentioned area. The species diversity when measured by Simpson diversity Index, the value came out to be D=3.0409 which indicated that the study locations were dominated by several fruit fly species.

4.1.3 Diversity of fruit flies at FSR, Chatha during 2019

A total of six (06) fruit fly species were recorded at orchard locations at FSR, Chatha during 2019(Table 2). In the area under study, six species of Bactocera were recorded viz., *Bactocera dorsalis, B. zonata, B. tau, B. correcta, B. diversa* and *B. scutallaris*. A total of 236 fruit fly individuals were recorded wherein 90 individuals of *B. dorsalis*, 64 individuals of *B. zonata*, 22 individuals of *B. tau*, 38 individuals of *B. correcta*, 14 individuals of *B. diversa* and 8 individuals of *B. scutallaris* were noticed. Species diversity measured by Shannon Weiner's index showed a value of H=1.5191 which indicated higher magnitude of diversity of fruit flies at FSR orchards. The value of species diversity as measured by Simpson diversity Index was computed to be D=3.8721 which indicated that the study locations were dominated by several fruit fly species.

4.1.4 Diversity of fruit flies at Miran Sahib during 2019

During 2019, a total of three (03) fruit fly species were recorded at orchard locations at Miran Sahib (Table 3). Three *Bactocera* species viz., *Bactocera dorsalis*, *B. zonata* and *B. correcta* were recorded at orchard locations under study. A total of 101 fruit fly individuals were recorded wherein 46 individuals of *B. dorsalis*, 37 individuals of *B. zonata* and 18 individuals of *B. correcta* were noticed. Species diversity measured by Shannon Weiner's index showed a value of H=1.0335 which indicated low magnitude of diversity of fruit flies at orchards at Miran sahib. The value of species diversity as measured by Simpson diversity Index was computed to be D=2.6781 which indicated that the study locations were dominated by more than one fruit fly species.

4.1.5 Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2019

The Shannon and Simpson diversity index of fruit flies at three experimental locations viz., Raya, FSR and Miran sahib has been presented in Table 4. The Shannon index (H) for fruit flies at Raya, FSR and Miran sahib were computed to be H=1.2812, H=1.5191 and H=1.0335, respectively. The perusal of the computed data indicated that out of three experimental orchard locations, the experimental orchards at FSR, Chatha had highest diversity of fruit flies in terms of species richness and species abundance whereas experimental orchards at Miran Sahib has less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.6428 which indicated that all the three communities under study had a bit of overlap or similarity in terms of fruit fly species diversity.

4.1.6. Diversity of fruit flies at RRSS, Raya during 2020

Comparatively, during 2020, a total of six (06) fruit fly species were recorded at experimental orchards in Raya (Table 5). In the area under study, five species of Bactocera viz., *Bactocera dorsalis*, *B. zonata*, *B. tau*, *B. correcta* and *B. cucurbitae* and one species of *C. vesubiana* were recorded. A total of 333 fruit fly individuals were recorded wherein, 156 individuals of *B. dorsalis*, 90 individuals of *B. zonata*, 22 individuals of *B. tau*, 31 individuals of *B. correcta*, 27 individuals of *B. cucurbitae* and 7 individuals of *C. vesubiana* were noticed. Species diversity measured by Shannon Weiner's index showed a value of H = 1.3943 which indicated higher magnitude of diversity of fruit flies at Raya. The value of species diversity when measured by Simpson diversity Index came out to be D=3.1994 which indicated that the study locations were dominated by several fruit fly species.

4.1.7 Diversity of fruit flies at FSR, Chatha during 2020

A total of eight (08) fruit fly species were recorded at orchard locations at FSR, Chathaduring 2019 (Table 6; Plate 6 to 8). In the area under study, seven species of Bactocera viz., *Bactocera dorsalis*, *B. zonata*, *B. tau*, *B. correcta*, *B. cucurbitae*, *B. diversa* and *B. scutallaris* and one species of *C. vesubiana* were recorded. A total of 625 fruit fly individuals were recorded wherein, 250 individuals of *B. dorsalis*, 182 individuals of *B. zonata*, 37 individuals of *B. tau*, 48 individuals of *B. correcta*, 43 individuals of *B. cucurbitae*, 28 individuals of *B. diversa*, 16 individuals of *B. scutallaris* and 21 individuals of *C. vesubiana* were noticed. Species diversity measured by Shannon

Table 2: Diversity of fruit flies at FSR, Chatha orchard locations in Jammu Sub-tropics during 2019

FSR, Chatha	Species of fruit fly	n	P=n/N	Pi	lnPi	Pi * lnPi	Pi^2	Shannon Index (H)	Simpson diversity Index (D)
1	*B.dorsalis*	90	90/236	0.3813	-0.9640	-0.3676	0.1454	**1.5191**	**3.8721**
2	*B. zonata*	64	64/236	0.2712	-1.3049	-0.3538	0.0735		
3	*B. tau*	22	22/236	0.0932	-2.3727	-0.2212	0.0086		
4	*B. correcta*	38	38/236	0.1610	-1.8262	-0.2941	0.0259		
5	*B. diversa*	14	14/236	0.0593	-2.8247	-0.1676	0.0035		
6	*B. scutallaris*	8	8/236	0.0338	-3.3843	-0.1147	0.0011		
		236	-	-	**-12.677**	**-1.5191**	0.2582		

Table 3: Diversity of fruit flies at Miran Sahib orchard locations in Jammu Sub-tropics during 2019

Miran Sahib	Species of fruit fly	n	P=n/N	Pi	lnPi	Pi * lnPi	Pi^2	Shannon Index (H)	Simpson diversity Index (D)
1	*B.dorsalis*	46	46/101	0.4554	-0.7865	-0.3582	0.2074	**1.0335**	**2.6781**
2	*B. zonata*	37	37/101	0.3663	-1.0042	-0.3679	0.1342		
3	*B. correcta*	18	18/101	0.1782	-1.7247	-0.3074	0.0317		
	N=	**101**	-	-	**-3.5154**	**-1.0335**	0.3734		

Table 4: Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2019

Raya Orchard	Shannon Index (H)= Simpson diversity Index (D)=	**1.2812** 3.0409
FSR, Chatha	**Shannon Index (H)=** **Simpson diversity Index (D)=**	**1.5191** **3.8720**
Miran Sahib	Shannon Index (H)= Simpson diversity Index (D)=	**1.0335** 2.6781
Evenness or Sorenson coefficient (CC)=	3×3/14	**0.6428**

- *The bigger value is of more diverse area*
- *According to Sorenson coefficient, these communities have quite a bit of overlap or similarity*

Table 5: Diversity of fruit flies at Raya orchard in Jammu Sub-tropics during 2020

Raya	Species of fruit fly	n	P=n/N	Pi	lnPi	Pi * lnPi	Pi^2	Shannon Index (H)	Simpson diversity Index (D)
1	*B.dorsalis*	156	156/333	0.4684	-0.7583	-0.3552	0.2194	**1.3943**	**3.1994**
2	*B. zonata*	90	90/333	0.2703	-1.3083	-0.3536	0.0731		
3	*B. tau*	22	22/333	0.0660	-2.7171	-0.1795	0.0044		
4	*B. correcta*	31	31/333	0.0930	-2.3741	-0.2210	0.0087		
5	*B. cucurbitae*	27	27/333	0.0810	-2.5123	-0.2037	0.0066		
6	*C. vesubiana*	7	7/333	0.0210	-3.8622	-0.0812	0.0004		
	N=	**333**	**-**	**-**	**-13.5324**	**-1.3943**	**0.3125**		

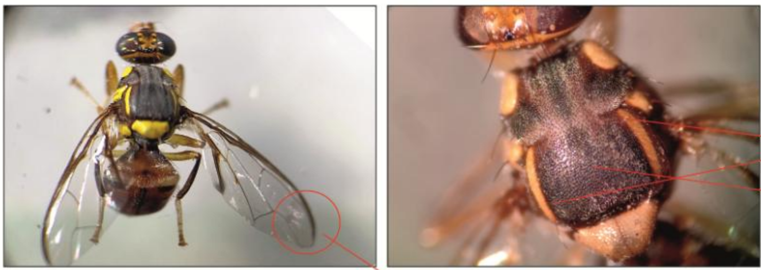
Table 6: Diversity of fruit flies at FSR Chatha orchard in Jammu Sub-tropics during 2020

FSR, Chatha	Species of fruit fly	n	P=n/N	Pi	lnPi	Pi * lnPi	Pi^2	Shannon Index (H)	Simpson diversity Index (D)
1	*B.dorsalis*	250	250/625	0.4	-0.9163	-0.3665	0.16	**1.6213**	**3.8062**
2	*B. zonata*	182	182/625	0.2912	-1.2337	-0.3592	0.0847		
3	*B. tau*	37	37/625	0.0592	-2.8268	-0.1674	0.0035		
4	*B. correcta*	48	48/625	0.0768	-2.5665	-0.1971	0.0058		
5	*B. cucurbitae*	43	43/625	0.0688	-2.6765	-0.1842	0.0047		
6	*B. diversa*	28	28/625	0.0448	-3.1055	-0.1391	0.0020		
7	*B. scutallaris*	16	16/625	0.0256	-3.6652	-0.0938	0.0006		
8	*C. vesubiana*	21	21/625	0.0336	-3.3932	-0.1140	0.0011		
	N=	**625**	**-**	**-**	**-20.3839**	**-1.6213**	**0.2627**		

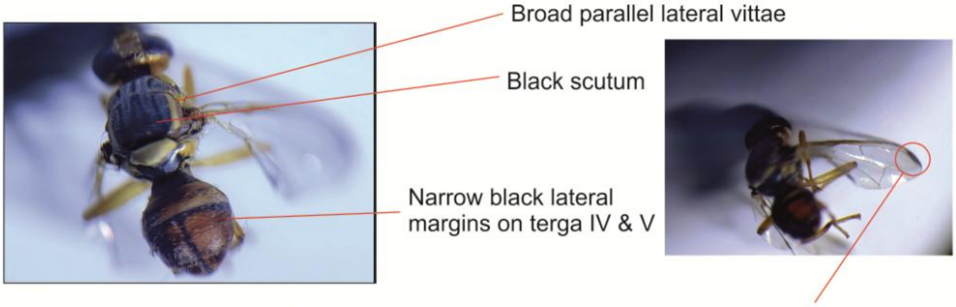
Plate 6: Identification characters of different fruit fly

Groupings of fruit fly by morphological similarity

TWO VITTAE



Bactrocera dorsalis



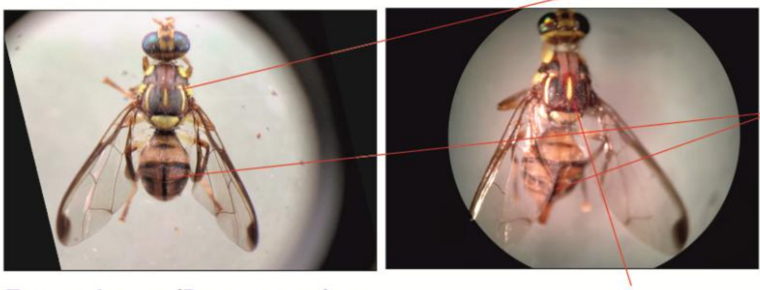
Bactrocera correcta

Bactrocera zonata

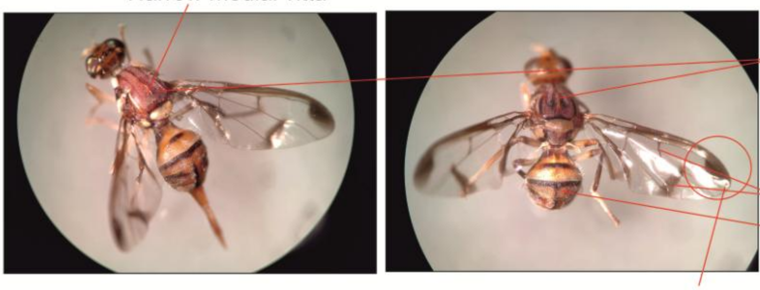
Plate 7: Identification characters of different fruit fly

Groupings of fruit fly by morphological similarity

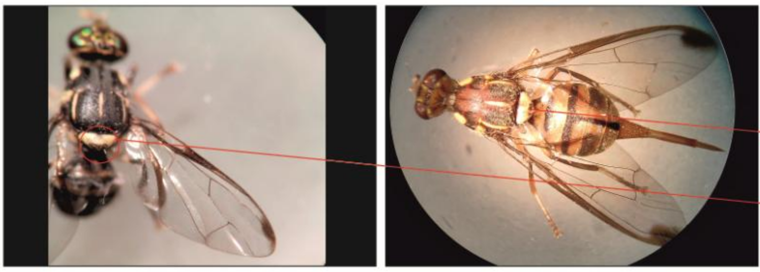
THREE VITTAE



Zeugodacus (Bactrocera) tau



Zeugodacus (Bactrocera) cucurbitae



Bactrocera scutellaris

Plate 8: Identification characters of different fruit fly

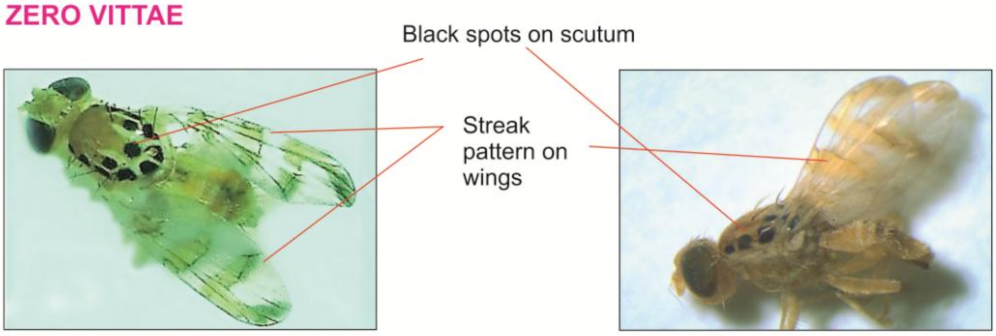
Groupings of fruit fly by morphological similarity

THREE VITTAE

Bactrocera diversa

Groupings of fruit fly by morphological similarity

ZERO VITTAE



Carpomyia vesuviana

Weiner's index showed a value of H=1.6213 which indicated higher magnitude of diversity of fruit flies at FSR orchards. The value of species diversity as measured by Simpson diversity Index was computed to be D=3.8062 which indicated that the study locations were dominated by several fruit fly species.

4.1.8 Diversity of fruit flies at Miran Sahib during 2020

During 2020, a total of four (04) fruit fly species were recorded at orchard locations at Miran Sahib (Table 7). Three *Bactocera* species viz., *Bactocera dorsalis, B. zonata* and *B. correcta* and one species of *C. vesubiana* were recorded at orchard locations under study. A total of 206 fruit fly individuals were recorded wherein 98 individuals of *B. dorsalis,* 70 individuals of *B. zonata*, 26 individuals of *B. correcta* and 12 individuals of *C. vesubiana* were noticed. Species diversity measured by Shannon Weiner's index showed a value of H=1.1471 which indicated high magnitude of diversity of fruit flies at orchards at Miran sahib. The value of species diversity as measured by Simpson diversity Index was computed to be D=2.7693 which indicated that the study locations were dominated by more than one fruit fly species.

4.1.9 Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2020

The Shannon and Simpson diversity index of fruit flies at three experimental locations viz., Raya, FSR and Miran sahib has been presented in Table 8. The Shannon index (H) for fruit flies at Raya, FSR and Miran sahib were computed to be H=1.3942, H=1.6213 and H=1.1471, respectively. The perusal of the computed data indicated that out of three experimental orchard locations, the experimental orchards at FSR, Chatha, again, had highest diversity of fruit flies in terms of species richness and species abundance whereas experimental orchards at Miran Sahib has less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.67 which indicated that all the three communities under study had a bit of overlap or similarity in terms of fruit fly species diversity.

4.2 Study the population dynamics of fruit fly in mango, guava and peach

4.2.1 Population dynamics of fruit flies at orchard of experimental locations during 2019

The natural infestation of fruit flies was recorded from 8th to 50th Standard Weeks during two consecutive years (2019 and 2020) at three different locations *viz.*, RRSSS

Raya, FSR (Farming System Research Centre, Chatha) and Miran Sahib, Jammu. For recording the data on adult fruit flies, fruit fly pheromone traps were installed in the orchards at all the three experimental sites. The data on population dynamics of fruit flies during both the years revealed that they remain active almost the entire growing season. Further, the correlation studies of obtained data with different weather parameters indicated that weather parameters had an inevitable effect on the population build-up of fruit flies.

During 2019, the seasonal population dynamics of fruit flies was observed. The data obtained on the population dynamics of fruit flies at three different experimental locations is presented in Table 9; Fig. 1A to 1C. The perusal of the data indicates that the population of fruit flies fluctuated from 8th to 50th standard weeks at all the experimental locations. At Raya, Jammu, the fruit fly population ranged from 0.50-238.75. The commencement of fruit flies was first noticed from 8th standard week with an initial mean population of 0.50 fruit flies per trap catches when the mean weekly maximum and minimum temperature was 20.3°C and 8.6°C, respectively and morning and evening relative humidity during the period were recorded to be 91.3 and 58.6 per cent, respectively. The fruit fly population, then, started to increase gradually and reached to its peak in 25th standard week with mean number of 207.75 fruit flies per trap catches when maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 36.7°C, 23.9°C, 52.7 per cent and 38.1 per cent, respectively. From 26th standard week onwards, the fruit fly population again decreased. However, during 40th standard week, a second peak of fruit fly population was noticed with mean number of 238.75 fruit flies per trap catches. The subsequent maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 28.8°C, 18.8°C, 88.6 per cent and 64.6 per cent, respectively. However, from 41st standard week onwards, the fruit fly population declined and reached to its minimum in 50th standard week (0.50 fruit flies/trap catches) when the associated maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 16.7°C, 7.8°C, 93.7 per cent and 72.7 per cent, respectively.

Similarly, at FSR, Chatha, the fruit fly population ranged from 1.25-287.25. The fruit flies commenced from 8th standard week with an initial mean population of 1.50 per trap catches. From there, the population increased and reached to its peak in 25th standard

Table 7: Diversity of fruit flies at Miran Sahib orchard in Jammu Sub-tropics during 2020

Miran Sahib	Fruit flies species	**n**	**P=n/N**	**Pi**	**lnPi**	**Pi * lnPi**	**Pi^2**	Shannon Index **(H)**	Simpson diversity Index **(D)**
1	*B.dorsalis*	98	98/206	0.4757	-0.7429	-0.3534	0.2263	**1.1471**	**2.7693**
2	*B. zonata*	70	70/206	0.3398	-1.0793	-0.3667	0.1154		
3	*B. correcta*	26	26/206	0.1262	-2.0697	-0.2612	0.015		
4	*C. vesubiana*	12	12/206	0.0582	-2.8429	-0.1656	0.0034		
	N=	**206**	**-**	**-**	**-6.7350**	**-1.1471**	**0.3611**		

Table 8: Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2020

Raya Orchard	Shannon Index (H)= Simpson diversity Index (D)=	**1.3942** **3.1994**
FSR, Chatha	Shannon Index (H)= Simpson diversity Index (D)=	**1.6213** **3.8062**
Miran Sahib	Shannon Index (H)= Simpson diversity Index (D)=	**1.1471** **2.7693**
Evenness or Sorenson coefficient (CC)=	3×4/18	**0.67**

- *The bigger value is of more diverse area. Therefore, FSR Chatha is having more diversity of fruit fly species*
- *According to Sorenson coefficient, these communities have quite a bit of overlap or similarity*

Table 9: Population dynamics of fruit flies at orchard of experimental locations during 2019

Standard Weeks(SW)	*Raya fruit fly Population	*FSR fruit fly population	*Miran Sahib fruit fly population	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative humidity Morning (%)	Relative humidity Evening (%)	Rainfall (mm)
8	0.50	1.50	0.50	20.3	8.6	91.3	58.6	67.8
9	2.75	3.00	1.75	18.0	6.3	92.3	56.6	11.2
10	1.75	5.25	1.75	22.4	8.8	91.1	49.0	0.0
11	3.25	9.75	2.75	24.3	9.1	91.3	46.1	10.8
12	4.25	3.00	2.00	25.2	10.9	91.9	51.6	14.2
13	5.50	4.75	2.75	29.1	13.5	89.0	44.4	0.0
14	22.75	11.50	2.75	33.4	15.9	80.9	37.1	0.0
15	13.75	17.50	3.50	33.8	17.8	81.4	38.7	7.2
16	16.75	15.75	3.00	30.2	17.1	77.1	43.4	26.8
17	23.25	21.00	3.00	37.1	17.9	57.6	22.9	8.4
18	28.50	28.50	3.50	36.6	18.3	42.4	18.7	0.0
19	18.75	18.75	5.25	38.5	19.6	47.9	23.9	0.0
20	39.50	39.50	9.75	34.9	20.9	58.6	32.0	0.6
21	69.50	60.25	3.00	37.1	21.1	58.3	28.6	5.0
22	60.25	69.50	4.75	43.1	21.7	46.4	24.6	0.0
23	102.00	113.25	13.25	41.9	24.2	47.0	26.7	0.0
24	153.50	213.00	21.00	41.1	23.7	51.0	29.1	11.6
25	207.75	287.25	18.00	36.7	23.9	52.7	38.1	8.8
26	62.25	76.25	25.25	41.7	25.4	51.9	20.7	3.8
27	116.75	142.50	29.50	38.9	27.5	66.7	46.9	13.2
28	149.25	177.00	21.00	32.9	25.2	88.0	63.4	94.8
29	74.75	93.50	41.00	34.4	26.3	79.0	59.7	1.2
30	41.25	49.50	59.00	32.3	26.1	90.1	72.9	170.6
31	31.75	33.50	34.50	32.7	26.2	86.0	67.7	50.2
32	44.75	20.00	25.00	34.1	27.2	87.3	70.0	23.0
33	48.50	52.75	56.25	32.7	26.2	86.0	67.7	131.1
34	32.75	35.50	37.00	34.6	25.8	84.4	58.3	9.4
35	58.00	56.75	58.50	35.2	26.7	87.7	61.0	2.0
36	137.50	157.50	123.00	34.6	25.6	85.4	61.9	9.0
37	211.00	215.50	91.75	35.0	25.9	87.0	63.4	3.0
38	187.25	238.75	119.00	32.2	23.0	89.4	61.1	62.8
39	232.25	271.25	98.00	29.7	23.1	93.1	75.9	93.4
40	238.75	232.75	67.50	28.8	18.8	88.6	64.6	21.4
41	190.25	197.75	40.50	30.5	18.6	86.4	52.1	0.0
42	183.50	92.25	9.25	29.2	17.3	87.3	51.6	9.2
43	98.50	116.50	9.25	29.3	14.5	84.6	43.6	0.0
44	88.25	97.00	2.50	28.0	15.8	89.9	52.3	0.0
45	61.25	66.25	1.75	25.4	13.0	83.1	52.0	51.8
46	32.50	39.00	0.50	24.0	13.4	89.9	61.7	2.8
47	5.25	8.25	0.75	22.4	12.4	92.6	63.3	0.8
48	3.75	9.00	0.50	21.9	9.8	93.1	52.1	22.0
49	1.50	2.50	0.50	22.4	6.4	90.3	45.6	0.0
50	0.50	1.25	0.25	16.7	7.8	93.7	72.7	82.6

*** Mean of 4 traps catches**

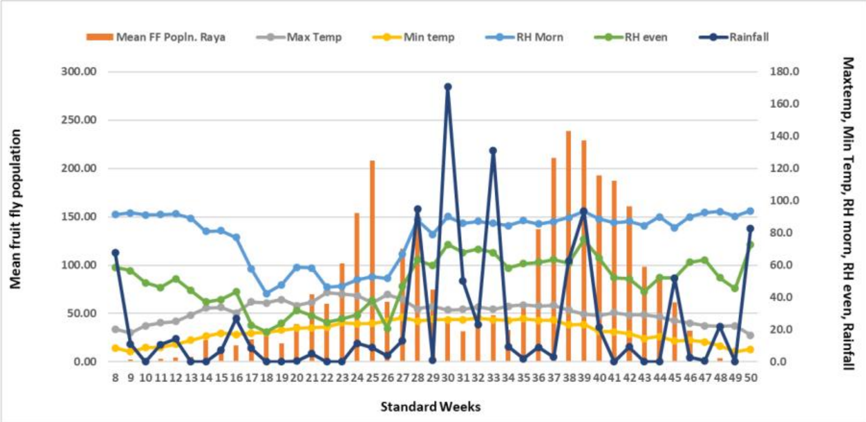


Fig 1A: Population dynamics of fruit flies at RRSSS, Raya during 2019

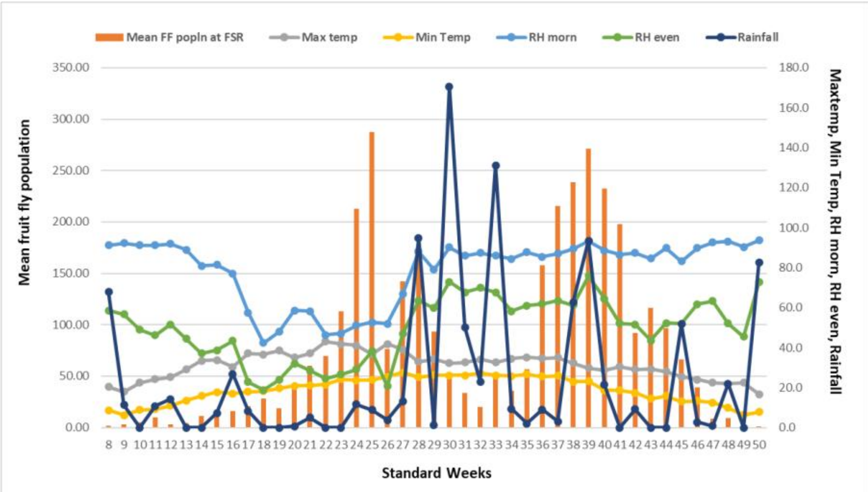


Fig 1B: Population dynamics of fruit flies at FSR, Chatha during 2019

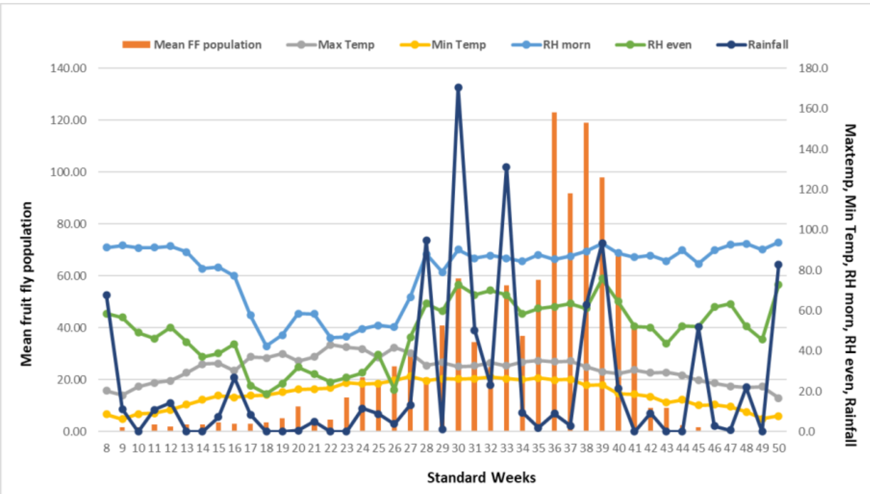


Fig 1C: Population dynamics of fruit flies at Miran Sahib during 2019

week with mean number of 287.25 fruit flies per trap catches. The population then began to decline till 37th standard week. But it was only in 39th standard week that second peak of fruit fly population was recorded with mean population of 271.25 fruit flies per trap catches when the maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 29.7°C, 23.1°C, 93.1 per cent and 75.9 per cent, respectively. From 40th standard week onwards, the fruit fly population declined and reached to its minimum in 50th standard week (1.25 fruit flies/catches).

Comparatively, the fruit fly population at Miran Sahib was not as abundant as at other two locations and the population ranged from 0.25-123.00. The incidence of fruit flies was recorded from 8th standard week with an initial mean population of 0.50 per trap catches. The population gradually increased afterwards and reached to its peak in 36th standard week with mean number of 123.00 fruit flies per trap catches when maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 34.6°C, 25.6°C, 85.4 per cent and 61.9 per cent, respectively. Then, the fruit fly population declined steadily and reached to its minimum in 50th standard week (0.25 fruit flies/ trap catches).

4.2.2 Correlation studies

Correlation studies were worked out to find out the influence of weather factors (maximum and minimum temperatures, morning and evening RH and rainfall) on the population dynamics of fruit flies in orchards at three experimental sites during 2019 (Table 10). The perusal of the data obtained indicates that at Raya, the population of adults of fruit fly was positively correlated with mean maximum and minimum temperature, mean evening relative humidity and mean rainfall with r=0.337*, 0.496**, 0.175 and 0.071, respectively but negative correlation with morning relative humidity (-0.060). Likewise, at FSR, population of adult fruit fly was positively correlated with mean maximum and minimum temperature, mean evening relative humidity and mean rainfall with r=0.360*, r=0.506**, r=0.142 and r=0.101, respectively but negatively correlated with morning relative humidity (-0.116). However, with regard to the fruit fly population at Miran Sahib, a non-significant positive correlation existed with maximum temperature (0.249) and morning relative humidity (0.208) and significant positive correlation existed with minimum temperature (0.590**), evening relative humidity (0.479**) and rainfall (0.330*).

4.2.3. Regression studies

The values of linear regression equations for population dynamics of fruit flies at Raya, FSR and Miran Sahib were calculated to be $Y= -244.239+7.938X_1-1.945X_2-1.027X_3+3.915X_4-0.340X_5$, $Y= -198.258+7.849X_1-1.851X_2-1.885X_3+4.480X_4-0.272X_5$ and $Y= -199.237+3.692X_1+0.184X_2-0.428X_3+1.441X_4-0.010X_5$, respectively. The equations depicted the decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) were worked out to be 0.305, 0.300 and 0.577, respectively and were found statistically non-significant at 5% level of significance. The overall impact of weather factors on population buildup of fruit flies were 30.5, 30.0, 57.7 per cent, respectively (Table 11).

4.2.4 Population dynamics of fruit flies at orchard of experimental locations during 2020

The data with respect to the population dynamics of fruit flies in 2020 at three different experimental locations (Raya, FSR, Miran Sahib) is presented in Table 12; Fig. 2A to 2C. The perusal of the data indicated the incidence of fruit flies from 8th to 50th standard weeks at all the experimental sites. At Raya, the fruit fly population ranged from 0.50- 262.75. The commencement of fruit flies was noticed from 8th standard week with an initial mean population of 1.50 fruit flies per trap catches when the mean weekly maximum temperature, minimum temperature, morning and evening relative humidity was 23.3°C, 10.1°C, 86.7 and 47.3 per cent, respectively. Afterwards, the population increased gradually and reached to its peak in 26th standard week with mean number of 255.25 fruit flies per trap catches when maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 37.5°C, 26.4°C, 73.7 per cent and 45.9 per cent, respectively. From 27th standard week onwards, the fruit fly population again decreased. However, during 39th standard week, a second peak of fruit fly population was noticed with mean number of 262.75 fruit flies per trap catches. The subsequent maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were recorded to be 34.1°C, 21.4°C, 79 per cent and 49 per cent, respectively. However, from 40th standard week onwards, the fruit fly population declined again and reached to its minimum in 50th standard week (0.50 fruit flies/trap catches) when the associated maximum temperature, minimum temperature,

Table 10: Correlation between population fluctuation of fruit fly with abiotic factors during 2019

Insect pest	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Maximum	Minimum	Morning	Evening	
Adult population of fruit fly/ traps at Raya	0.337*	0.496**	-0.060	0.175	0.071
At FSR, Chatha	0.360*	0.506**	-0.116	0.142	0.101
At Miran Sahib	0.249	0.590**	0.208	0.479**	0.330*

** Significant at the 0.01 level
* Significant at the 0.05 level

Table 11: Regression equations and co- efficient of multiple determination (R^2) of adult fruit fly in relation to abiotic factors during 2019

Experimental locations	Regression linear equations of adult fruit fly	Multiple correlation (r)	Co-efficient of determination (R^2)
Raya	$Y= -244.239+7.938X_1-1.945X_2-1.027X_3+3.915X_4-0.340X_5$	0.552	0.305
FSR, Chatha	$Y= -198.258+7.849X_1-1.851X_2-1.885X_3+4.480X_4-0.272X_5$	0.547	0.300
Miran sahib	$Y= -199.237+3.692X_1+0.184X_2-0.428X_3+1.441X_4-0.010X_5$	0.760	0.577

Where,

Y= Adult fruit fly catches / trap
X_1=Maximum temperature
X_2=Minimum temperature
X_3= R.H morning
X_4= R.H Evening
X_5= Rainfall (mm)

Table 12: Population dynamics of fruit flies at orchard of experimental locations during 2020

Standard Weeks (SW)	*Raya fruit fly Population	*FSR fruit fly population	*Miran Sahib fruit fly population	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative humidity Morning (%)	Relative humidity Evening (%)	Rainfall (mm)
8	1.50	1.50	0.50	23.3	10.1	86.7	47.3	9.2
9	5.75	5.25	2.25	24.5	11.8	90.4	52.4	20.0
10	11.50	9.50	6.50	20.5	10.7	88.6	61.4	35.4
11	27.25	25.50	12.25	24.2	10.2	81.0	53.6	40.8
12	13.50	17.25	13.75	26.0	13.9	83.1	51.3	9.0
13	12.25	19.25	21.50	25.3	14.0	81.6	61.1	50.4
14	20.75	31.25	33.75	28.0	13.2	77.1	44.4	6.8
15	14.50	17.25	17.25	32.7	17.2	74.4	39.4	0.0
16	32.50	41.00	31.25	30.9	17.2	67.4	44.3	15.0
17	58.75	63.75	43.25	32.4	18.6	69.3	38.9	4.0
18	67.00	71.25	63.75	34.0	20.1	66.3	36.1	11.0
19	48.25	55.75	45.75	35.3	19.7	61.6	32.3	2.2
20	58.25	62.00	51.25	34.7	19.2	59.7	30.4	5.8
21	88.75	129.75	59.00	41.8	20.9	48.9	18.2	0.0
22	129.75	69.75	90.50	33.7	21.9	64.1	47.0	10.8
23	170.00	165.25	103.75	33.5	23.2	71.1	51.6	28.0
24	200.50	151.75	110.00	39.4	23.8	58.0	28.9	1.0
25	203.00	238.75	97.00	39.2	26.6	57.7	39.9	8.8
26	255.25	271.25	155.50	37.5	26.4	73.7	45.9	13.2
27	225.50	232.75	123.00	37.7	26.5	72.9	47.3	18.2
28	158.50	197.75	58.50	36.0	26.0	78.4	54.1	48.8
29	166.25	219.50	37.25	33.5	25.5	82.0	65.1	50.2
30	173.25	199.50	46.25	35.8	25.6	83.0	57.1	40.2
31	120.25	141.50	51.75	34.6	25.7	87.0	64.6	54.6
32	108.00	105.50	69.25	34.8	27.0	86.6	67.7	25.6
33	142.50	79.50	74.25	33.3	25.8	93.4	72.4	185.6
34	155.00	137.00	86.25	31.2	25.2	91.1	73.4	170.8
35	161.50	161.50	96.25	31.7	24.9	91.1	71.4	160.6
36	173.25	180.25	115.75	32.7	25.2	89	64	17.6
37	180.25	199.50	124.00	35.2	26.0	85	56	00.0
38	202.00	223.25	135.50	36.0	25.3	82	49	00.0
39	262.75	232.75	143.50	34.1	21.4	79	49	00.0
40	156.00	157.75	101.50	33.9	18.2	76	40	00.0
41	116.00	118.00	86.75	33.5	18.0	81	40	00.0
42	103.00	99.75	73.75	32.4	14.4	90	32	00.0
43	93.00	60.75	65.00	30.3	12.4	90	34	00.0
44	88.50	42.75	57.00	28.7	10.8	86	32	00.0
45	74.75	31.50	43.50	27.9	9.6	88	40	00.0
46	66.00	19.25	28.50	23.2	9.8	93	58	27.8
47	26.25	13.50	17.00	20.6	8.5	92	56	00.0
48	7.75	6.50	8.75	23.7	7.4	92	48	08.0
49	1.75	1.25	2.25	23.3	9.8	92	58	00.8
50	0.50	0.50	0.50	18.5	8.3	94	66	27.6

*** Mean of 4 traps catches**

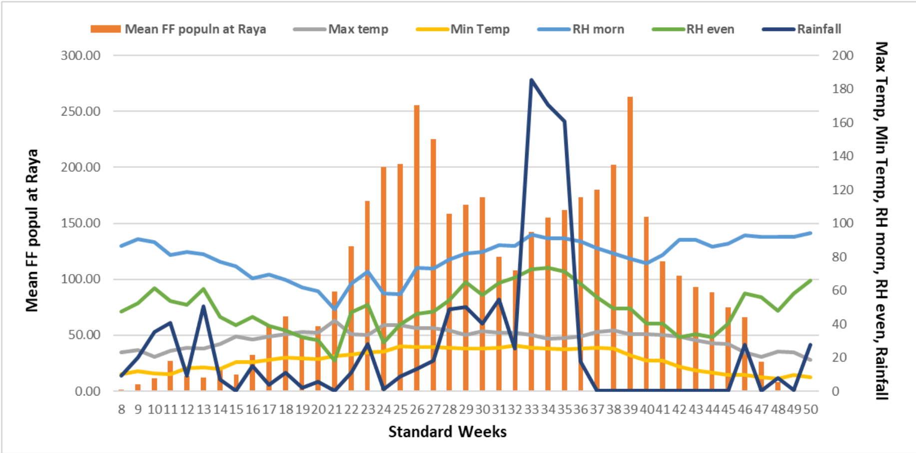


Fig 2A: Population dynamics of fruit flies at RRSSS, Raya during 2020

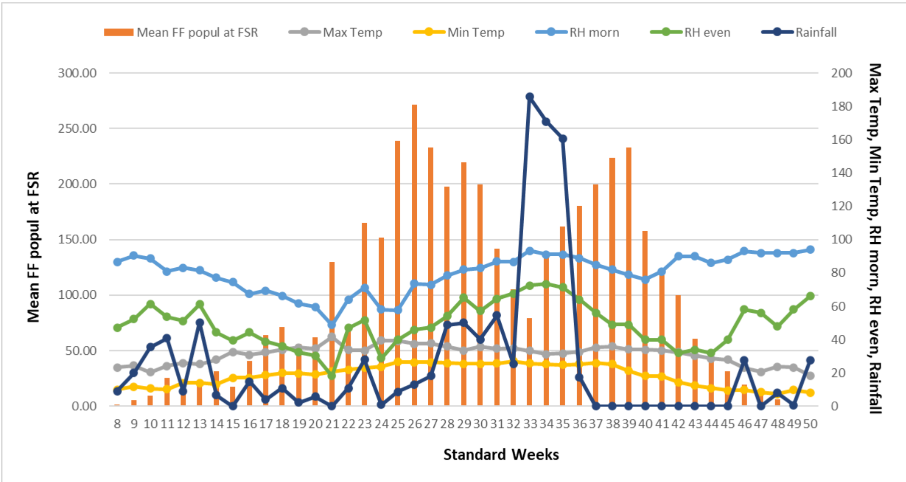


Fig 2B: Population dynamics of fruit flies at FSR, Chatha during 2020

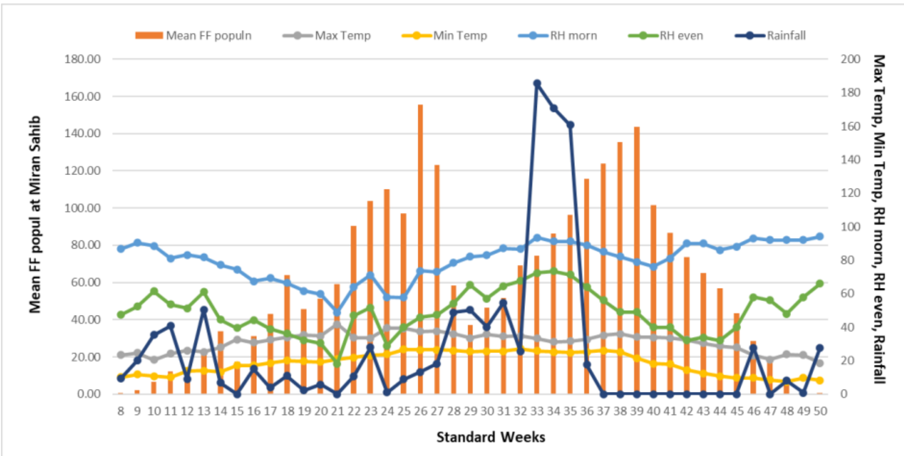


Fig 2C: Population dynamics of fruit flies at Miran Sahib during 2020

morning relative humidity and evening relative humidity were recorded to be 16.7°C, 7.8°C, 93.7 per cent and 72.7 per cent, respectively.

Similarly, at FSR, Chatha, the fruit fly population ranged from 0.50-271.25. The fruit flies commenced from 8th standard week with an initial mean population of 1.50 per trap catches. The fruit fly population kept on increasing and reached to its peak in 26th standard week with mean number of 271.25 fruit flies per trap catches. The population then began to decline till 38th standard week. But it was only in 39th standard week that second peak of fruit flies was recorded with mean population of 232.75 fruit flies per trap catches. From 40th standard week onwards, the fruit fly population declined and reached to its minimum in 50th standard week (0.50 fruit flies/ trap catches).

Again, the fruit fly population at Miran Sahib was not abundant as compared to other two locations and the population ranged from 0.50-155.50. The incidence of fruit flies was recorded from 8th standard week with an initial mean population of 0.50 per trap catches. The population gradually increased afterwards and reached to its peak in 26th standard week with mean number of 155.50 fruit flies per trap catches. Then, the fruit fly population declined till 38th standard week, but in 39th standard week, second peak of fruit fly population was recorded (143.50 fruit flies/trap catches). The population then declined steadily and reached to its minimum in 50th standard week (0.50 fruit flies/ trap catches).

4.2.5 Correlation studies

The correlation studies indicated that at RRSSS-Raya, the population of adult fruit fly was positively but significantly correlated with mean maximum and minimum temperature with r=0.808** and 0.742**, respectively. Further, the fruit fly population was positively but non-significantly correlated with evening relative humidity (0.053) and rainfall (0.165) but negative correlation with morning relative humidity (-0.210). Likewise, at FSR, the population of adult fruit fly was positively but significantly correlated with mean maximum and minimum temperature with r=0.771** and r=0.847**, respectively. Further, the fruit fly population was positively but non-significantly correlated with evening relative humidity (0.053) and rainfall (0.108) but negative correlation with morning relative humidity (-0.269). However, the population of adult fruit fly was positively but significantly correlated with mean maximum and minimum temperature with r=0.734** and 0.734**, respectively. Further, the fruit fly population was positively but non-significantly correlated with rainfall with r=0.051 and negatively correlated with morning (-0.276) and evening relative humidity (-0.092) with respect to fruit fly population at Miran Sahib (Table 13).

4.2.6. Regression studies

The values of linear regression equations for population dynamics of fruit flies at Raya, FSR and Miran Sahib were calculated to be Y^1= -326.346+2.761X_1+10.074X_2+2.818X_3-1.304X_4-0.199X_5, Y^2= -340.362+3.062X_1+10.871X_2+2.149X_3-0.322X_4-0.461X_5 and Y^3= -45.328-2.863X_1+9.002X_2+1.842X_3-2.361X_4-0.090X_5, respectively. The equations signify decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) were worked out to be 0.729, 0.786 and 0.664, respectively and were found statistically significant at 5% level of significance. The overall impact of weather factors on population buildup of fruit flies was 72.9, 78.6, 66.4 per cent, respectively (Table 14).

4.3 Evaluation of different techniques for the management of fruit fly on mango, guava and peach

4.3.1. Evaluation of different MAT and BAT techniques for the management of fruit fly on mango during 2019

During 2019, Male Annihilation Technique (MAT) and Bait Application Technique (BAT) were followed to assess their efficacy in managing the population of fruit flies on mango and the data obtained has been presented in Table 15**.** Three bait trap combinations *viz*., Methyl eugenol (ME)+malation, Banana+yeast+spinosad and Fishmeal+diazinon were evaluated for their efficacy against fruit flies on mango. The perusal of the obtained data revealed that the population of fruit flies was noticed from March to August (9^{th} to 32^{nd} standard weeks) for all the three traps. The fruit fly population commenced from the month of March with mean number of 4.67, 1.25 and 0.25 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad, and fishmeal+diazinon traps, respectively. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in the month of July for ME+malathion (856.42 fruit flies per trap catches) and Banana+yeast+spinosad (59.83 fruit flies per trap catches). However, for Fishmeal+diazinon traps, the highest fruit fly population was noticed in August with mean number of 11.58 fruit flies per trap catches.

Table 13: Correlation between population fluctuation of fruit fly with abiotic factors during 2020

Insect pest	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Maximun	Minimum	Morning	Evening	
Adult population fruit fly Raya	0.742**	0.808**	-0.210	0.053	0.165
FSR Chatha	0.771**	0.847**	-0.269	0.053	0.108
Miran sahib	0.734**	0.734**	-0.276	-0.092	0.051

** Significant at the 0.01 level
* Significant at the 0.05 level

Table 14: Regression equations and co-efficient of multiple determination (R^2) of adult fruit fly in relation to abiotic factors during 2020

Experimental locations	Regression linear equations of adult fruit fly	Multiple correlation (r)	Co-efficient of determination (R^2)
Raya	$Y^1 = -326.346+2.761X_1+10.074X_2+2.818X_3-1.304X_4-0.199X_5$	0.854	0.729
FSR, Chatha	$Y^2 = -340.362+3.062X_1+10.871X_2+2.149X_3-0.322X_4-0.461X_5$	0.886	0.786
Miran Sahib	$Y^3 = -45.328-2.863X_1+9.002X_2+1.842X_3-2.361X_4-0.090X_5$	0.815	0.664

Where,

Y= Adult fruit fly catches / trap
X_1=Maximum temperature
X_2=Minimum temperature
X_3= R.H morning
X_4= R.H Evening
X_5= Rainfall (mm)

Table 15:Evaluation of different MAT and BAT techniques for the management of fruit fly on Mango during 2019

Treatments	**Monthly trap catches data of fruit flies in different treatments***						
	March (9-12)**	**April (13-16)**	**May (17-20)**	**June (21-24)**	**July (25-28)**	**August (29-32)**	
ME+ Malathion	4.67 (1.74)	19.58 (3.02)	200.00 (5.30)	236.92 (5.47)	856.42 (6.75)	401.67 (6.00)	**4.7108[a]**
Banana+ yeast+ spinosad	1.25 (0.81)	6.25 (1.98)	43.00 (3.78)	41.50 (3.75)	59.83 (4.11)	47.67 (3.89)	**3.0445[b]**
Fishmeal+ diazinon	0.25 (0.22)	1.50 (0.92)	8.08 (2.21)	8.58 (2.26)	9.17 (2.32)	11.58 (2.53)	**1.7386[c]**
	0.9006[e]	**1.9701[d]**	**3.7632[c]**	**3.8245[c]**	**4.3914[a]**	**4.1378[b]**	
F value							
Treatment							2301.17
Month							1016.01
Treatment*Month							48.56
P value							<0.00

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks,**=Range of standard weeks

Treatments with the same letters are not significantly different (P <0.05) according to Tukey HSD test

The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.3.2 Evaluation of different MAT and BAT techniques for the management of fruit fly on guava during 2019

During 2019, Male Annihilation Technique (MAT) and Bait Application Technique (BAT) were followed to assess their efficacy in managing the population of fruit flies on guava. Three bait trap combinations *viz*., Methyl eugenol (ME)+malation, Banana+yeast+spinosad and Fishmeal+diazinon were evaluated for their efficacy against fruit flies on guava (Table 16; Plate- 9 and 10). The perusal of the obtained data revealed that the population of fruit flies was noticed from July-December (34^{th} to 50^{th} standard weeks) for all the treatments. The fruit fly population commenced from July with mean number of 3.08, 1.50 and 1.17 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The fruit fly population, then, increased gradually and reached to its peak in October for all the three traps *viz*., ME+malathion (304.00 fruit flies per trap catches), Banana+yeast+spinosad (29.92 fruit flies per trap catches) and Fishmeal+diazinon traps (9.58 fruit flies per trap catches). Thereafter, the fruit fly population decreased and reached to its minimum in December in all the treatments wherein mean number of 8.67, 2.42 and 0.50 fruit flies per trap catches was noticed in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.3.3. Evaluation of different MAT and BAT techniques for the management of fruit fly on peach during 2019

During 2019, Male Annihilation Technique (MAT) and Bait Application Technique (BAT) were followed to assess their efficacy in managing the population of fruit flies on mango and the data obtained has been presented in Table 17. Three bait trap combinations *viz*., Methyl eugenol (ME)+malation, Banana+yeast+spinosad and Fishmeal+diazinon were evaluated for their efficacy against fruit flies on mango. The perusal of the obtained data revealed that the population of fruit flies was noticed from February to June (7^{th}-26^{th} standard weeks) for all the three traps. The fruit fly population commenced from the month of February with mean number of 1.42, 0.50 and 0.33 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad, and fishmeal+diazinon traps, respectively. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in the month of June for ME+malathion (51.08 fruit flies per trap catches), Banana+yeast+spinosad (14.67 fruit flies per trap catches) and Fishmeal+diazinon traps (5.17 fruit flies per trap catches). The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.3.4 Evaluation of different MAT and BAT techniques for the management of fruit fly on Mango during 2020

The perusal of the obtained data of MAT and BAT techniques for the managing the fruit fly on Mango during 2020 (Table 18) revealed that the population of fruit flies was noticed from March to August (9^{th}-32^{nd} standard weeks) for all the three evaluated traps viz., ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon trap. The fruit fly population commenced from March with mean number of 6.00, 3.25 and 2.50 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon trap, respectively. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in July for ME+malathion (1373.17 fruit flies per trap catches).Banana+yeast+spinosad (757.67 fruit flies per trap catches) and Fishmeal+diazinon traps (103.67 fruit flies per trap catches) recorded peak population in August and June, respectively. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.3.5 Evaluation of different MAT and BAT techniques for the management of fruit fly on Guava during 2020

During 2020, MAT and BAT techniques were followed to assess its efficacy in managing the population of fruit flies on guava. Three bait trap combinations *viz*., Methyl eugenol (ME)+malathion, Banana+yeast+spinosad and Fishmeal+diazinon were evaluated for their efficacy against fruit flies on guava (Table 19). The perusal of the obtained data revealed that the population of fruit flies was noticed from July-December (34^{th} to 50^{th} standard weeks) for all the treatments. The fruit fly population commenced from July with mean number of 3.08, 2.33 and 1.83 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The fruit fly population, then, increased gradually and reached to its peak in October for all the three traps wherein 314.83, 53.25 and 34.00 fruit flies per trap catches were recorded in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. Afterwards, the fruit fly population decreased constantly in the successive months

Table 16:Evaluation of different MAT and BAT techniques for the management of fruit fly on Guava during 2019

Treatments	**Monthly trap catches data of fruit flies in different treatments***						
	July (27-30)**	**August (31-34)**	**September (35-38)**	**October (39-42)**	**November (43-46)**	**December (47-50)**	
ME+ Malathion	3.08 (1.41)	14.08 (2.71)	257.17 (5.55)	304.00 (5.72)	110.67 (4.72)	8.67 (2.27)	**3.7205**^{a}
Banana+ yeast+ spinosad	1.50 (0.92)	6.00 (1.95)	23.33 (3.19)	29.92 (3.43)	23.50 (3.20)	2.42 (1.23)	**2.3060**^{b}
Fishmeal+ diazinon	1.17 (0.77)	3.42 (1.49)	8.67 (2.27)	9.58 (2.36)	7.00 (2.08)	0.50 (0.41)	**1.5528**^{c}
	1.0198^{e}	**2.0412**^{c}	**3.6654**^{a}	**3.8280**^{a}	**3.3226**^{b}	**1.2817**^{d}	
F value							
Treatment							1216.36
Month							771.31
Treatment*Month							56.95
P value							<0.00

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks,**=Range of standard weeks

Treatments with the same letters are not significantly different (P <0.05) according to Tukey HSD test

Table 17:Evaluation of different MAT and BAT techniques for the management of fruit fly on Peach during 2019

Treatments	**Monthly trap catches data of fruit flies in different treatments***					
	February (7-10)**	**March (11-14)**	**April (15-18)**	**May (19-22)**	**June (23-26)**	
ME+ Malathion	1.42 (0.88)	6.42 (2.00)	9.00 (2.30)	13.92 (2.70)	51.08 (3.95)	**2.3612[a]**
Banana+ yeast+ spinosad	0.50 (0.41)	2.25 (1.18)	3.67 (1.54)	5.08 (1.81)	14.67 (2.75)	**1.5355[b]**
Fishmeal+ diazinon	0.33 (0.29)	1.17 (0.77)	1.42 (0.88)	1.67 (0.98)	5.17 (1.82)	**0.9351[c]**
	0.5091[e]	**1.3054[d]**	**1.5721[c]**	**1.8279[b]**	**2.8386[a]**	
F-value						
Treatment						**347.54**
Month						**291.14**
Treatment*Month						**11.16**
P value						<0.00

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks,**=Range of standard weeks

Treatments with the same letters are not significantly different (P <0.05) according to Tukey HSD test

Table 18:Evaluation of different MAT and BAT techniques for the management of fruit fly on Mango during 2020

Treatments	**Monthly trap catches data of fruit flies in different treatments***						
	March (9-12)**	**April (13-16)**	**May (17-20)**	**June (21-24)**	**July (25-28)**	**August (29-32)**	
ME+ Malathion	6.00 (1.95)	20.58 (3.07)	182.58 (5.21)	270.42 (5.60)	1373.17 (7.23)	300.33 (5.71)	**4.7903[a]**
Banana+ yeast+ spinosad	3.25 (1.45)	8.75 (2.28)	78.08 (4.37)	98.83 (4.60)	151.92 (5.03)	757.67 (6.63)	**4.0546[b]**
Fishmeal+ diazinon	2.50 (1.25)	3.92 (1.59)	40.50 (3.73)	103.67 (4.65)	18.92 (2.99)	4.83 (1.76)	**2.6548[c]**
	1.5286[e]	**2.3090[d]**	**4.4331[c]**	**4.9512[a]**	**5.0777[a]**	**4.6997[b]**	
F value							
Treatment							**1186.30**
Month							**1163.68**
Treatment*Month							**191.06**
P value							**<0.00**

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks,**=Range of standard weeks

Treatments with the same letters are not significantly different (P <0.05) according to Tukey HSD test

Table 19:Evaluation of different MAT and BAT techniques for the management of fruit fly on Guava during 2020

Treatments	Monthly trap catches data of fruit flies in different treatments*						
	July (27-30)**	August (31-34)	September (35-38)	October (39-42)	November (43-46)	December (47-50)	
ME+ Malathion	3.08 (1.41)	11.92 (2.56)	100.67 (4.62)	314.83 (5.76)	98.33 (4.60)	12.33 (2.59)	**3.5818[a]**
Banana+ yeast+ spinosad	2.33 (1.20)	6.67 (2.04)	23.92 (3.22)	53.25 (3.99)	21.17 (3.10)	3.00 (1.39)	**2.4719[b]**
Fishmeal+ diazinon	1.83 (1.04)	4.42 (1.69)	12.67 (2.62)	34.00 (3.56)	21.75 (3.12)	3.75 (1.56)	**2.2619[c]**
	1.1986[e]	**2.0918[c]**	**3.4746[b]**	**4.4320[a]**	**3.6011[b]**	**1.8332[d]**	
F value							
Treatment							444.77
Month							685.85
Treatment*Month							23.61
P value							<0.00

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks, **=Range of standard weeks

Treatments with the same letters are not significantly different ($P < 0.05$) according to Tukey HSD test

Plate 9: Evaluation of different techniques for the management of fruit fly on Mango, Guava and Peach during 2019 and 2020

A) Low cost mineral bottle containing Cue-lure

B) Low cost mineral bottle containing Protein hydrolyzate

C) Low cost mineral bottle containing methyl eugenol (ME)

D) Bait attractant Technique containing Fish meal

E) Bait attractant Technique containing Meshed banana

F) Traps of fruit flies in mashed banana containing diazinon

Plate 10: Different types of commercial traps used for trapping fruit flies during experimentation

A) Green valley trap with trap catches on Guava

B) Observation on fruit flies catches in Green valley traps on Guava

C) PCI Methyl Eugenol (ME) trap in cucurbits

D) Inspecting the trap catches by advisor on Guava

E) Methyl Eugenol traps commercial traps on Peach

F) Green valley trap with trap catches on Mango plant reaching to its minimum in December in all the treatments wherein mean number of 12.33, 3.00 and 3.75 fruit flies per trap catches was noticed in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.3.6. Evaluation of different MAT and BAT techniques for the management of fruit fly on Peach in 2020

The data obtained on Male Annihilation Technique (MAT) and Bait Application Technique (BAT) to assess their efficacy in managing the population of fruit flies during 2020 on peach has been presented in Table 20**.** Three bait trap combinations *viz.*, Methyl eugenol (ME)+malathion, Banana+yeast+spinosad and Fishmeal+diazinon were evaluated for their efficacy against fruit flies on mango. The perusal of the obtained data revealed that the population of fruit flies was noticed from February to June (7^{th}-26^{th} standard weeks) for all the three traps. The fruit fly population commenced from the month of February with mean number of 2.42, 0.83 and 0.50 fruit flies per trap catches in ME+malathion, Banana+yeast+spinosad, and fishmeal+diazinon traps, respectively. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in the month of June for ME+malathion (55.92 fruit flies per trap catches), Banana+yeast+spinosad (15.67 fruit flies per trap catches) and Fishmeal+diazinon traps (6.58 fruit flies per trap catches). The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

4.4. Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) against major fruit flies

4.4.1 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2019

In order to analyze the affinity of adult fruit flies, MAT and BAT techniques were refined in different fruit orchards viz., peach, guava and mango in 2019. The collected data has been given in Table 21. A total of ten (10) treatments were evaluated against adult fruit flies *viz.*, Cue-lure + wooden block; Cue-lure + absorbent plastic; Protein hydrolysate + wooden block; Protein hydrolysate + absorbent plastic; Mineral bottle traps (ME + wooden block + malathion); Mineral bottle traps (ME + absorbent plastic +

spinosad); fishmeal + diazinon; mashed banana + malathion; commercially available traps (Green valley fruit fly traps and PCI). All the treatments were significantly different from each other. Among all the treatments, commercially available traps (green valley fruit fly traps) were successful in attracting highest number of fruit flies wherein about 359.00, 375.33, 329.67 fruit flies per trap were recorded in mango, guava and peach orchards, respectively. This trap was followed by another commercially available traps (PCI) which recorded the mean trap catch of 317.33, 330.00 and 283.00 fruit flies per trap on mango, guava and peach, respectively. However, the least trap catches were recorded in cue-lure+absorbent plastic wherein mean number of 88.00, 96.33 and 64.67 fruit flies per trap were recorded on mango, guava and peach, respectively.

4.4.2 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2020

During 2020, MAT and BAT techniques were again refined to trap the adults of fruit flies on three study crops viz., mango, guava and peach. The data pertaining to our analysis has been given in Table 22. The collected data reveals that the commercially available traps (green valley fruit fly traps) was successful in attracting highest number of fruit flies wherein, about 384.00, 381.67, 310.00 fruit flies per trap were recorded in mango, guava and peach orchards, respectively. This trap was followed by PCI traps which are another commercially available traps wherein, about 332.67, 338.00, 270.00 fruit flies per trap were recorded in mango, guava and peach orchards, respectively. On the contrary, cue-lure+absorbent plastic traps did not prove much effective and marked themselves as the least among treatment in capturing fruit flies wherein only 91.33, 105.33, 68.00 fruit flies were recorded in mango, guava and peach, respectively. All the used treatments had significant difference from each other.

4.4.3 Pooled data of both the years

The pooled data of two years (2019 and 2020) on the refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies has been illustrated in Table 23. The perusal of the data revealed that commercially available green valley fruit fly traps followed by commercially available PCI traps had highest efficacy in attracting the fruit flies wherein 371.50, 378.50 and 319.83 fruit flies/trap catch and 325.00, 334.00 and 276.50 fruit flies/trap catch were recorded in mango, guava and peach, respectively. Cue-lure+absorbent plastic had least effectiveness in attracting

Table 20:Evaluation of different MAT and BAT techniques for the management of fruit fly on Peach during 2020

Treatments	**Monthly trap catches data of fruit flies in different treatments***					
	February (7-10)**	**March (11-14)**	**April (15-18)**	**May (19-22)**	**June (23-26)**	
ME+ Malathion	2.42 (1.23)	7.42 (2.13)	8.75 (2.28)	12.92 (2.63)	55.92 (4.04)	**2.4590[a]**
Banana+ yeast+ spinosad	0.83 (0.60)	2.67 (1.30)	3.33 (1.47)	5.17 (1.82)	15.67 (2.81)	**1.5963[b]**
Fishmeal+ diazinon	0.50 (0.41)	1.25 (0.81)	1.42 (0.88)	2.17 (1.15)	6.58 (2.03)	**1.0409[c]**
	0.7265[d]	**1.4046[c]**	**1.5391[c]**	**1.8659[b]**	**2.9576[a]**	
F-value						
Treatment						**317.90**
Month						**249.33**
Treatment*Month						**5.56**
P value						<0.00

Note: Figures in parentheses are logarithmic "log(x+1), Monthly trap catch data*= Mean of 4 Standard weeks, **=Range of standard weeks

Treatments with the same letters are not significantly different (P <0.05) according to Tukey HSD test

Table 21:Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2019

Treatments	Treatments details	Mean of trapped adult fruit flies on Mango	Mean of trapped adult fruit flies on Guava	Mean of trapped adult fruit flies on Peach
T1	Cue- lure + wooden block	171.67 (2.24e)	185.00 (2.27d)	140.33 (2.15ef)
T2	Cue- lure+ absorbent plastic	88.00 (1.95i)	96.33 (1.99g)	64.67 (1.81i)
T3	Protein hydrolyzate + wooden block	109.00 (2.04h)	124.00 (2.10f)	78.33 (1.90hi)
T4	Protein hydrolyzate + absorbent plastic	212.67 (2.33d)	230.00 (2.36c)	174.33 (2.24de)
T5	Mineral bottle traps (ME+ wooden block+ malathion)	290.33 (2.46b)	309.00 (2.49b)	245.33 (2.39bc)
T6	Mineral bottle traps (ME+ absorbent plastic + Spinosad)	241.33 (2.38c)	258.33 (2.41c)	203.00 (2.31cd)
T7	Fish meal + Diazinon	129.67 (2.11g)	146.67 (2.17e)	96.67 (1.99gh)
T8	Mashed banana +Malathion	152.00 (2.18f)	168.00 (2.23d)	118.67 (2.08fg)
T9	Commercially available traps Green Valley fruit fly traps	359.00 (2.56a)	375.33 (2.57a)	329.67 (2.52a)
T10	Commercially available traps PCI	317.33 (2.50b)	330.00 (2.52b)	283.00 (2.45ab)
	F-value (P-value)	**520.76 P <0.01**	**332.09 P <0.01**	**120.17 P <0.01**

Note: Figures in parentheses are logarithmic "log(x+0.5)

Tukey HSD test, Treatments with the same letters are not significantly different (P <0.05)

Table 22:Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2020

Treatments	Treatments details	Mean of trapped adult fruit flies on Mango	Mean of trapped adult fruit flies on Guava	Mean of trapped adult fruit flies on Peach
T1	Cue- lure + wooden block	184.67 (2.27d)	176.00 (2.25c)	139.67 (2.14de)
T2	Cue- lure+ absorbent plastic	91.33 (1.96f)	105.33 (2.02e)	68.00 (1.82h)
T3	Protein hydrolyzate + wooden block	105.33 (2.02f)	118.67 (2.07de)	84.00 (1.92gh)
T4	Protein hydrolyzate + absorbent plastic	220.67 (2.34c)	224.00 (2.35b)	170.00 (2.22cd)
T5	Mineral bottle traps (ME+ wooden block+ malathion)	311.33 (2.49b)	318.67 (2.50a)	234.00 (2.37b)
T6	Mineral bottle traps (ME+ absorbent plastic + Spinosad)	253.33 (2.40c)	251.00 (2.40b)	210.00 (2.32bc)
T7	Fish meal + Diazinon	129.67 (2.11e)	141.67 (2.15cd)	102.33 (2.01fg)
T8	Mashed banana +Malathion	152.00 (2.18e)	172.00 (2.23c)	125.00 (2.09ef)
T9	Commercially available traps Green Valley fruit fly traps	384.00 (2.58a)	381.67 (2.58a)	310.00 (2.49a)
T10	Commercially available traps PCI	332.67 (2.52ab)	338.00 (2.53a)	270.00 (2.43ab)
	F-value (P-value)	**225.72 P <0.01**	**108.41 P <0.01**	**90.36 P <0.01**

Note: Figures in parentheses are logarithmic "log(x+0.5)

Tukey HSD test, Treatments with the same letters are not significantly different (P <0.05)

Table 23: Pooled data on refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies during 2019 and 2020

Treatments	Treatments details	Mean of trapped adult fruit flies on Mango	Mean of trapped adult fruit flies on Guava	Mean of trapped adult fruit flies on Peach
T1	Cue- lure + wooden block	178.17 (2.25e)	180.50 (2.26d)	140.00 (2.15e)
T2	Cue- lure+ absorbent plastic	89.67 (1.95i)	100.83 (2.01g)	**66.33 (1.82h)**
T3	Protein hydrolyzate + wooden block	107.17 (2.03h)	121.33 (2.09f)	81.17 (1.91g)
T4	Protein hydrolyzate + absorbent plastic	216.67 (2.34d)	227.00 (2.36c)	172.17 (2.24d)
T5	Mineral bottle traps (ME+ wooden block+ malathion)	300.83 (2.48b)	313.83 (2.49b)	239.67 (2.38b)
T6	Mineral bottle traps (ME+ absorbent plastic + Spinosad)	247.33 (2.39c)	254.67 (2.41c)	206.50 (2.32c)
T7	Fish meal + Diazinon	129.67 (2.11g)	144.17 (2.16e)	99.50 (1.99f)
T8	Mashed banana +Malathion	152.00 (2.18f)	170.00 (2.23d)	121.83 (2.09e)
T9	Commercially available traps Green Valley fruit fly traps	371.50 (2.57a)	378.50 (2.58a)	319.83 (2.51a)
T10	Commercially available traps PCI	325.00 (2.51b)	334.00 (2.52ab)	276.50 (2.44b)
	F-value (P-value)	**752.93 P <0.01**	**414.61 P <0.01**	**446.94 P <0.01**

Note: Figures in parentheses are logarithmic "log(x+0.5)

Tukey HSD test, Treatments with the same letters are not significantly different (P <0.05)

fruit flies in all the three experimental orchards and recorded the mean trap catches of 89.67, 100.83 and 66.33 fruit flies per trap in mango, guava and banana, respectively. All the treatments were significantly different from each other.

Chapter-V

Discussion

CHAPTER-V

DISCUSSION

The present investigation was carried out with an objective to study the diversity of fruit flies in Jammu Sub-tropics, population dynamics of fruit flies, evaluation of different techniques for the management of fruit fly and refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) against major fruit flies on selected fruit crops viz., mango, guava and peach, respectively. Tephritidae, the true fruit flies are the world's most serious agricultural and horticultural pests which include 484 genera and more than 4500 species worldwide. For successful management of any pest, it would be essential to have an idea of biology and bionomics of fruit fly in relation to preferred host plants in causing damage to the extent of economic losses. Regular monitoring and assessment of crop losses caused by fruit flies is an important prerequisite to devise the management options to mitigate the damage or losses which facilitates in making management or no management decision. The information on pest population densities, and prevailing beneficial insects *viz*., parasitoid and predatory fauna to suppress the pest densities, play a pivotal role on which a multifaceted pest management program can be executed. For the effective pest management, it is advocated that only selective, safe and eco-friendly use of different types of traps and baits (MAT and BAT techniques) should be adopted to avoid extra pressure on ecosystem and further refinement of existing techniques will be helpful in keeping the areawide best management options dynamics against dreaded fruit fly species. This chapter discusses the results and findings during the present experimental study entitled "Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics" are discussed under the following headings:

5.1 Study the diversity of fruit flies in Jammu Sub-tropics

5.1.1 Survey on diversity of fruit flies in Jammu Sub-tropics

The survey was conducted for two consecutive years (2019 and 2020) at three locations *viz*., RRSSS, Raya; FSR, Chatha and Govt. Orchard, Miran Sahib to assess the diversity of fruit flies on cultivated fruits and vegetable crops and their interaction for food sources on other wild host plants in different ecosystems of Jammu sub-tropics. Each location was further categorized with different host plants such as mango, guava and peach orchards into sub-locations for collecting and recording the existing fruit fly diversity in Jammu sub-tropics. Different species of *Bactocera*, *Dacus* fruit flies along with *Carpomyia* were collected from mango, guava and peach host plants and were brought to the laboratory for the further identification of up to species level.

5.1.2 Diversity of fruit flies at RRSSS-Raya, FSR-Chatha and Miran Sahib during 2019

During 2019, a total of five (05) fruit fly species were recorded at study orchards in Raya which included four species of *Bactocera viz*., *Bactocera dorsalis*, *B. zonata*, *B. tau* and *B. correcta* and one species of *C. vesuviana*. Among the total of 217 recorded fruit fly individuals, 98 individuals were of *B. dorsalis*, 70 individuals of *B. zonata*, 16 individuals of *B. tau*, 26 individuals of *B. correcta* and 7 individuals of *C. vesuviana.* Species diversity measured by Shannon Weiner's index and Simpson diversity Index showed a value of H = 1.28 and D=3.04, respectively which indicated somewhat higher magnitude of diversity of fruit fly species in the experimental area.

While a total of six (06) *Bactocera* species were recorded at orchard locations at FSR, Chatha during 2019 *viz*., *Bactocera dorsalis*, *B. zonata*, *B. tau*, *B. correcta*, *B. diversa* and *B. scutellaris*. Among a total of 236 recorded fruit fly individuals, 90 individuals were of *B. dorsalis*, 64 individuals of *B. zonata*, 22 individuals of *B. tau*, 36 individuals of *B. correcta*, 14 individuals of *B. diversa* and 8 individuals of *B. scutallaris*. Species diversity measured by Shannon Weiner's index and Simpson diversity Index showed a value of H=1.52 and D=3.87, respectively which indicated higher magnitude of diversity of fruit fly species at FSR orchards.

At, Miran Sahib location during 2019, a total of three (03) *Bactocera* species were recorded *viz*., *Bactocera dorsalis*, *B. zonata* and *B. correcta*. A total of 101 fruit fly individuals were recorded wherein 46 individuals of *B. dorsalis*, 37 individuals of *B.*

zonata and 18 individuals of *B. correcta* were noticed. Species diversity measured by Shannon Weiner's index and Simpson diversity Index was computed to be H=1.03 and D=2.67, respectively which indicated low magnitude of diversity of fruit flies at orchards at Miran sahib and the study locations were dominated by more than one fruit fly species.

5.1.3 Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2019

The Shannon index (H) for fruit flies at Raya, FSR and Miran sahib were computed to be H=1.2812, H=1.5191 and H=1.0335, respectively which revealed that the experimental orchards at FSR, Chatha had highest diversity of fruit flies in terms of species richness and species abundance whereas experimental orchards at Miran Sahib has less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.6428 which indicated that all the three communities had a bit of overlap or similarity in terms of fruit fly species diversity.

5.1.4 Diversity of fruit flies at RRSSS-Raya, FSR-Chatha and Miran Sahib during 2020

During 2020, a total of six (06) fruit fly species were recorded at experimental orchards in Raya which included five species of *Bactocera viz*., *Bactocera dorsalis, B. zonata, B. tau, B. correcta* and *B. cucurbitae* and one species of *C. vesuviana*. Out of total 333 recorded fruit fly individuals, 156 individuals were of *B. dorsalis*, 90 individuals of *B. zonata*, 22 individuals of *B. tau*, 31 individuals of *B. correcta*, 27 individuals of *B. cucurbitae* and 7 individuals of *C. vesuviana*. Species diversity measured by Shannon Weiner's index and Simpson diversity index showed a value of H = 1.394 and D=3.199 which indicated higher magnitude of diversity of fruit fly species at Raya.

However, a total of eight (08) fruit fly species were recorded at orchard locations at FSR, Chatha wherein, seven species of *Bactocera viz*., *Bactocera dorsalis*, *B. zonata*, *B. tau*, *B. correcta*, *B. cucurbitae*, *B. diversa* and *B. scutallaris* and one species of *C. vesuviana* were recorded. Out of total 625 recorded fruit fly individuals, 250 individuals were of *B. dorsalis*, 182 individuals of *B. zonata*, 37 individuals of *B. tau*, 48 individuals of *B. correcta*, 43 individuals of *B. cucurbitae*, 28 individuals of *B. diversa*, 16 individuals of *B. scutallaris* and 21 individuals of *C. vesuviana.* Species diversity measured by Shannon Weiner's index and Simpson diversity Index showed a value of H=1.621 and D=3.806 which indicated higher magnitude of diversity of fruit fly species at FSR orchards.

At Miran Sahib during 2020, a total of four (04) fruit fly species were recorded at orchard locations at Miran Sahib which included three *Bactocera* species *viz*., *Bactocera dorsalis, B. zonata* and *B. correcta* and one species of *C. vesuviana*. Out of a total 206 recorded fruit fly individuals, 98 individuals were of *B. dorsalis*, 70 individuals of *B. zonata*, 26 individuals of *B. correcta* and 12 individuals of *C. vesuviana.* Species diversity measured by Shannon Weiner's index and Simpson diversity Index showed a value of H=1.147 and D=2.769, respectively which indicated high magnitude of diversity of fruit fly species at orchards at Miran sahib.

5.1.5 Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations during 2020

The Shannon and Simpson diversity index of fruit flies at three experimental locations *viz*., Raya, FSR and Miran sahib was calculated wherein Shannon index (H) were computed to be H=1.394, H=1.621 and H=1.147, respectively. The experimental orchards at FSR, Chatha, had highest species richness and species abundance of fruit flies whereas experimental orchards at Miran Sahib had less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.67 which indicated that all the three communities under study had a bit of overlap or similarity in terms of fruit fly species diversity.

Our results are in accordance with the results obtained by Bhagat (2014) who reported 48 species of fruit flies, belonging to 21 genera under families Drosophilidae and Tephritidae in diverse areas and localities of Jammu and Kashmir Himalayan region. The tropical fruits such as ber, citrus, guava, mango and phalsa are observed to be severely affected by *Bactrocera* complexes (*B.*) *dorsalis* and *B. zonata*in Jammu region (Rai, 2008; Tara *et al.,* 2006). In addition to this, in Kashmir region, the vegetables (bottle gourd, cucumber and other members of family Cucurbitaceae) have been found to be affected by *B.* (*B.*) *dorsalis*, *B.* (*Z.*) *scutellaris*, *B.* (*Z.*) *cucurbitae* and *B.* (*Z.*) *tau* (Bhagat, 2014; Ganie *et al.*,2013).

Pujar *et al*. (2018) recorded the maximum species diversity of 0.15 among fruit flies in gourds wherein, *Bactrocera cucurbitae* (Coquillet) was the predominant species (>95%) followed by *Dacus ciliates* (Loew) (5 per cent). Isabirye *et al*. (2015) recorded a total of 368,332 specimens of fruit flies in mango belonging to 10 species in four genera (*Bactrocera*, *Ceratitis*, *Trirhithrum* and *Dacus*) in which, 98.9 per cent belonged to *Bactrocera invadens*, while the second and third most common species were

Dacusbivittatus (0.4 per cent) and *Ceratitis anonae* (0.3 per cent), respectively. Fruit fly, *Carpomyia vesuviana* Costa is the most destructive and monopahagous pest, infests only on *Zizyphus* species causes the yield loss up to 80 per cent under severe infestation (Cherian and Sundaram, 1941; Batra 1953). The incidence of *C. vesuviana* reduces the yield from 13 to 20 per cent per plant (Bagle, 1992) and may even reach 90-100 per cent (Joshi and Shinde, 1971). *C. vesuviana* incidence increased with attainment of maturity and size of fruits (Arora *et al*., 2001). In Northern India, infestation occurs during November to April, the fly activity gets high at the time of fruit maturity and there given up to 2 to 3 generation during the active period (Batra, 1953). The slight variation in the obtained results may be due to the differences in topography, seasonal availability of suitable and preferred hosts and geographical barriers.

5.2 Study the population dynamics of fruit fly in mango, guava and peach

5.2.1 Population dynamics of fruit flies at orchard of experimental locations during 2019

During 2019, the data was recorded on the population dynamics of fruit flies at three different experimental locations and the recorded data indicated that the population of fruit flies fluctuated from 8th to 50th standard weeks at all the experimental locations. At Raya, Jammu, the commencement of fruit flies was first noticed from 8th standard week (0.50 fruit flies per trap catches). The fruit fly population, then, started to increase gradually and reached to its peak in 25th standard week (207.75 fruit flies per trap catches) and afterwards, the population declined again from 26th standard week onwards. However, during 40th standard week, a second peak of fruit fly population was noticed (238.75 fruit flies per trap catches). However, from 41st standard week onwards, the fruit fly population declined and reached to its minimum in 50th standard week (0.50 fruit flies/ trap catches). Similarly, at FSR, Chatha, the fruit fly population commenced from 8th standard week (1.50 per trap catches). From there, the population increased and reached to its peak in 25th standard week (287.25 fruit flies per trap catches). The population then began to decline till 37th standard week. But it was only in 39th standard week that second peak of fruit fly population was recorded (271.25 fruit flies per trap catches). From 40th standard week onwards, the fruit fly population declined and reached to its minimum in 50th standard week (1.25 fruit flies/ trap catches). Comparatively, the fruit fly population at Miran Sahib was not as abundant as at other two locations and incidence of fruit flies was recorded from 8th standard week (0.50 per trap catches). The population gradually increased afterwards and reached to its peak in 36th standard week (123.00 fruit flies per trap catches). Then, the fruit fly population declined steadily and reached to its minimum in 50th standard week (0.25 fruit flies/trap catches).

The correlation studies carried out during 2019 indicated that adult fruit fly population had a positive correlation with minimum and maximum temperature, non-significant positive correlation with evening relative humidity and rainfall but negative correlation with morning relative humidity at Raya and FSR. However, with regard to the fruit fly population at Miran Sahib, a non-significant positive correlation existed with maximum temperature and morning relative humidity and significant positive correlation existed with minimum temperature, evening relative humidity and rainfall.

The values of linear regression equations for population dynamics of fruit flies at Raya, FSR and Miran Sahib were calculated to be $Y=-244.239+7.938X_1-1.945X_2-1.027X_3+3.915X_4-0.340X_5$, $Y= -198.258+7.849X_1-1.851X_2-1.885X_3+4.480X_4 - 0.272X_5$ and $Y= -199.237+3.692X_1+0.184X_2-0.428X_3+1.441X_4-0.010X_5$, respectively. The equations depicted the decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) were worked out to be 0.305, 0.300 and 0.577, respectively and were found statistically non-significant at 5% level of significance. The overall impact of weather factors on population buildup of fruit flies were 30.5, 30.0, 57.7 per cent, respectively.

5.2.2 Population dynamics of fruit flies at orchard of experimental locations during 2020

The data with respect to the population dynamics of fruit flies in 2020 at three different experimental locations (RRSSS-Raya, FSR-Chatha, Miran Sahib) indicated that at Raya and FSR, the fruit fly population commenced from 8th standard week and increased afterwards and reached to its peak in 26th standard week. Again during 39th standard week, a second peak of fruit fly population was noticed at both the study areas. However, from 40th standard week onwards, the fruit fly population declined again and reached to its minimum in 50th standard week. However, the fruit fly population at Miran Sahib was not as abundant as compared to other two locations and the incidence of fruit flies was recorded from 8th standard week which gradually increased and reached to its peak in 26th standard week. Then, the fruit fly population declined till 38th standard week, but in 39th standard week, second peak of fruit fly population was recorded. The population then declined steadily and reached to its minimum in 50th standard week.

The correlation studies indicated that adult fruit fly population had a significant positive correlation with minimum and maximum temperature at all the three locations. The fruit fly population had a non-significant positive correlation with evening relative humidity and rainfall at Raya and FSR and non-significant positive correlation with rainfall and negative correlation with evening relative humidity at Miran Sahib. There was a negative correlation with morning relative humidity at all the three locations.

The values of linear regression equations for population dynamics of fruit flies at Raya, FSR and Miran Sahib were calculated to be Y^1= -326.346+2.761X_1+10.074X_2+2.818X_3 -1.304X_4-0.199X_5, Y^2= -340.362+3.062X_1+10.871X_2 +2.149X_3-0.322X_4 -0.461X_5 and Y^3= -45.328-2.863X_1+9.002X_2+1.842X_3-2.361X_4-0.090X_5, respectively. The equations signify decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) were worked out to be 0.729, 0.786 and 0.664, respectively and were found statistically significant at 5 per cent level of significance. The overall impact of weather factors on population buildup of fruit flies was 72.9, 78.6, 66.4 per cent, respectively.

The present findings are in conformity with the results obtained by Vargas *et al.* (2013) who documented two fruit fly species namely *Fopius arisanus* and *Diachasmimorpha longicaudata* belonging to family Tephritidae and order Diptera along with their spatial distribution in fruit orchards of guava in Hawaii. Khan *et al.* (2020) recorded *B. zonata*as the most abundant species both in mango and guava orchards as compared to *B. dorsalis*. They recorded highest mean number of *B. zonata* (3690.57 flies/trap) in August 2018 in guava orchard and afterwards, the population of *B. zonata* declined up to February. Moreover, they revealed a significantly positive correlation among the incidence of *B. zonata* and minimum and maximum temperatures and sunshine hours whereas relative humidity (R.H.) and rainfall were found to have a negative correlation with *B. zonata* abundance and *B. dorsalis* revealed a significant positive correlation with maximum temperature, minimum temperature, R.H. and sunshine duration which also supports our findings. The findings of Abro *et al*. (2020) wherein, theyrecorded significantly higher population of *B. dorsalis* and *B. zonata* flies per trap in the month of June and lowest population in the month of December in mango orchards, also conform our present findings. Moreover, both fruit fly species were positively correlated with the temperature while negatively correlated to relative humidity.

Apart from fruit flies, large number of parasitoids were recovered in naturally and severely infested fruits. The most abundant native parasitoid was recovered from the mango, guava and ber fruits were larval-pupal parasitoids *Diachasmimorpha longicaudata* from all the experimental sites in Jammu region. The current findings are in agreement with the results obtained by Rai and Shankar (2012) who recorded the *Diachasmimorpha longicaudata* for the first time in Jammu and Kashmir state on ber fruits. Further they also recovered it from guava and mango infested fruits with fruit flies.

5.3 Evaluation of different techniques for the management of fruit fly on mango, guava and peach

5.3.1 Evaluation of different MAT and BAT techniques for the management of fruit fly on mango in 2019

During 2019, the data collected on MAT and BAT techniques for population management of fruit flies on mango revealed that the population of fruit flies commenced from March to August (9^{th}-32^{nd} standard weeks) in ME+malathion and Banana+yeast+spinosad traps and in Fishmeal+diazinon trap. The fruit fly population then fluctuated, increasing and decreasing at various instances throughout the standard weeks and reached to its maximum in July for ME+malathion (856.42 fruit flies per trap catches) and Banana+yeast+spinosad (59.83 fruit flies per trap catches) whereas August for Fishmeal+diazinon traps (11.58 fruit flies per trap catches).

5.3.2 Evaluation of different MAT and BAT techniques for the management of fruit fly on guava in 2019

During 2019, the results on Male Annihilation Technique (MAT) and Bait Application Technique (BAT) against fruit flies on guava revealed that the fruit fly population commenced from July (27^{th} standard week). The population increased gradually and reached to its peak in October for all the three traps). Thereafter, the fruit fly population decreased and reached to its minimum in December in all the treatments The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

5.3.3 Evaluation of different MAT and BAT techniques for the management of fruit fly on Peach in 2019

The perusal of the obtained data on different treatments against peach fruit fly during 2019 revealed that the population of fruit flies was noticed from February to June (7^{th} to 26^{th} standard weeks) for all the three traps. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in the month of June for ME+malathion (51.08 fruit flies per trap catches), Banana+yeast+spinosad (14.67 fruit flies per trap catches) and Fishmeal+diazinon traps (5.17 fruit flies per trap catches). The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

5.3.4 Evaluation of different MAT techniques for the management of fruit fly on mango in 2020

During 2020, the data collected on Male Annihilation Technique (MAT) for population management of fruit flies on mango revealed that the population of fruit flies commenced from March in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in July wherein mean population of 1373.17, 757.67, and 103.67 fruit flies per trap catches were recorded for ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

5.3.5 Evaluation of different BAT techniques for the management of fruit fly on guava in 2020

During 2020, the results on evaluation of BAT technique against fruit flies revealed that the fruit fly population commenced from July in all the three treatments *viz*., ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps. The fruit fly population, then, increased gradually and reached to its peak in October for all the three traps. Thereafter, the fruit fly population decreased and reached to its minimum in in December for all the three treatments. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

5.3.6 Evaluation of different BAT techniques for the management of fruit fly on peach in 2020

During 2020, three bait trap combinations were evaluated for their efficacy against fruit flies on peach. The evaluation of fruit fly population commenced from February in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The fruit fly population then fluctuated, increasing and decreasing at various instances and reached to its maximum in the month of June for ME+malathion (55.92 fruit flies per trap catches), Banana+yeast+spinosad (15.67 fruit flies per trap catches) and Fishmeal+diazinon traps (6.58 fruit flies per trap catches). The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

Our results are in conformation with the findings of Souder (2020) who found that a binary lure system may function as a generic MAT (ME + CL) against *B. dorsalis* and *B. cucurbitae* when populations of both species are associated in a cropping area. Ekesi *et al*. (2014) after comparing the catches of *Bactrocera invadens* Drew, Tsuruta, & White (Diptera: Tephritidae) in Multi-lure traps baited with six commercial food-based attractants reported that Mazoferm E802 and Torula yeast were the most effective attractants and captured 2.4-2.6 times more females and 3.4-4.0 times more males than the standard Nulure. Lasa and Williams (2021) recorded a positive correlation between the concentration of ammonia in solution (1.5–150 mM ammonium solution) and gaseous ammonia released by bottle-type traps which resulted in an asymptotic response in captures of *A. obliqua* flies in traps that released 99–295 µg ammonia/h.

The present findings are in conformity with the results obtained by Vijaysegaran (1997); Latif *et al.* (2002); Stonehouse *et al.* (2002); Ravikumar and Viraktamath (2007); Singh and Sharma (2011) Rizk *et al.* (2014); Bhowmik (2017); Patel *et al.* (2020); Singh *et al.* (2020). All investigators have postulated that various types of techniques MAT (ME, cue lure, protein hydrolysate and BAT (permutation of combinations used for trapping fruit flies populations) were used for successful trapping of different types of fruit flies in their localities.

`Stonehouse *et al.* (2002) assessed the abundance and distribution of fruit flies (*Bactrocera zonata*, *B. cucurbitae* and *Carpomyia vesuviana*) in melon, guava, jujube and mango in farmers' fields, using male annihilation technique (MAT) on mango, and bait application technique (BAT) on melon, guava and jujube. While, Vadivelu (2014) also advocated about the integrated manner and incorporation of neem-based formulations and biological pesticide, spinosad, bait application, male annihilation technique to manage the *C. vesuviana* in a successful manner.

Apart from theses, Rizk *et al.* (2014) and demonstrated that the factors affecting the efficacy of trapping system to the peach fruit fly (PFF) males, *Bactrocera zonata* wherein, four types of traps; Bottle trap, Glass McPhail trap, Plastic McPhail trap, and Abdel-Kawi trap baited with different doses of methyl eugenol (ME) were used while, Laskar *et al.* (2016) recorded six different species of fruit flies out of nine tephritid flies by using Cue lure annihilation technique which have also been recommended by Singh *et al.* (2020). Laskar *et al.* (2016) recorded four species, viz., *B. dorsalis* (Hendel), *B. zonata* (Saunders), *B. versicolor* (Bezzi), and *B. correcta* (Bezzi), were trapped in guava orchards by using methyl eugenol traps.

5.4. Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) against major fruit flies

5.4.1 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2019

In 2019, the refinement of MAT and BAT techniques performed in different orchards of mango, guava and peach showed that commercially available traps (green valley fruit fly traps) recorded highest fruit fly trap catches on all the three fruit crops. It was followed by another commercially available traps (PCI) and the least trap catches were recorded in cue-lure+absorbent plastic wherein mean number of 88.00, 96.33 and 64.67 fruit flies per trap were recorded on mango, guava and peach, respectively.

5.4.2 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies on Mango, Guava and Peach during 2020

During 2020, Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) was refined again to trap the adults of fruit flies on mango, guava and peach and the data collected revealed that the highest trap catches were recorded in commercially available green valley fruit fly traps wherein 384.00, 381.67, 310.00 fruit flies per trap were recorded in mango, guava and peach, respectively. On the contrary, cue-lure+absorbent plastic had least effectiveness in attracting fruit flies wherein mean number of 91.33, 105.33 and 68.00 fruit flies per trap were recorded on mango, guava and peach, respectively. All the treatments were significantly different from each other.

The pooled data of two years (2019 and 2020) on the refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies revealed that commercially available green valley fruit fly traps followed by commercially available PCI traps had highest efficacy in attracting the fruit flies in all the three experimental orchards. However, cue-lure+absorbent plastic had least effectiveness in attracting fruit flies in all the study areas.

The present findings are in corroboration with the findings of Ormsby (2021) who focused on biology of fruit flies and their management by using traps and their utility to combat the infestation of fruit flies at the time of their outbreak in order to limit the setback caused to global trade of crops. Steiner (1952) brought about a major upgrade in bait composition and reported that bait infused with protein hydrolysate accompanied with insecticide and sugar can act as an effective control strategy for Bactrocera dorsalis or oriental fruit fly. In tropical areas, protein bait act as powerful controlling strategy for fruit flies. The principle of this method is that female fruit flies require a source of protein for increased oviposition. Vargas *et al*. (2008) reported that bait technique to control fruit flies (wherein protein hydrolysate is the principal compound and malathion is the insecticide) has been used to combat fruit fly infestation over the years. The backbone of bait development and use against fruit flies arose after the knowledge on ill effects of organophosphorus insecticides on non-target organisms including human beings and also the adverse effects of these insecticides on environment. Novel bait formulations including protein hydrolysate (from maize) were prepared and they were used in combination with naturally occurring insecticides like spinosad and this combination proved to be highly effective against fruit flies (Moreno and Mangan, 2002; Peck and McQuate, 2000; Vargas *et al*., 2001). GF-120 or NF Naturalyte was used to combat fruit fly populations which was a preparation made from mixing protein, sugar, spinosad and ammonium acetate (Corteva Agriscience, Indianapolis, IN, USA). Modifying bait colour is another possible avenue for improving the attraction of fruit fly baits. The location of mates, oviposition sites, food and many other aspects of insect behaviour are guided by visual cues (Giurfa and Menzel, 1997). Wazir *et al*. (2019) reported that green victory methyl eugenol (ME) fruit fly trap showed the best performance in capturing adult fruit fly population and among innovative traps, low-cost mineral bottle trap (ME + wooden block + spinosad) was found superior.

Chapter-VI

Summary and Conclusion

CHAPTER-VI

SUMMARY AND CONCLUSION

The results of the present investigation on **'Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics'** are summarized in this chapter.

The broad objectives of present studies were as follows:

1. To study the diversity of fruit flies in Jammu Sub-tropics
2. To study the population dynamics of fruit fly in mango, guava and peach
3. Evaluation of different techniques for the management of fruit fly on mango, guava and peach
4. Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies

6.1 Study the diversity of fruit flies in Jammu Sub-tropics

6.1.1 Survey on diversity of fruit flies in Jammu Sub-tropics

The survey was conducted for two consecutive years (2019 and 2020) at three locations *viz.*, RRSSS, Raya; FSR, Chatha and Govt. Orchard, Miran Sahib to assess the diversity of fruit flies on cultivated fruits and vegetable crops and their interaction for food sources on other wild host plants in different ecosystems of Jammu sub-tropics. Each location was further categorized with different host plants such as mango, Guava and peach orchards into sub-locations for collecting and recording the existing fruit fly diversity in Jammu sub-tropics. Different species of *Bactocera*, *Carpomyia* and *Dacus* fruit flies were collected from mango, guava and peach host plants and were brought to the laboratory for the further identification of up to species level. During 2019, five fruit fly species were recorded at study orchards in Raya while as six (06) and three (03) *Bactocera* species were recorded at orchard locations at FSR, Chatha and Miran Sahib, respectively. During 2020, a total of six (06), eight (08) and four (04) fruit fly species were recorded at experimental orchards in Raya, FSR, Chatha and Miran Sahib, respectively.

6.1.2 Comparison of biodiversity indices and community similarity of fruit flies located at experimental locations

During 2019, the Shannon index (H) for fruit flies at Raya, FSR and Miran sahib were computed to be H=0.554, H=0.659 and H=0.448, respectively which revealed that the experimental orchards at FSR, Chatha had highest diversity of fruit flies in terms of species richness and species abundance whereas experimental orchards at Miran Sahib has less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.642 which indicated that all the three communities had a bit of overlap or similarity in terms of fruit fly species diversity. However, during 2020, the Shannon index (H) were computed to be H=1.394, H=1.621 and H=1.147 for species at Raya, FSR and Miran Sahib, respectively. The experimental orchards at FSR, Chatha, had highest species richness and species abundance of fruit flies whereas experimental orchards at Miran Sahib had less diversity of fruit flies. The Sorenson's evenness coefficient (CC) was computed to be 0.67 which indicated that all the three communities under study had a bit of overlap or similarity in terms of fruit fly species diversity.

6.2 Population dynamics of fruit fly in mango, guava and peach

During 2019, the population of fruit flies fluctuated from 8th to 50th standard weeks at all the experimental locations. At Raya and FSR, Jammu, the commencement of fruit flies was first noticed from 8th standard week and reached to its peak in 25th standard week and the population declined afterwards. However, a second peak of fruit fly population was observed during 40th and 39th standard week at Raya and FSR, respectively. Comparatively, the fruit fly population at Miran Sahib was not as abundant as at other two locations and incidence of fruit flies was recorded from 8th standard week and the population gradually increased afterwards and reached to its peak in 36th standard week. During 2020, the fruit fly population commenced from 8th standard week at Raya and FSR and increased afterwards and reached to its peak in 26th standard week. Again during 39th standard week, a second peak of fruit fly population was noticed at both the study areas. The fruit fly population at Miran Sahib was recorded from 8th standard week which reached to its peak in 26th standard week and then again in 39th standard week. The fruit fly population reached to its minimum in 50th standard week during both the years.

6.2.1 Correlation studies

The correlation studies carried out during 2019 indicated that adult fruit fly population had a positive correlation with minimum and maximum temperature, non-significant positive correlation with evening relative humidity and rainfall but negative correlation with morning relative humidity at Raya and FSR. However, with regard to the fruit fly population at Miran Sahib, a non-significant positive correlation existed with maximum temperature and morning relative humidity and significant positive correlation existed with minimum temperature, evening relative humidity and rainfall. During 2020, the correlation studies indicated that adult fruit fly population had a significant positive correlation with minimum and maximum temperature at all the three locations. The fruit fly population had a non-significant positive correlation with evening relative humidity and rainfall at Raya and FSR and non-significant positive correlation with rainfall and negative correlation with evening relative humidity at Miran Sahib. There was a negative correlation with morning relative humidity at all the three locations.

6.2.2 Regression studies

During 2019, the values of linear regression equations for population dynamics of fruit flies at Raya, FSR and Miran Sahib were calculated to be $Y= -244.239+7.938X_1-1.945X_2-1.027X_3+3.915X_4-0.340X_5$, $Y= -198.258+7.849X_1-1.851X_2-1.885X_3+4.480X_4-0.272X_5$ and $Y= -199.237+3.692X_1+0.184X_2-0.428X_3+1.441X_4-0.010X_5$, respectively. However, in 2020, the values of linear regression equations at Raya, FSR and Miran Sahib were calculated to be $Y^1= -326.346+2.761X_1+10.074X_2+2.818X_3-1.304X_4-0.199X_5$, $Y^2= -340.362+3.062X_1+10.871X_2+2.149X_3-0.322X_4-0.461X_5$ and $Y^3= -45.328-2.863X_1+9.002X_2+1.842X_3-2.361X_4-0.090X_5$, respectively. The equations signify decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) obtained were found statistically significant at 5 per cent level of significance.

6.3 Evaluation of different techniques for the management of fruit fly on mango, guava and peach

6.3.1 Evaluation of different MAT and BAT techniques for the management of fruit fly on mango in 2019

During 2019, the data collected on MAT and BAT techniques for population management of fruit flies on mango revealed that the population of fruit flies commenced from March to August (9^{th} to 32^{nd} standard weeks) in ME+malathion and Banana+yeast+spinosad traps and in Fishmeal+diazinon trap. The fruit fly population then fluctuated, increasing and decreasing at various instances throughout the standard weeks and reached to its maximum in July for ME+malathion (856.42 fruit flies per trap catches) and Banana+yeast+spinosad (59.83 fruit flies per trap catches) whereas, August for Fishmeal+diazinon traps (11.58 fruit flies per trap catches). During 2020, the population of fruit flies reached to its maximum in July wherein mean population of 1373.17, 757.67, and 103.67 fruit flies per trap catches were recorded for ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps, respectively. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

6.3.2 Evaluation of different MAT and BAT techniques for the management of fruit fly on guava

During 2019, the results on Male Annihilation Technique (MAT) and Bait Application Technique (BAT) against fruit flies on guava revealed that the fruit fly population commenced from July (27^{th} standard week). The population increased gradually and reached to its peak in October for all the three traps). Whereas, during 2020, the fruit fly population commenced from July in all the three treatments *viz*., ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps and reached to its peak in October (314.83, 53.25 and 34.00, respectively) for all the three traps. Thereafter, the fruit fly population decreased and reached to its minimum in in December for all the three treatments. The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

6.3.3 Evaluation of different MAT and BAT techniques for the management of fruit fly on Peach

The perusal of the obtained data on different treatments against peach fruit fly during 2019 revealed that the population of fruit flies was noticed from February to June (7^{th}-26^{th} standard weeks) for all the three traps. The fruit fly population reached to its maximum in the month of June for ME+malathion (51.08 fruit flies per trap catches), Banana+yeast+spinosad (14.67 fruit flies per trap catches) and Fishmeal+diazinon traps (5.17 fruit flies per trap catches). While, during 2020, the fruit fly population commenced from February and reached to its maximum in the month of June for ME+malathion (55.92 fruit flies per trap catches), Banana+yeast+spinosad (15.67 fruit flies per trap catches) and Fishmeal+diazinon traps (6.58 fruit flies per trap catches). The results revealed that the fruit fly trap catches in all the three treatments were significantly different from each other.

6.4 Refinement of Male Annihilation Technique (MAT) and Bait Attractant Technique (BAT) for fruit flies

During 2019 and 2020, the refinement of MAT and BAT techniques in different orchards of peach, mango and guava inferred that commercially available traps (green valley fruit fly traps) followed by another commercially available traps (PCI traps) recorded highest number of fruit flies in all the study orchards. However, cue-lure+absorbent plastic traps recorded least number of fruit fly trap catches.

The conclusion drawn during present investigation is summarized below-

- Different species of *Bactocera*, and *Dacus* along with *Carpomyia* fruit flies were collected from mango, guava and peach host plants.
- During 2019, five (05) fruit fly species were recorded at study orchards in Raya while, six (06) and three (03) *Bactocera* species were recorded at orchard locations at FSR, Chatha and Miran Sahib, respectively. During 2020, a total of six (06), eight (08) and four (04) fruit fly species were recorded at experimental orchards in RRSSS-Raya, FSR-Chatha and Govt. orchard Miran Sahib, respectively.
- A total of 217, 236 and 101 fruit fly individuals were recorded at Raya, FSR and Miran Sahib in 2019, respectively. However, in 2020, a total of 333, 625 and 206 fruit fly individuals were recorded during June month for diversity analysis at Raya, FSR and Miran Sahib, respectively.
- The experimental orchards at FSR, Chatha had highest diversity of fruit flies in terms of species richness and species abundance whereas, experimental orchards at Miran Sahib had less diversity of fruit flies. The Sorenson's evenness coefficient indicated that all the three localities had a bit of overlap or similarity in terms of fruit fly species diversity.
- The population of fruit flies at three different experimental locations fluctuated from 8th to 50th standard weeks at all the experimental locations. The peak fruit fly

population were recorded in 25th standard week with a second peak during 40th and 39th standard week at Raya and FSR, respectively while, the peak population was observed in 36th standard week at Miran Sahib during 2019.

- During 2020, the fruit fly population reached to its peak in 26th standard week with a second peak during 39th standard week at Raya and FSR. However, the fruit fly population at Miran Sahib peaked in 26th standard week and then again in 39th standard week.
- The adult fruit fly population was positively correlated with minimum and maximum temperature, evening relative humidity and rainfall but negatively correlation with morning relative humidity at Raya and FSR. However, at Miran Sahib, a positive correlation existed with maximum and minimum temperature, morning relative humidity, minimum temperature, evening relative humidity and rainfall during 2019.
- During 2020, the adult fruit fly population had a significant positive correlation with minimum and maximum temperature at all the three locations. The fruit fly population had a non-significant positive correlation with evening relative humidity and rainfall at Raya and FSR and non-significant positive correlation with rainfall and negative correlation with evening relative humidity at Miran Sahib. There was a negative correlation with morning relative humidity at all the three locations.
- The calculated regression equations signified decreasing trend of fruit fly population at all the three experimental sites due to gradual increase in temperature, preferably up to a certain extent. The corresponding correlation co-efficient of multiple determination (R^2) obtained were found statistically significant at 5 per cent level of significance.
- Experimentation on evaluation of different MAT and BAT technique during 2019, the population of fruit flies in mango commenced from March in ME+malathion and Banana+yeast+spinosad and Fishmeal+diazinon trap and reached to its maximum in July for ME+malathion and Banana+yeast+spinosad and in August in Fishmeal+diazinon traps. During 2020, similar trend was noticed and recorded maximum trap catches in July with significantly superior catches with ME+malathion.

- Evaluation of different MAT and BAT technique on guava during both the years showed the similar trend of maximum fruit fly trap catches in the month of October. While in case of Peach, the maximum fruit flies catches were recorded during June months for both the years of experimentation.
- While standardizing the refinement in existing MAT and BAT techniques, the fruit fly population in guava commenced from 34^{th} standard week in ME+malathion, Banana+yeast+spinosad and Fishmeal+diazinon traps and reached to its peak in 39^{th} standard week for ME+malathion, 40^{th} standard week for Banana+yeast+spinosad and Fishmeal+diazinon traps during 2019. A second peak of fruit fly population was noticed in 43^{rd} standard week for ME+malathion trap and 44^{th} standard week for Banana+yeast+spinosad and Fishmeal+diazinon traps.
- During 2020, the fruit fly population in guava commenced from 34^{th} standard week from where it increased gradually and reached to its peak in 34^{th} standard week for all the three traps. The fruit fly population reached to its minimum in 50^{th} standard week for all the three treatments during both the years.
- The Pooled analysis of both the years of experimentation, the highest trap catches were recorded in commercially available green valley fruit fly traps on all the three fruit crops (mango, guava and peach) followed by another commercially available traps (PCI) and the least trap catches were recorded in cue-lure+absorbent plastic.

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CERTIFICATE-IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled "**Studies on fruit fly diversity and their management on important fruit crops of Jammu Sub-tropics**", submitted by **Mr. Gaurav Bhagat**, Registration No. **J-16-D-274-A.**

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