Population Dynamics and Management of Mango Fruit Fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Population Dynamics and Management of Mango Fruit Fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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my guide

and

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@	at the rate of
°C	Degree Celsius
%	Per cent
ANOVA	Analysis of variance
ai	Active ingredient
am	Ante meridiem
BAT	Bait application technique
CD	Critical difference
cm	Centimeter
DDT	Dichlorodiphenyltrichloroethane
DAI	Days after inoculation
DAT	Days after treatment
d	Day
EC	Emulsifiable concentrate
EPF	Entomopathogenic fungi
EPN	Entomopathogenic nematodes
et al.	and other co workers
Fig.	Figure
g	Gram
h.	Hours
ha.	Hectare
IJs	Infective juveniles
IPM	Integrated pest management
ITCC	The Indian Type Culture Collection
i.e.	that is
Kg	Kilo gram
Km	Kilo metre

LT_{50}	Lethal time taken for killing 50 per cent of test insect.
l.	Litre
MAT	Male annihilation technique
m	Metre
mg	Milligram
mha	Million hectares
min	Minutes
ml^{-1}	per millilitre
ml	Millilitre
mm	Millimeter
mt	Million tones
NS	Not significant
NSKE	Neem seed kernel extract
No.	Number
pm	Post meridiem
ppm	Parts per million
Rs.	Rupees
SPLAT	Specialised pheromone and lure application technology
Sec	Seconds
Sl No.	Serial number
sp. or spp.	Species (Singular and plural)
TSS	Total soluble solids
viz.	Namely
WP	Wettable powder

INTRODUCTION

1. INTRODUCTION

Mango (*Mangifera indica* L.), the national fruit of India, popularly known as the 'King of Fruits' belonging to family Anacardiaceae is one of the most popular tropical fruits in the world (Majumdar and Sharma, 1990; Scherrer, 2007). It is a major fruit crop with high potential for exports. India ranks first in world production accounting for about 50 per cent of the world's mango production (FAOSTAT, 2011). According to the National horticultural database (2013), area under cultivation of mango is 2.5 mha with an annual production of 18 mt having an average productivity of 7.2 tonnes.

The optimum production of mango is limited by many insect pests which are responsible for the low yield and poor quality of fruits. About 250 insects and mite pests have been reported on mango from the Indian subcontinent. Out of these, 30 pests are economically important, capable of causing considerable loss to crop growth and yield (Tandon and Verghese, 1985). Among these, the most destructive and devastating pest is the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae). It affects both quantity and quality of mango fruits and can be considered as a major constraint to mango export. Abdullah *et al.* (2002) reported a pre and post harvest yield loss of 27 – 80 per cent in mango. Hence, it is regarded as a pest of quarantine importance.

Mango growers rely on chemical control measures for successful management of fruit flies including cover sprays, bait sprays, etc. with organophosphate insecticides like malathion as toxicant. According to Rahiman *et al.* (1986) indiscriminate and injudicious application of pesticides creates environmental pollution and pesticide residue problems. Therefore the present situation warrants an eco-friendly pest management strategy. Bait application technique (BAT) using food

baits and male annihilation technique (MAT) using methyl eugenol as attractant are considered as ecofriendly and safe management measures for fruit flies. Currently, malathion is being used as the only insecticide in BAT and MAT (KAU, 2011; Stonehouse *et al.,* 2005). Govt. of Kerala has also decided to declare the state as 'Organic' in 2016. In this context, use of malathion, a conventional organophosphate in BAT and MAT may create great concern. Hence, the use of botanicals, biocontrol agents and safer new generation insecticides in BAT and MAT is required. Newer chemicals are more target specific and required in smaller quantities. Identifying newer chemicals that are safe and effective will help to reduce pesticide load in the environment and can be used in organic farming.

It is necessary to have basic information on the incidence of the pest in relation to weather parameters before developing integrated pest management programme for a specific agro-ecosystem. This helps in determining appropriate time of action and suitable methods of management. Studies on the population build up of the pest are essential for its successful management.

Considering the above perspectives, the present study entitled "Population dynamics and management of mango fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)" was undertaken with following objectives.

- To conduct a preliminary survey of different homesteads and also Instructional Farm, Vellayani to gather information on pest incidence and host range of mango fruit fly, *B. dorsalis*.
- To study the population dynamics of mango fruit fly in relation with abiotic factors.
- To standardize the use of alternate chemicals in bait application technique and male annihilation technique for the management of *B. dorsalis*.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Oriental fruit fly, *Bactrocera dorsalis* (Hendel) has been considered as one of the most important agricultural pests in Southeast Asia (McPheron and Steck, 1996). The present work aims at the study of population dynamics of mango fruit fly and the laboratory and field evaluation of bait application technique (BAT) and male annihilation technique (MAT) using new generation insecticides. The relevant studies related to population dynamics and integrated management of mango fruit fly giving special emphasis to bait traps and pheromone traps are reviewed here.

2.1. ORIGIN AND DISTRIBUTION

The mango fruit fly, *B. dorsalis*, a polyphagous pest belonging to family Tephritidae was originally described as *Musca ferruginea* (Fabricius) (Fabricius, 1794). However, the name was preoccupied and became invalid. Hendel (1912) redescribed it as *Dacus dorsalis* (Hendel), based on the materials collected from Taiwan. Subsequently, Bezzi (1913; 1916) described *Chaetodacus ferrugineus* var. *pedestris* (Bezzi) from Los Banos in the Philippines and *C. ferrugineus* var. *occipitalis* (Bezzi) from Manila, in the Philippines, respectively. These two taxa were later described as synonyms of *D. dorsalis* or as distinct species. White and Hancock (1997) redescribed the specimens with a long ovipositor as *Dacus pedestris* (Bezzi) while specimens with short ovipositor as *D. dorsalis*. However, much later it was suspected that the Oriental fruit fly was more than just a single species.

Extensive studies on the incidence and distribution of fruit flies throughout South Asia was done by Kapoor *et al.* (1976) and Agarwal and Kapoor (1985). It was first recorded in Taiwan in 1907 (Lee, 1988). Now, this species is distributed throughout the Asia-Pacific Region (Clarke *et al*., 2005: Hsu, 1973; Ye, 2001). As *B. dorsalis* is widely distributed in the Oriental region from Australia and Hawaii to Pakistan it is called as Oriental fruit fly (Kapoor, 2005).

2.2 SPECIES COMPLEX

Bezzi (1914) was the first to describe four species of the Oriental fruit fly complex. The first serious attempt to resolve the confusion was made by Hardy (1969). He included sixteen species as closely related to *B. dorsalis* in this complex and also discussed the nomenclature of *B. dorsalis*. Drew (1989) and Drew and Hancock (1994) extensively revised, redefined and expanded the complex. They revised the Oriental fruit fly complex in Asia with fifty two species. Clarke *et al.* (2005) reported that seven species of the complex are considered to be economic importance with a wide host range. It includes *Bactrocera carambolae* Drew and Hancock, *Bactrocera caryeae* (Kapoor), *B. dorsalis*, *Bactrocera kandiensis* Drew and Hancock, *Bactrocera occipitalis* (Bezzi), *Bactrocera papayae* (Drew and Hancock) and *Bactrocera philippinensis* (Drew and Hancock).

B. dorsalis species complex now includes 76 species with seven species of the complex, *viz., B. caryeae*, *B. dorsalis*, *Bactrocera invadens* Drew, Tsuruta and White, *Bactrocera melastomatos* (Drew and Hancock), *Bactracera paraverbascifoliae* Drew, *Bactrocera verbascifoliae* Drew and Hancock and *Bactrocera vishnu* Drew and Hancock are recognized from India (Sithanantham *et al*., 2006). Oriental fruit fly complex have similar morphological characteristics but with different host plant ranges (Chen and Ye, 2007; Xiong *et al*. 2011).

2.3 HOST RANGE

Fruit flies possess a very wide host range due to their highly polyphagous nature and high dispersing ability. The Oriental fruit fly, *B. dorsalis* is a destructive polyphagous pest on wild and cultivated fruit crops. They are able to infest more than 300 host plants belonging to 40 families including many types of commercial fruit crops such as mango, guava, papaya, peach, plum and citrus (Kapoor, 1993). Host range varied between different regions. *B. dorsalis* mainly fed on breadfruit,

avocado, Tahitian chestnut and golden apple in North Mariana Islands in Pacific. In Asia, it preferred banana, citrus, peach, tomato, plum, loquat, guava, papaya, sweetsop and rambutan (Clarke *et al*, 2005). Each species within the Oriental fruit fly complex has a much more specific host range.

B. dorsalis was also recorded from the weed, *Solanicum indicum* L. (Agarwal, 1985). Allwood *et al.* (1999) reported the revised host range of *B. dorsalis* after the description of oriental fruit fly complex (Table 1). Host range of *B. dorsalis* was reduced to 117 species, belonging to 76 genera and 39 families.

Table 1. Host plants of *B. dorsalis*

Family	**Host**
ALANGIACEAE	*Alangium chinense* Lour. *Alangium salviifolium* Wangerin
ANACARDIACEAE	*Anacardium occidentale* Linn. *Bouea macrophylla* Griff. *Bouea oppositifolia* (Roxb.) Meisn *Mangifera caloneura* Kurz. *Mangifera foetida* Lour. *Mangifera indica* Linn. *Mangifera longipetiolata* King *Spondias cytherea* Sonn. *Spondias pinnata* Kurz.
ANNONACEAE	*Annona reticulata* Linn. *Annona squamosa* Linn. *Mitrephora maingayi* Hook and Thompson *Polyalthia longifolia* Sonn. *Polyalthia simiarum* Baillon *Uvaria macrophylla* Roxb.

APOCYNACEAE	*Carissa cochinchinensis* Pierre
ARECACEAE	*Areca catechu* (Linn.)
BURSERACEAE	*Garuga floribunda* Decne.
CAPPARACEAE	*Capparis sepiaria* Linn.
CAPRIFOLIACEAE	*Sambucus javanica* Blume
CARICACEAE	*Carica papaya* Linn.
CELASTRACEAE	*Siphonodon* sp.
CHRYSOBALANACEAE	*Parinari anamense* Hance
CLUSIACEAE	*Garcinia cowa* Roxb. *Garcinia speciosa* Wall. *Garcinia xanthochymus* Roxb. *Mammea siamensis* Anders
COMBRETACEAE	*Terminalia catappa* Linn.
CONVOLVULACEAE	*Erycibe subspicata* Wall. *Merremia vitifolia* (Burms) Hallier
CUCURBITACEAE	*Coccinia grandis* (Linn.) *Cucumis melo* Linn. *Cucumis sativus* Linn. *Melothria wallichii* Clarke *Momordica charantia* Linn. *Trichosanthes ovigera* Blume
EBENACEAE	*Diospyros castanea* (Craib) *Diospyros glandulosa* (Lace.) *Diospyros kaki* Thunb.

	Diospyros mollis Griff.
ELAEOCARPACEAE	*Elaeocarpus hygrophilus* Kurz *Elaeocarpus madopetalus* Pierre *Muntingia calabura* Linn.
EUPHORBIACEAE	*Aporusa villosa* (Lindl.) *Baccaurea racemosa* (Blume) *Baccaurea ramiflora* Lour. *Bridelia stipularis* (Linn.) Blume *Sapium baccatum* Roxb. *Securinega virosa* Roxb.
FABACEAE	*Afzelia xylocarpa* (Kurz.) Craib *Parkia speciosa* Hassk
FLACOURTIACEAE	*Flacourtia indica* (Burm.)
LAURACEAE	*Litsea salicifolia* (Roxb.)
LECYTHIDACEAE	*Careya arborea* Roxb. *Careya sphaerica* Roxb.
MALPIGHIACEAE	*Malpighia emarginata* DC.
MELIACEAE	*Chukrasia venlutina* M. Roem. *Lansium domesticum* Corr. *Sandoricum koetjape* Merr. *Walsura intermedia* Craib
MORACEAE	*Artocarpus altilis* (Parkinson) Foxberg *Artocarpus heterophyllus* Lam. *Artocarpus lanceifolius* Roxb.

	Artocarpus lanceolatus Merr. *Ficus fistulosa* Blume *Ficus hirta* Vahl. *Ficus racemosa* Linn. *Madura cochinchinensis* (Lour.)
MUSACEAE	*Musa acuminata* Colla. *Musa x paradisiaca* Linn.
MYRTACEAE	*Eugenia megacarpa* (Craib) *Eugenia paniala* Roxb. *Eugenia pseudosubtilis* King *Psidium guajava* (Linn.) *Psidium guajava* var. *cujavillum* Linn. *Syzygium aqueum* (Burm.) Alston *Syzygium cumini* (Linn.) *Syzygium jambos* Alston *Syzygium malaccense* Merr. *Syzygium samarangense* Merr. and Perry
OLACACEAE	*Olax scandens* Roxb. *Schoepfia fragrans* Wall.
OLEACEAE	*Myxopyrum smilacifolium* (Wall.)
OXALIDACEAE	*Averrhoa carambola* Linn.
POLYGALACEAE	*Xanthophyllum flavescens* Roxb.
RHAMNACEAE	*Ziziphus jujuba* Mill. *Ziziphus mauritiana* Lamk.

	Ziziphus oenoplia Mill. *Ziziphus rotundifolia* Lamk.
ROSACEAE	*Malus pumila* Mill. *Prunus avium* (Linn.) *Prunus cerasoides* D. Don *Prunus cerasus* Linn. *Prunus domestica* Linn. *Prunus mume* Beni-Chidori *Prunus persica* Linn. *Pyrus pyrifolia* (Burm.) Nakai
RUBIACEAE	*Coffea Arabica* Linn.
RUTACEAE	*Aegle marmelos* (Linn.) Corr. *Citrus aurantifolia* (Cristm) Swingle *Citrus grandis* (Linn.) Osbeck *Citrus reticulate* Swingle
SAPINDACEAE	*Dimocarpus longan* Lour. *Lepisanthes fruticosa* (Roxb.) Leenh. *Lepisanthes tetraphylla* (Vahl.) Radlk. *Litchi chinensis* Sonn. *Nephelium lappaceum* Linn.
SAPOTACEAE	*Chrysophyllum cainito* Linn. *Manilkara zapota* Linn. *Mimusops elengi* Linn. *Palaquium* sp. *Planchonella* sp.
SIMAROUBACEAE	*Irvingia malayana* Oliv.

SOLANACEAE	*Capsicum annuum* Linn. *Solanum trilobatum* Linn.

2.4 EXTENT OF LOSS

Fruit flies are the most devastating insect pests having a foremost influence on global agricultural products, effecting yield losses and dropping the value and marketability of horticultural crops. The incidence of fruit fly, not only reduces the yield and quality but also cause considerable economic loss. Mumford (2001) and Mishra *et al.* (2012) reported a crop loss of upto Rs. 2945 crores per annum in mango, guava, sapota and citrus in India. The yield loss due to fruit flies varies between 30-100 per cent depending on the fruit species and season (Dhillon *et al.,* 2005).

Economic significance of fruit flies in India was reported by Verghese *et al.* (2002), causing a yield loss of 2.5 to 59.0 per cent depending on the variety. They reported that the crop loss due to *B. dorsalis* varies with season and region. They observed higher percentage infestation on varieties Banganapalli and Totapuri with mean infestation of 46.0 and 59.0 %, respectively and least infestation on varieties Dushehari and Langra.

The extent of damage may go upto 80 per cent when the pest incidence occurs in an epidemic form (Abdullah *et al.*, 2002). The extent of damage caused to guava was upto 44 per cent as reported by Stonehouse *et al.* (2005). It also caused an indirect loss by affecting the export market due to strict quarantine restrictions of importing nations (Serem, 2010). The economic losses reported by various workers are given in Table 2.

Table 2. Extent of crop loss caused by *B. dorsalis*

Host	Crop loss (%)	Reference
Mango	27	Kumar *et al.,* 1994
Mango	31-86	Mann, 1996
Guava	60-80	Jalaluddin *et al.,* 1999
Guava	19-42	Arora *et al.,* 1998
Guava	5-70	Verghese *et al.,* 2002

2.5 BIOLOGY OF MANGO FRUIT FLY

The life cycle of mango fruit fly consists of three distinct larval instars. Larvae have got a characteristic jumping pattern of movement which serves as a defense mechanism. Adults generally mate at dusk (Christenson and Foote, 1960).

2.5.1 Egg

The females of adult *B. dorsalis* lays eggs in batches beneath the skin of the ripened or ripening host fruits 5-10 days after mating using her needle like ovipositor. A female can lay 10–30 eggs during each oviposition and can lay more than 1200 eggs during its lifespan. Egg is creamy white, spindle-shaped and measures 1mm in length. Eggs hatch within 3-10 days to produce larvae (Steiner, 1957).

2.5.2 Larvae

Larva is a creamy white maggot that caused damage to fruits by tunneling and feeding on pulpy content of the fruits. There are three larval stages known as larval instars in the life cycle of fruit flies. Larval period ranged from 10-14 days (Fletcher, 1987).

2.5.3 Pupae

Upon completion of larval feeding, the late third instar larvae measuring about 10 mm long and 2 mm wide leave the fruit and fall into the ground by making emergence hole and enter the 'wandering phase' during which larvae locate pupation sites (Zdarek and Denlinger, 1991).

After a very brief dispersal period the third instar larvae burrow into the soil and pupate inside a puparium at a depth of 6 cm (Fletcher, 1987). This transition from feeding to wandering occured when the larva attained a critical nutritional or developmental status (Denlinger and Zdarek, 1994).

2.5.4 Adult

After 8-10 days, adult flies emerge from the puparium and dig their way out of soil or debris. Adults fed on the host plants to obtain nutrient materials from nectar, dew and fruit. By feeding on the host plants, the flies attain sexual maturity within 10-20 days and mate together to start a new cycle of damage (Peng *et al.,* 2006).

2.5.5 Total developmental period

Total life cycle ranged about 1-2 months. Being facultative breeders and having short life cycle, fruit flies are multivoltine in nature having more than one generation per year (Narayanan and Batra, 1960). *B. dorsalis* can complete 3-5 generations per year. But it completed 5-10 generations in a year in tropical areas and less than 4 in subtropical areas and these generations of *B. dorsalis* show considerable overlap (Ye and Liu, 2005).

2.6 POPULATION DYNAMICS

The population buildup of any insect is very intimately associated with the weather parameters prevailing during preceding and corresponding periods. The pest status does not remain static throughout the year. It changes based on abiotic factors like temperature, relative humidity, rainfall, rainy days, sunshine hours, etc. (Wallner, 1987). The fruit fly activity varied depending mostly on the prevailing climatic conditions and the diversity of other hosts in a particular agro-ecosystem. It is relevant to study the seasonal abundance pattern and the abiotic factors on fruit fly activity for development and proper implementation of fruit fly management programmes. In addition to this, availability of suitable host plants also played a significant role in regulating the fruit fly population (Papadopoulos *et al*., 2001). Lv *et al.* (2008) reported that annual fluctuations within optimum levels of environmental variables act as limiting factors for population establishment and persistence of tephritid species. Studies to understand the role of weather factors in influencing fruit fly incidence are required (Boopathi *et al.,* 2013).

2.6.1 Influence of Host Plants on Population of Mango Fruit Fly

Fruit abundance and availability were the main factors for population build up of fruit flies in tropics (Vargas *et al.,* 1983). Chiu and Chu (1986) indicated a positive relationship between peak fruit fly population and period of ripening of fruit in Taiwan. Tan and Muney (1994) concluded a positive correlation between methyl eugenol trap catches and host fruit availability. *B. dorsalis* is a polyphagous pest with a wide host range. The principal host fruits of *B. dorsalis* include mango, peach, guava, papaya, citrus, lemon, pear, carambola and orange. These host plants form a rich source of food for the fruit fly. Fruiting periods of different host plants alternately make up a host successive spectrum for the occurrence of *B. dorsalis* throughout the year. The population of *B. dorsalis* started building up from April and attained a peak in May-June which coincided with the peak period for the infestation

as reported by Chen *et al.* (2006) and Lutap *et al*. (2009). It continued upto October on different fruit crops and then declined due to unavailability of host fruits (Mahmood and Mishkatullah, 2007). The peak capture of the adult flies was mostly consistent with the fruiting period of hosts, indicated that these hosts have an influence in determining the fly population. This interpretation is sustained by the observations made by Patel *et al.* (2013) that the highest fruit fly infestation occurred from April to July during 2009-10 and 2010-11, which coincided with fruiting and harvesting periods of mango fruit.

The fruiting periods of suitable host were one of the major factors that contributed to the peak population of *B. dorsalis* (He *et al.,* 2002). When the fruiting periods of one host ends, *B. dorsalis* begins to infest other suitable host plants (Chen *et al.,* 2006). However, the population of the fly was influenced by the most suitable host. Along with this, environmental factors also influence the population fluctuations of the fly.

2.6.2 Influence of Temperature on Population of Mango Fruit Fly

Temperature significantly influenced the development and population activities of the fruit fly population in all stages of life (Bateman, 1972). According to Aliniazee (1976), peak emergence of *B. dorsalis* coincided with a maximum temperature range of 28-33^{0}C. The population of the *B. dorsalis* declined in winter due to low temperature and started build up in summer (Vargas *et al.,* 1983; Ye and Liu, 2005a). Studies conducted by Bagle and Prasad (1983) revealed the crucial role played by temperature in determining the fruit fly activity. The temperature for development and reproduction of *B. dorsalis* ranged from 15^{0}C to 34^{0}C, and the optimum temperature ranged from 18^{0}C to 30^{0}C. When the temperature was beyond 34^{0}C or below 15^{0}C, a large number of adults and larvae of the fly died. When the temperature was below 18^{0}C, growth periods of the eggs, larvae and pupae were

prolonged whereas the emergence rate of new adults was decreased (Xiao *et al.,* 2001). Kannan and Rao (2006) found that maximum and minimum temperatures were positively correlated with fruit fly population. Mahmood and Mishkatullah (2007) observed that number of flies caught in traps increased gradually and peak population (141 flies) was recorded in May with mean temperature 29.11°C and the lowest population (0 flies) was in January with mean temperature 9.87°C. Nandre and Shukla (2014) recorded the maximum activity of flies (172.1 flies per trap) during March to August with a maximum temperature range of 30 to 40 ^{o}C.

2.6.3 Influence of Relative Humidity on Population of Mango Fruit Fly

According to Shukla and Prasad (1985), fruit fly population was inversely related to rainfall. Kannan and Rao (2006) were also of the opinion that incidence of fruit flies was negatively correlated with relative humidity. But studies conducted by Rajitha and Viraktamath (2006) and Patel *et al.* (2013) contradicted the findings and they reported a positive relationship between fruit fly population and relative humidity. Agarwal and Kumar (2005) found that minimum relative humidity had significant positive correlation, while maximum relative humidity had negative interaction with fruit fly population in mango. This finding was also supported by Nandre and Shukla (2014).

2.6.4 Influence of Rainfall on Population of Mango Fruit Fly

The rainfall frequency influences soil moisture and was favourable for pupation and eclosion of *B. dorsalis* (Hsu, 1973). The positive impact of rainfall on the fruit fly incidence was studied by Su (1984). Mahmood *et al.* (2002) reported a significant correlation between rainfall and fly activity. Monthly rainy days was the major decision factor affecting the population and its force of integrated effects was the strongest of all the other climatic factors (Chen *et al.,* 2006). It played a crucial role in influencing the population fluctuations of *B. dorsalis.* During warm and rainy

months, the flies were more active than in winter (Laskar and Chatterjee, 2010). Boopathi *et al.* (2013) reported that rainy days and rainfall were negatively correlated with population of *B. dorsalis*.

2.7 NATURE OF DAMAGE

The larvae and adults were the destructive stages of the pest. The fruit flies caused both direct as well as indirect damage to the fruits.

2.7.1 Direct damage

Direct damages caused by the fruit flies include oviposition damage by adult female fruit flies and feeding damage by larvae. The external damage caused by fruit fly varied from host to host although the pattern of the damage inside the pulp was more or less similar (Janjua, 1948). The damage started when the female fruit fly punctures the fruit with its long and sharp ovipositor to lay eggs under the fruit skin (Smith, 1989; Vargas *et al.,* 1984). The insertion of the ovipositor caused wounds and this lead to gummy exudation from oviposition site. A brown patch was developed around the oviposition sites which later lead to oviposition punctures on fruit (Shah *et al.,* 1999; York, 1992). Sometimes pseudo punctures (punctures without eggs) have also been observed on the skin of the fruit. These necrotic marks reduced the market value of the produce (Clarke *et al.,* 2005).

The larvae that hatch from the eggs fed on the pulpy content of the fruit and make feeding galleries. The fruit subsequently rot or became distorted (Nair, 1995). Young larvae move to healthy tissues and make it unsuitable for consumption (Hollingsworth and Allwood, 2000; Pena and Mohyuddin, 1997).

2.7.2 Indirect damage

The mango fruit fly has been considered as a severe quarantine pest in most countries (Bateman, 1972; Shukla and Prasad, 1985). It affected the export market of

mangoes due to strict quarantine restrictions of importing nations (Andrei *et al.,* 2001; Serem, 2010). So import and export of fruit fly infested mango fruits were restricted between nations. Thus mango growers faced huge loss due to lower prices from downgraded fruit in the market (Zhang and Hou, 2005).

Another indirect damage caused by the female fruit flies was they introduce bacteria into the fruit at the time of oviposition. It hastened the decomposition of fruits causing the early fall of fruits (Uchoa and Nicacio, 2010: White and Elson-Harris, 1992).

2.8 MANAGEMENT OF MANGO FRUIT FLY

The lack of basic knowledge about the biology of fruit flies and safer management strategies among farmers is a major constraint to increase production (Sithanantham, 2004). Mango growers suffered heavy losses due to fruit fly infestation. Therefore, affordable and environment friendly IPM options should be adopted to tackle the problem. Verghese *et al.* (2004) warrants the need of integrated approach for fruit fly management involving IPM strategy including field sanitation, soil raking, bait traps and male annihilation traps.

2.8.1 Cultural control

The manipulation of farming practices for reducing or avoiding pest damage to crops is known as cultural control. It is based on habitat management and requires a thorough understanding of different components of the agroecosystem in which the pests thrive. It is also known as ecological management or environmental management (Srivastava and Dhaliwal, 2010).

2.8.1.1 Early harvesting

Lakra *et al*. (1991) reported lower survival of fruit fly larva in fruits when harvested at colour change stage, avoiding over ripening stage. Fruit flies do not

prefer green or immature fruits for oviposition. So early harvesting of fruits prevents fruit fly infestation (Liquido, 1993). In Maharashtra and North Karnataka, early harvested fruit (March/April) escaped infestation as observed by Verghese *et al.* (2006). Some fruits at early stage are not preferred by fruit flies due to their colour preferences for oviposition. So this method can be employed for the management of fruit flies (Kumar *et al.,* 2011).

2.8.1.2 Soil raking

Narayanan (1953) reported that pupae of fruit flies can be destroyed by ploughing the field during summer months. Wesley (1956) also made similar observations and suggested raking of soil under infested plants. The residual pupae are the major source of infestation. Physiological adaptations like aestivation and hibernation help the fruit flies to survive at pupal stage in dormant condition beneath the soil around tree (Singh *et al.,* 1973). Mature larvae enter the soil, pupate and overwinter under unfavourable conditions. Soil raking exposed the dormant pupae to sunlight and predators and also caused mechanical injury on over wintering pupae (Lakra, 1998; Vadivelu, 2014).

Raking or ploughing of soil at two times- two weeks after colour break and again three weeks later around and below the canopy to a 6cm depth helped to reduce infestation by about 80 per cent (Patel *et al.,* 2005; Stonehouse *et al.,* 2005).

2.8.1.3 Field Sanitation

Vijaysegaran (1985) reported that orchard sanitation by collecting and destructing all unwanted fruits on the trees and on the ground significantly contributed for the reduction of fruit fly population. It disrupted the lifecycle of fruit flies (Verghese and Jayanthi, 2001). According to Singh (2008), field sanitation is an effective preventive measure in fruit fly management and need to be done systematically to break down the reproductive cycle and minimized the population build up and infestation.

Liquido (1993) reported that the percentage of infestation by *B. dorsalis* in half and fully-ripe fruits from sanitary fields were lower than those from unsanitary fields. Collection and destruction of fallen, damaged, over-ripe, and excess ripe fruits are strongly recommended to reduce resident populations of fruit flies in all kind of fruit host. The percentage of damaged fruits gradually decreased to about 20 per cent when sanitary practices were adopted (Hasyimab *et al.,* 2008). Poorly managed or abandoned farms are highly susceptible to fruit fly infestation (Singh, 2008).

There are many proven methods of field sanitation for the fruit flies. Srivastava and Nanda (1983) found that most maggot and other stages tend to die when discarded fruits are kept in sealed plastic bags under sun for a period of 10 days. Liquido (1991) recommended the use of fallen and damaged fruits as compost or animal feed. Deep burial to a depth of one meter and thick covering by soil reduced the probability of survival of the fruit fly maggots and other life stages (Patel, 1994). It was also supported by Reghupathy *et al.* (1997). Mortality of *B. cucurbitae* pupae at different depths was studied by Makhmoor and Singh (1999). They reported 13 per cent mortality at 10 cm depth and 93 per cent mortality on the surface. Pupae can also be killed by heating of soil by burning grass and irrigation during summer (Singh, 2008).

A new way of disposing the infested fruits was developed by Hawaii Area-wide fruit fly IPM Programme known as augmentorium. The augmentorium served the double purpose of field sanitation and conservation of natural enemies of fruit flies (Klungness *et al*., 2005). Jang *et al.* (2007) described augmentorium as a tent-like structure in which fallen rotten fruits collected from the field are deposited. It sequestered the fruit flies emerged while at the same time conserve the natural enemies by allowing parasitoids to escape from the structure through a fine mesh at

the top of the tent. In a study conducted by Deguine *et al.* (2011), augmentoria with a mesh having a hole area of 3 mm^2 prevented the escape of 100 per cent of adult of *B. cucurbitae* while 100 per cent of the parasitoids (*Psyttalia fletcheri* Silv. and *Fopius arisanus* Sonn.) escaped from the mesh.

2.8.2 Mechanical control

The reduction or suppression of insect populations by means of manual devices is referred to as mechanical control (Srivastava and Dhaliwal, 2010).

2.8.2.1 Bagging of fruits

Hutson (1940) recommended covering of fruits with newspaper bags to exclude fruit flies from egg laying and complete protection of fruits against flies. This finding was also supported by Fang and Chang (1987) and Wen (1988). Fruit bagging is regularly practiced in Taiwan to protect fruits from *B. dorsalis* (Lee, 1988). Bagging of bitter gourd fruits in Taiwan against *B. cucurbitae* was successful in increasing the yield and net income by 45 per cent on bitter gourd and 58 per cent on angled luffa (Fang, 1989). Karim (1989) reported that *B. dorsalis* preferred to lay eggs on mango fruits at 30 to 40 days before crop harvest. Hence, fruit bagging was recommended 30 days prior to harvest. Wrapping of fruits with polythene bags is safe and economical as compared with cloth or paper bags (Jalaja, 1989). Field experiments conducted by Sarker *et al.* (2009) using different bagging materials *viz.,* black poly bag, transparent poly bag, brown paper bag gave 100 per cent protection against fruit flies. They also reported that bagging of fruits with brown paper bag was the best in protecting mango fruits and recorded almost similar total soluble solid (TSS) percentage (24.2 to 25.2 per cent) and physical fruit quality change (4.3 to 5.5 per cent) as that of unbagged healthy fruits of the control treatment (24.6 to 25.9 per cent TSS and 5.6 to 8.7 per cent physical fruit quality change). A recent study conducted by Abbasi *et al.* (2014) reported minimum fruit fly damage in perforated polyethylene bags (3.93 per cent), followed by newspaper bags (5.71 per cent) and

muslin cloth bags (7.65 per cent), while the maximum attack (96.02 per cent) occurred in unbagged fruits.

Though bagging was inexpensive and easy to apply and guaranteed complete protection from fruit flies, it was ideal only for small scale growers and homesteads and not suitable for commercial cultivation of crop (Nandakumar, 1999).

2.8.2.2 Trapping

The control of fruit flies at the destructive larval stage is difficult because insecticides in the form of dust or sprays cannot reach them. The ways to deal with them is to target adult flies before they start laying eggs by trapping them or using insecticides to control their populations (Mugure, 2012).

2.8.2.2.1 Food bait traps

Fruit flies require protein source to mature sexually and also for the development of their eggs (Christenson and Foote, 1960). Exploiting this need, fruit fly attractive baits were used against this pest for monitoring and direct control (Mazor *et al.*, 2002). Bait traps can directly reduce the number of pre reproductive females and constituted a useful tool in fruit fly control (Lux *et al*., 2003). Fruit flies are attracted and killed by food baits mixed with toxicants (Jiji *et al.,* 2005).

Over several decades a number of different baits have been assessed for the attraction of fruit flies (Gupta and Verma, 1982). Use of protein hydrolysate was recommended to attract fruit fly adults. Ammonium acetate was reported as the most effective in attracting the fruit flies by Reissig (1976). Honey at one per cent and banana traps using Palayamkodan or Poovan were effective in trapping melon flies in bittergourd (Jalaja, 1989). Pillai *et al.* (1991) reported maximum fly catch in Palayamkodan banana baited traps than jaggery, honey and molasses. Kapoor (1993) suggested benzyl acetate as an attractant for *B. dorsalis* and *B. cucurbitae*. One per cent yeast protein and one per cent sugar served as good attractant for fruit flies as

reported by Srinivasan (1993). Singh (1997) reported the use of 2 per cent brewery waste in water, hydrolysed by oven baking at 40 ^{0}C for 48 hours. Reghupathy *et al.* (1997) advocated setting up of trap with wet fish meal 5 g in polythene bags of size 20 x 15 cm with six holes and dichlorvos 0.1 ml in cotton plug inside the bag. They also reported that addition of 100 ml fermented palm juice to 5 ml saturated sugar solution and 5 ml malathion 50 EC increased the effectiveness of trap catch.

Bait application technique normally consisted of traps baited with a liquid solution made from protein and fermenting sugar (Epsky *et al.*, 1999). Nandakumar (1999) and Sivakumar (2001) reported that setting up of banana trap or starch-jaggery trap showed zero per cent fruit fly infestation. In a study conducted in Pakistan, Stonehouse *et al.* (2002) observed that a meat based bait (beef meat broth) was found to be 68.7 per cent effective than commercial protein hydrolysate.

Lall and Singh (1960) reported maximum catch of *B. cucurbitae* in bait containing fermented palm juice (one part), saturated sugar solution (one part) and malathion at 50 WP 5g/100ml. Jiji *et al.* (2003) assessed the male and female count in different bait materials. They observed maximum male catch in robusta + jaggery + carbofuran and female catch in red banana + boiled jaggery + carbofuran. Jhala *et al.* (2005) also has the opinion that banana and jaggery at 10 per cent in isolation or combination are cost-effective baits. In Southern Kerala, 10 per cent jaggery solution was found superior (Jiji *et al.,* 2005) and use of boiled jaggery at 80^{0}C increased its effectiveness when mixed with banana (Vidya, 2005). Among the various banana varieties in the traps, Rasakadali was superior to other banana varieties to attract the flies (Jiji *et al.,* 2005). The attraction of melon fly to different baits was assessed by Singh *et al.* (2006) in traps in bittergourd field in Orissa. Results showed that mean number of flies attracted were the highest in banana (5.00), followed by jaggery (4.64), mashed sweetgourd (2.52), yeast-sugar mixture (0.52), 100% protein

hydrolysate (0.60), 3% protein hydrolysate (0.12) and water (0.12). Jiji *et al.* (2009) recommended the use of 100 ml of 10 per cent jaggery, containing 0.2 ml of malathion as food bait trap at the rate of one per tree. The food bait was replenished every week.

Studies were also conducted to evaluate the efficacy of safer low dose new generation insecticides in bait traps. Field tests conducted by King and Hennessey (1996) and Peck and McQuate (2000) in Hawaii and Florida, respectively demonstrated that spinosad-based baits aim significant control of Mediterranean fruit fly, *Ceratitis capitata* and the Caribbean fruit fly, *Anastrepha ludens*. Toxicity of spinosad in protein baits was evaluated against *B. dorsalis* and was found to be susceptible (Stark *et al.,* 2004). It was also observed that spinosad was less toxic to parasitoids than fruit flies. Barry and Polavarapu (2005) reported that exposure of fruit flies to 40 ppm of imidacloprid resulted in significantly higher fly mortality within one hour after treatment than control. The field experiments conducted by *Khursheed and Raj (2012*) to evaluate the efficacy of insecticides against fruit flies revealed that abamectin (0.0015%) was very effective treatment in terms of reducing the fruit infestation as well as number of maggots per infested fruits, compared with lambda cyhalothrin (0.004%) and azadirachtin (0.0045%). But lambda cyhalothrin was a better option from the economic point of view.

2.8.2.2.2 Pheromone traps- Male Annihilation Technique

Male annihilation technique (MAT) is a fruit fly control method that killed male flies and reduced the insect's chances of mating. Hence the females produce very few progeny. As a result, the wild population in the target area declined and lead to eradication (Cunningham, 1989). MAT was used successfully to eradicate the Oriental fruit fly, *Bactrocera dorsalis* in Rota (Steiner *et al.,* 1965), Saipan (Steiner *et al.,* 1970) and Okinawa (Koyama *et al.,* 1984), Asian papaya fruit fly, *Bactrocera*

papayae in Australia (Cantrell *et al.,* 2002) and *Bactrocera* species in Nauru (Allwood *et al.,* 2002). Methyl eugenol was used to attract males of mango fruit fly (Mirani, 2007).

Howlett (1912) reported that oil of citronella attracted male fruit flies of three species *viz., Bactrocera zonata* (Saunders), *B. dorsalis* and *Dacus diversus* Coq. Shah and Patel (1976) reported that leaves of *Ocimum sanctum* Linn.containing 20.4% essential oils as methyl eugenol attracted male flies of *Dacus* spp. in mango and sapota. Roomi *et al.* (1993) showed that 0.3 mg of cotton pad treated with 0.25 ml of extract of tulsi leaves was effective attractant in trapping *Dacus ciliates* (Loew), *B. zonata*, *B. dorsalis* and *B. cucurbitae* from a distance of 0.8 km in orchards in Pakistan. Trap was designed using a ply wood block of 5x5x1 cm^3 impregnated with 6: 4: 1 mixture by volume of ethyl alcohol, methyl eugenol and malathion 50EC (Stonehouse *et al.,* 2002). Then the blocks were suspended in a plastic bottle. Then the traps were nailed or hung on trees at 1.5 m above the ground below branches to protect them from rain (Verghese *et al.,* 2006a) and are placed at the rate of 1trap/ 15 cents (Jiji *et al.,* 2014).

Methyl eugenol together with an insecticide impregnated into a suitable substrate forms the basis of male annihilation technique (Verghese *et al.,* 2006a). These traps also have high specificity and low cost (Vargas *et al.,* 2010). MAT was also found very effective in monitoring and management of *Bactrocera* spp. on different fruit crops (Singh and Sharma, 2011). Field evaluation of methyl eugenol traps was conducted by Reji Rani *et al.* (2012) from flowering season of mango in Kerala (December – January) to the period of fruit maturity (April to May) for two years; 2007 and 2008. They reported that percentage of fruit infestation for 2007 and 2008 was 1.13 per cent and 1.34 per cent, respectively and was low compared with

other control measures. They also found that methyl eugenol trap alone was sufficient to manage the pest.

Sarada *et al.* (2001) conducted experiments in mango orchard by using open pan traps of various colours *viz.,* yellow, white, blue, orange, red and green for capturing fruit flies with 0.1% methyl eugenol as attractant at different heights (0, 1.0, 1.5 and 2.0 meters) at different locations in the orchard. Results indicated that more flies were captured by white (16.95 flies/trap) and yellow (15.31 flies/trap) followed by green, orange, red and blue, respectively. Similarly more flies were captured on ground traps (12.43 flies/ trap) and the trap catch progressively decreased with height. Effect of neonicotinoid insecticides *viz.,* imidacloprid and thiamethoxam treated spheres at 2% ai were evaluated by Stelinski *et al.* (2001) against apple maggot. They found maximum fly catch for imidacloprid treated spheres than thiamethoxam treated spheres. Specialised pheromone and lure application technology (SPLAT) using methyl eugenol and cue lure along with spinosad was developed by Vargas *et al*. (2008). It was found a promising substitute for current liquid organophosphate formulation used for area wide suppression of *B. dorsalis* and *B. cucurbitae*.

Studies were made by Ravikumar and Viraktamath (2007) on attraction of different species of fruit flies to different coloured traps in guava and mango orchards during 2005-06 at Dharwad. The results indicated that yellow colour traps were attractive in guava (71.91 fruit flies/ trap/ week) while black colour traps in mango (8.68 fruit flies/ trap/ week). Setting up of ocimum trap (4/tree) at canopy level reduced fruit fly incidence on mango (KAU, 2007). Field studies conducted by Jiji *et al.* (2009) revealed that mean percentage fruit fly incidence in methyl eugenol trap was low (13.93 %) compared to control (79.75 %).

2.8.3 Biological control

Biological control has been defined as the utilization of natural enemies to reduce the damage caused by noxious organisms to tolerable levels (DeBach and Rosen, 1991). It is a viable strategy for the suppression and management of tephritid pests.

2.8.3.1 Entomopathogenic fungi

Fungal agents belong to the most promising group of biological control agents against insect pests. Particularly, the Deuteromycete fungi are known to cause epizootics in fly populations under laboratory and field conditions (Lacey *et al.,* 1994; Reithinger *et al.,* 1997). Entomopathogenic fungi (EPF) are rich source of natural bioactive compounds. Antibioactive compounds present in entomopathogenic fungi serve as regulators, chemical messengers in developmental processes, or as a defense system for the survival of the organism against their environment (Schnieder *et al.,* 2008). EPF are classified as fungi that infect, invade, and eventually kill their host insects (Singkaravanit *et al.,* 2010).

In nature, fruit fly pupation takes place in the soil (Christenson and Foote, 1960) and the control strategies of the pupal stage is one of the appropriate methods for successful management of fruit flies. Fungal attack resulted in mortality or reduced fecundity and fertility. Several studies were done to assess the soil treatment with fungal pathogens for the control of different agricultural pests (Booth and Shanks*,* 1998; Krueger *et al.,* 1991; Villani *et al.,* 1994). Ekesi *et al.* (2002) found that isolates of *Metarhizium anisopliae* and *B. bassiana* caused a significant reduction in adult emergence and a corresponding large mortality of puparia of *Ceratitis capitata* (Wiedmann) and *C. rosa* var. *fasciventris* when exposed as late third-instar larvae in sand. In this study, adult emergence for *B. zonata* and *B. cucurbitae* varied from 60 to 93 per cent and 52 to 92 per cent, respectively. Two strains of *Beauveria* namely, *B. bassiana* and *B. brongniarti* caused 97.4 per cent and 85.6 per cent

mortality to the adults of Mediterranean fruit fly, *C. capitata*, respectively (Konstantopoulos and Mazomenos, 2005). Three fungal strains namely *Beauvaria bassiana* (ITCC No. 6063), *Paecilomyces lilacinus* (ITCC No. 6064) and *Aspergillus candidus* (ITCC No. 5428*)* were found to be pathogenic to fruit flies (Jiji *et al.,* 2006). They observed that *P. lilacinus* @ 1.0 x 10^9 spores ml^{-1} caused 96.67 and 100 per cent cumulative mortality in fruit flies on second and third day, respectively while *B. bassiana* @ 1.0 x 10^9 spores ml^{-1} caused 70, 80 and 90 per cent mortality on fourth, fifth and sixth day, respectively. Cumulative per cent mortality caused by *A. candidus* @ 1.25 x 10^9 spores ml^{-1} was 63.33%, 83.33% and 100 % on third, fourth and fifth day, respectively. Laboratory and field studies on *P. lilacinus* activity on pupae and adults of melon fly were reported by Amala *et al.* (2013). When *P. lilacinus* was drenched at 1.3 x 10^9 spores ml^{-1} in soil under trough conditions reported to cause 92.45 per cent mortality of pupae within 5 DAI. Spraying with *P. lilacinus* at 2.4 x 10^9 spores ml^{-1} recorded 100 per cent mortality in adults within 3 DAT. It was also observed that soil drenching + spraying with *P. lilacinus* reduced the percentage infestation of *B. cucurbitae* in bittergourd.

2.8.3.2 Entomopathogenic nematodes

The use of entomopathogenic nematodes (EPN) is a promising approach to control the fruit fly. Poinar and Hislop (1981) first suggested the use of entomopathogenic nematodes as a suppression method for fruit flies. The infective juveniles of entomopathogenic nematodes enter their host through natural openings and rarely through the direct penetration of host cuticle (Heterorhabditidae) (Shapiro and Lewis, 1999). EPNs of the genera *Steinernema* and *Heterorhabditis* are widely used for the biological control of fruit flies (Grewal *et al.,* 2005). Third instar larvae of fruit flies which exit the host fruit and burrow into the soil for pupation are susceptible to infection by infective juveniles of EPN (Hulthen and Clarke, 2006).

Beavers and Calkins (1984) evaluated the susceptibility of *Anastrepha suspensa* (Loew) to steinernematid and heterorhabditid nematodes under laboratory conditions and found that larvae and adults were highly susceptible. Entomopathogenic nematodes kill their hosts in association with the mutualistic bacteria, *i.e. Xenorhabdus* spp. in steinernematids and *Photorhabdus spp.* in heterorhabitids. These mutualistic bacteria release toxins or metabolites or proteases that finally kill the host within 2-3 days (Kaya and Gaugler, 1993). Susceptibility of different larval instars and pupae of *B. zonata* to *Steinernema feltiae* (Filipjev) were evaluated by Mahmoud and Osman (2007). They observed the mortality ranges for third instar larvae as 32 to 88 per cent and for one day old pupae as 4 to 56 per cent were highly susceptible to *S. feltiae*. Pot experiments conducted by Karagoz *et al.* (2009) with *S. feltiae* at rate of 100 and 200 IJs cm^{-2} caused 96 per cent and 97 per cent mortality of Mediterranean fruit fly. Heterorhabditis nematode was the best candidate for the control of *B. zonata* and *D. ciliatus* as it caused high mortality to target pests (Fetoh *et al.,* 2011). Effectiveness of *Steinernema carpocapsae* and *Heterorhabditis* sp. for control of fruit fly, *C. capitata* was also studied by Rohde *et al.* (2012). They reported that *S. carpocapsae* was more effective than *Heterorhabditis sp.* when applied at the rate of 62.5 IJ cm^{-2} caused 74.5 per cent mortality of Mediterranean fruit fly.

2.8.3.3 Natural enemies

Natural enemies used in the biological control of fruit flies include parasitic Hymenopterans and staphylinids, spiders and ant predators.

2.8.3.3.1 Parasitoids

The use of parasitoids to control fruit flies began in 20^{th} century by the introduction of a hymenopteran parasitoid, *Diachasimorpha longicaudata* (Ashmead) from Africa to Hawaii to control Mediterranean fruit fly, *C. capitata* (Wharton, 1989). Biological control using parasitoids was successful in suppression of the major tephritid pests and was made an important component in IPM programs

(Purcell, 1998). Among established parasitoids of tephritids in Hawaii, *Fopius arisanus* (Sonan) is the dominant species (Wong and Ramadan, 1987; Vargas *et al.,* 2001) due to its competitive superiority (Wang and Messing, 2002; Wang *et al.,* 2003). Purcell (1998) reported two braconid parasitoids, *Diachasmimorpha tryoni* (Cameron) and *Pysttalia fletcheri* (Silvestri) attacking larval instars of *C. capitata* and *B. cucurbitae*.

Table 3. Important parasitoids of mango fruit flies

Parasitoids	**Native place**	**Reference**
O. Hymenoptera **F. Braconidae**		
Diachasmimorpha longicaudata	Indo- Australia	Wharton and Marsh, 1978
Diachasmimorpha albobalteata (Cameron)	Thailand	Chinajariyawong *et al.,* 2000
Opius compensans (Silvestri)	India	Narayanan and Chawla, 1962
Opius formosanus (Fullaway)	Taiwan	Clausen, 1956
Psyttalia fletcheri	Thailand	Chinajariyawong *et al.,* 2000
Fopius arisanus	Malaysia	Serit *et al.,* 1986
Opius fijiensis (Fullaway)	Australia	Wharton and Gilstrap, 1983
Diachasmimorpha *Kraussii* (Fullaway)	Australia	Wharton and Gilstrap, 1983
F. Eulophidae		
Syntomosphyrum indicum (Silvestri)	India	Kapoor, 1993
Aceratoneuromyia indica (Silvestri)	Malaysia	Ooi, 1984
Tetrastichus dacicida (Silvestri)	Kenya	Narayanan and Chawla, 1962
F. Encyrtidae		
Tachinaephagus sp.	Malaysia	Thompson, 1943

F. Chalcididae		
Dirhinus anthracina (Walker)	India	Kapoor, 1993
Dirhinus luzonensis (Rohwer)	Malaysia	Narayanan and Chawla, 1962
Dirhinus auratus (Ashmead)	India	Kapoor, 1993

2.8.3.3.2 Predators

Predators are used only rarely for fruit fly control (Marucci and Clancy, 1952; Clausen *et al.,* 1965). Two predators of fruit flies, namely, lynx spiders (*Oxyopes lineatipes* Koch) and weaver ants (*Oecophylla smaragdina* Fabricius) are effective predators for the control of fruit fly population (Peng and Christian, 2007). They observed that fewer fruit fly puparia from fruits collected in the weaver ant treatment (0-0.6 puparia/fruit) than from fruits collected in the insecticide treatment (1.2-3.7 puparia/fruit). Ant predation on fruit fly larvae emerged from fallen fruit was observed by Van Mele *et al.* (2007). Adandaonon *et al.* (2009) reported that active weaver ant colonies reduced fruit fly egg-laying in developing mangoes due to the repulsive effect of pheromones left by the ants on fruits and with good colony management can be effective in commercial practice. Ativor *et al.* (2012) observed that total number of fly landings in the presence of African weaver ants, *Oecophylla longinoda* Latreille (72.00) was significantly lower than its absence (114.20). They also recorded the highest infestation index of 71.17 in the absence of *Oecophylla* sp. while the presence recorded 45.83. These results suggested that *O. longinoda* can be used as a biocontrol agent for IPM programs in citrus orchards.

Predatory potential of *O. lineatipes* against melon fly was observed by Vidya (2005) in bittergourd. Lynx spider inhabit in weedy areas around fruit trees and hunt fruit flies that emerge from the pupae. This can be done by modifying the orchard ecosystem to bring about lynx spider population and consequently bring down fruit

fly population. Studies conducted by Kriengkrai *et al.* (2010) in mango orchard areas of Chachoengsao province throughout the year revealed that about sixty six species of 50 genus and 17 families of spider fauna were found inhabiting in mango orchards and the lynx spider, *O. lineatipes* was the most important predacious spider in consuming fruit flies. They observed that the immature stage, adult females and males consumed fruit flies at the rate of 7.78, 7.67 and 6.53 flies/ day. They also suggested that conservation of the predacious spider in mango orchards is essential by maintaining weeds at certain spots as to provide a shelter for them.

The studies were conducted by Caesear *et al.* (2010) on ground-dwelling polyphagous predators of *C. capitata* inhabiting the ground surface of citrus orchards throughout the year. About 17,526 ground dwelling predator specimens belonging to 110 different species were captured. The prevalent predators found were the lycosid *Pardosa cribata* Simon (Araenae), the ground beetle *Pseudophonus rufipes* De Geer (Coleoptera: Carabidae) and the earwig *Forficula auricularia* Linn. They were evaluated under laboratory conditions and found that *P. rufipes* was the most efficient predator, while *F. auricularia* was the least. *P. rufipes* preyed mainly upon pupae, with an estimated attack rate of 3.07 d^{-1}, *P. cribata* used teneral adults as the main prey, with an estimated attack rate of 0.771 d^{-1} and *F. auricularia* showed the highest preference for third-instar larvae, with an estimated attack rate of 0.269 d^{-1}.

2.8.4 Botanicals

Chen *et al.* (1996) studied the deterrent effect of neem seed kernel extract (NSKE) on oviposition of Oriental fruit fly, *B. dorsalis*. They revealed that guava fruits treated with NSKE (0.2 to 0.4 %) resulted in reduction in oviposition preference (87.5 to 99.2 %) over the untreated check fruits. Hassan (1998) also tested the efficacy of NSKE on persimmon against developing stages of the Queensland fruit fly and found it significantly effective @ 120-140 mg l^{-1} of water against first

and second instar larvae. Laboratory studies conducted by Nair and Thomas (2001) on the chemosterilant effect of sweet flag extracts on *B. cucurbitae* at different dosages ranging from 0.1 to 0.01 per cent revealed remarkable changes in the size and morphology of the reproductive organs of adult flies with no signs of mating even upto the 25th day after the emergence. Studies conducted by Mondal and Ghatak (2009) at Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal indicated reduction in fruit damage in the range of 53.57 - 68.63 per cent, 43.60 - 64.82 per cent and 43.46 - 63.72 per cent in treatments with NSKE, methanol extract of custard apple seeds and petroleum ether extract of sweet flag rhizome, respectively. Rehman *et al.* (2009) reported the percentage repellency of peach fruit fly in petroleum ether extract of *Curcuma longa* L., ethanol and acetone extracts of *Penganum harmala* L. at 2 per cent as 57.14 per cent, 59.38 per cent and 46.19 per cent, respectively. Agrawal and Dev (2013) tested the bioefficacy of aqueous extract of six indigenous plants *viz.,* Cuscuta (*Cuscuta reflexa* Roxb.), Kaner (*Thevetia nerefolia* Juss.), Parthenium (*Parthenium histerophorus* Linn.), Karanj (*Pongamia pinnata* Linn.), Dhatura (*Datura latifolia* Linn.), and Neem seed kernel extract (*Azadirachta indica* Juss.) were tested at 2 per cent and 5 per cent concentration. They found that pupal dipping in Kaner at 5 per cent recorded 86.2 per cent pupal mortality of *B. cucurbitae*.

2.8.5 Chemical control

Chemical pesticides are also used for controlling fruit flies and to reduce the heavy yield loss caused by them.

2.8.5.1 Insecticide cover sprays

The history of fruit fly control with full cover sprays started with inorganic insecticides in the early 1900s. Thereafter, a transition from inorganic to synthetic insecticides such as chlorinated hydrocarbons, organophosphates, and synthetic pyrethroids occurred. Insecticide cover sprays are cheap, convenient and provide good protection against fruit fly (Allwood, 1997).

Strong (1935) suggested the effectiveness of tartar emetic against fruit flies. Ayyar (1940) recommended the use of nicotine sulphate for the suppression of fruit flies. The first synthetic chemical insecticide used to control fruit flies was DDT. Preliminary tests conducted by Nishida and Bess (1950) revealed that application of oil emulsion of 10-12 per cent DDT on cucurbits and tomato eliminated all flies within 50-100 feet. Tominic (1959) evaluated the toxicity of diazinon and dimethoate against fruit flies. Results revealed that spraying of 0.2 per cent diazinon gave 100 per cent mortality of larvae whereas dimethoate 0.2 per cent killed eggs laid 6 DAT. David (1967) recommended spraying of carbaryl 0.1 per cent three times at fortnightly intervals from the flowering against *B. cucurbitae*. Nagappan *et al.* (1971) advocated spraying with 0.1 per cent dimethoate or fenthion at tri-weekly intervals at the time of flowering. Similar observations were also made by David and Kumaraswamy (1995).

Field studies conducted by Bhatnagar and Yadav (1992) in Rajasthan revealed that malathion 50 EC at 0.5 per cent was effective in reducing the fruit fly infestation in bottlegourd and spongegourd. They also recorded lowest number of maggots per infested fruit (3.8 maggots/fruit) in malathion treatment over control (11.9 maggots/ fruit). A bait spray of 0.1 per cent malathion with 2 per cent sugar at monthly intervals from initial fruit set up to harvest are effective against fruit flies (KAU, 2007). Oke (2008) evaluated foliar application of two insecticides *viz.*, deltamethrin and lambda cyhalothrin for the control of *B. cucurbitae* on cucumber. He observed that plot treated with lambda cyhalothrin recorded no pupae from the first to fifth harvest as compared with deltamethrin. Hence, spraying with lambda cyhalothrin was found better in respect of reducing the oviposition marks and number of pupae than that of deltamethrin. Sharma and Sinha (2009) reported that three foliar sprays of alphamethrin (20 g ai/ha) at fortnight interval reduced infestation of melon fly in

cucurbits. Laboratory bioassay done against *A. fraterculus* revealed that imidacloprid has the lowest LT50 values of 10.6 min for males and 13.0 min for females, exposed respectively, to 120.0 mg and 150.0 mg l^{-1} (Raga and Sato, 2011).

2.8.5.2 Bait Sprays

Georghiou (1956) suggested a bait spray of 1.0 per cent malathion in 10 per cent sugar solution applied in several orchards to a patch of foliage on each tree at 2-3 times at 10 days interval. Protein hydrolysate was identified as a good attractant for fruit flies (Orlando and Puzzi, 1958; Steiner, 1952; Steiner and Lee, 1955). Sugarcane molasses are the cheapest attractants in bait spraying. Dale (1965) reported that a coarse spray with a liquid bait containing one per cent yeast protein and 0.1 per cent malathion reduced melon fly infestation. Gupta and Verma (1982) evaluated fenitrothion alone as well as with various attractants and malathion + jaggery. They found the lowest attack (8.7 %) in plots treated with fenitrothion + protein hydrolysate. However, pest incidence in fenitrothion alone (13.7 %) was equally effective as malathion + jaggery (16.7 %) as compared to control (43.3 per cent). Agarwal *et al.* (1987) recommended spraying with 500 g molasses and 50 g malathion in 50 l of water at seven days as an effective method to control fruit fly.

The practice of addition of protein food baits to insecticide sprays was developed in order to reduce the amount of pesticides used in cover spray and to make them environmentally safe (Prokopy *et al.,* 1992; Roessler, 1989; Steiner *et al.,* 1961). Protein bait spray technique was developed because of concerns over damage to the environment and human health by insecticide cover sprays for fruit fly control (Sabine, 1992). Protein hydrolysate bait sprays were used to control adult population which are attracted and killed by spots of protein bait mixed with an insecticide (Allwood *et al.,* 2001). Protein baits consist of 3 per cent protein hydrolysate and 0.1 per cent malathion at 80 ml m^{-2} as coarse spot spray (Patel *et al.,* 2005). Borah

(1997) observed that 0.1 per cent cypermethrin + 1.0 per cent molasses solution at 10 days interval after 15 days of germination in cucumber resulted in the lowest fruit infestation (24.4 %), followed by cypermethrin (26.6 %) and deltamethrin (26.9 %), but malathion was found the least effective (36.2 %) over the control (40.1 per cent). Field experiments were conducted by Chinachariyong *et al.* (2003) in angled luffa and bittergourd to test the efficacy of Australian Pinnacle protein bait (420 g l^{-1}) and Thai yeast bait (33 ml l^{-1}) with trichlorfon 6 g ai l^{-1} as toxicant in bait spray. Results revealed that percentage infestation of Pinnacle protein bait treatment in angled luffa remained low (0.94 %) while in the untreated plot it was high (31.36 %). In the bittergourd trial, protein bait treatment resulted in continuous low fruit infestation (1.59 % for Pinnacle and 1.71 % for Thai bait) while in the untreated plot it was 40.18 per cent. Stonehouse *et al.* (2005) recommended a bait spray consisting of a spray liquid of 0.1 per cent malathion and 10 per cent jaggery or 10 per cent pulped ripe banana in water. Laboratory and field tests conducted by Manrakhan *et al.* (2013) to evaluate the efficacy of six different insecticides *viz.,* abamectin, alpha cypermethrin, fipronil, imidacloprid, spinosad and tartar emetic in combination with HymLure (a protein based attractant) for the replacement of malathion in bait sprays against mediterranean fruit fly. They found that a mixture of 2 per cent HymLure and spinosad at 48 ppm was found effective against both *C. capitata* and *C. rosa* and recommended it as a replacement for malathion based bait sprays.

2.8.6 IPM methods for fruit fly control

According to Varela *et al*. (2006), IPM is a monitoring and decision-making process for selecting the most appropriate, cost effective, compatible method of managing pests. It minimized pest damage with minimal disturbance to the natural balance of the agro-ecosystem and minimal risk to human health. Muhammad *et al*. (2004) suggested that IPM strategies for mango growers must be compatible and economically viable. Stonehouse *et al.* (2005) reviewed the data generated in a

multilocational project on the control of fruit flies *viz*. "Integrated management of fruit flies in India". It covered various locations and states all over India and recommended the adoption of an integrated practice using BAT, MAT and cultural methods (destruction of fallen fruits and soil raking). They also observed that BAT and MAT reduced the crop losses each by 50 per cent with only little interaction between them. A study conducted by Verghese *et al.* (2006) on pre harvest IPM of mango fruit fly in susceptible variety Banganapalli revealed that a combination of MAT + sanitation + cover spray of deltamethrin 2.8EC 0.5ml l^{-1} + 0.03 per cent azadirachtin 2ml l^{-1} gave 100 per cent control.

Many studies have indicated that an integrated management of fruit flies, in which more than one component combine to suppress population, is the most effective in farm situation (Singh, 1997). Verghese *et al.* (2004) recommended a combined integrated package consisting of collection and destruction of fallen fruits, raking or ploughing of the soil to disrupt pupae, MAT, bait sprays and early harvest. It reduced the yield loss by 90 per cent. An IPM module involving insecticide (dipterex at 100 gm $acre^{-1}$); baiting (molasses at 5 per cent + dipterex 100 gm $acre^{-1}$), cultural (hoeing + collection of fallen fruits from June to December) was effective against ber fruit fly and it gave a yield potential of 35 kg/plant with minimum damage of 2 per cent during the year 2005 in Pakistan (Ahmad *et al.,* 2005). Patel *et al.* (2005) reported that a cultural IPM of fruit flies (MAT + Raking + Sanitation) gave 100 per cent control in mangoes in Gujarat. Field trial carried out by Jiji *et al.* (2014) observed that IPM measures including collection and destruction of fallen fruits, use of methyl eugenol traps, swabbing the tree trunk with one litre of 10 per cent jaggery containing 0.1 per cent malathion during fruiting season at fortnightly intervals, and soil application of *B. bassiana* recorded lower fruit fly incidence of 17.4 per cent as compared with control plots (72.5 %) and malathion treatment (40.0 %).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study "Population dynamics and management of mango fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) aims to study the population dynamics of mango fruit fly and standardize the use of alternate chemicals in bait application technique (BAT) and male annihilation technique (MAT) for its management. Survey was conducted in the homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani. Laboratory experiments were undertaken at the Department of Agricultural Entomology, College of Agriculture, Vellayani. Field evaluation on the efficacy of promising treatments was conducted in the homesteads of Balaramapuram panchayath in Thiruvananthapurm district.

3.1 POPULATION DYNAMICS AND HOST RANGE OF FRUIT FLIES

3.1.1. Documentation of pest incidence

A preliminary survey was conducted to document the percentage infestation and host range of *B. dorsalis* in twenty homesteads of Kalliyoor panchayath having having at least 25 cents as well as in the Instructional Farm, Vellayani during 2014-15. Five fruit crops *viz*., mango, guava, papaya, banana and sapota were selected for the study. Pest incidence was recorded by collecting ten fruit samples selected at random from each plant during the peak fruiting season and the percentage infestation was recorded. Observations on symptoms, nature of damage caused and other host plants were also recorded. The infested fruits were collected and the pest was reared out in the laboratory.

3.1.2. Assessment of pest status

Studies were carried out in the laboratory to find out the number of fruit fly maggots harbouring within the infested fruits and to identify different species of fruit flies emerging out of these fruits. Infested fruits collected from field were taken for rearing. Glass troughs with thirty centimeter diameter were used for rearing (Plate

1a, b). Each trough was filled with moist soil to a thickness of four centimeters. The infested fruit were cut open carefully and the number of maggots inside the fruit was counted and recorded. Fruit pieces along with maggots were kept over the moist soil for pupation and were covered with a muslin cloth and fastened using a rubber band (Amala, 2010). The data on number of maggots per fruit were converted into maggot population per fruit (Gupta and Verma, 1992).

$$\text{Maggot population per fruit} = \frac{\text{No. of infested fruits x No. of maggots per infested fruit}}{\text{Total no. of fruits sampled}}$$

Troughs were constantly examined for emergence of adult fruit flies. Emerged flies were collected and the number of *B. dorsalis* and other fruit fly species emerged was counted and recorded. The different species of fruit flies emerged per fruit were identified based on the key given by David and Ramani (2011) and also sent for taxonomic identification at National Bureau for Agriculturally Important Insect Research (NBAIR), Bangalore.

3.1.3 Reaction of mango and guava varieties against fruit fly attack

Occurrence of fruit fly infestation in eleven mango varieties *viz.,* Neelum, Mulgoa, Bangalora, Vellari, Kalapady, Kasthoori, Vellayani Local, Neelamundappa, Kottukonam Varikka, Alphonso and Kappa was evaluated. Varietal variation in susceptibility to fruit flies between different varieties of guava was also assessed. Guava varieties selected were white fleshed varieties, pink fleshed varieties and strawberry guava (small fruited variety). The pest incidence and percentage infestation was recorded as specified in 3.1.1. Observations were recorded as mentioned in para 3.1.2. The infestation levels in different mango varieties were categorized adopting the grades developed by Sharma *et al.* (1998) as detailed in Table 4.

Plate 1a. Glass troughs with infested fruit pieces

Plate 1b. Glass troughs covered with muslin cloth

Plate 1. Rearing of fruit flies

Table 4. Scale for assessing the susceptibility of mango varieties

Infestation (%)	Category of susceptibility
0	Totally immune
1-10	Highly resistant
11-20	Resistant
21-30	Moderately resistant
31-40	Moderately susceptible
41-50	Susceptible
>50	Highly susceptible

3.1.4 Natural enemies

Natural enemies of fruit flies including parasites and predators were recorded from field during the survey.

3.1.5 Population dynamics of fruit flies

Studies on population dynamics of mango fruit fly was conducted in ten homesteads of Kalliyoor Panchayath and Instructional Farm, Vellayani during 2013-2014. Standardized methyl eugenol traps were used for monitoring the pest population (Jiji *et al.,* 2009) (Plate 2). Traps were kept at ten homesteads in Kalliyoor Panchayath having at least one mango tree and five traps also were kept the Instructional Farm, Vellayani. Trap catches were taken at fortnightly intervals to study the population dynamics of the pest. Species diversity was estimated by taxonomic identification and quantification. The fruit flies were identified based on the key specified in 3.1.2. *B. dorsalis* and other fruit fly species were sorted out and counted. Fruit fly species collected were preserved as dry specimens.

3.1.5.1 Correlation with weather parameters

The weather parameters *viz.,* maximum and minimum temperature, morning and evening relative humidity, average relative humidity, rainfall and sun shine hours were collected from the Department of Meteorology, College of Agriculture, Vellayani. The average of the monthly data was worked out. The monthly weather parameters were correlated with the population of pest during the month of observation and correlation coefficients were worked out.

3.2 BIOLOGY OF MANGO FRUIT FLY

The biology of *B. dorsalis* on different mango varieties *viz.,* Neelum, Mulgoa, Bangalora and Vellari and different hosts *viz.,* mango, guava, banana, sapota and papaya were studied under room temperature in the laboratory. The nucleus culture was obtained by collecting infested fruits from field. Rearing of flies was done as per the procedure described under 3.1.2. Cotton swabs soaked in ten per cent jaggery and yeast were kept inside the troughs in petri dishes as artificial diet for freshly emerged flies. Sexually matured ten day old flies were introduced into cages (Plate 3) in the ratio 1:1. Fresh fruit pieces of 5 cm length split into two halves were kept in petri dishes and placed inside the cage for the adult female flies to lay eggs. The females were removed from the cage 24 h after introduction.

3.2.1 Duration of life stages

Time taken for hatching of eggs was recorded. The egg period was recorded as number of days from date of egg laying to the date of larval emergence. Ten maggots were selected for the study. Maggots were reared separately in respective fruit pieces in plastic containers of 10 x 10 cm and covered with muslin cloth. Fruit pieces were replaced with fresh ones at two days interval. The maggots were carefully transferred using a soft and fine bristled brush into the fresh fruit pieces.

The larval period was recorded as number of days from date of larval emergence to the date of pupation.

When the larvae became full grown they were transferred to glass troughs (30 x 15 cm) provided with soil at a depth of 4 cm for pupation. The pupal period was recorded as number of days from the date of pupation till the date of adult emergence. The emerged adults were fed with artificial diet mentioned in para 3.2. The adult longevity was recorded as the days taken for adult emergence to the death of the adult.

3.3 EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIOAGENTS IN FOOD BAIT IN THE LABORATORY

A cage experiment was conducted for testing the efficacy of alternate insecticides, botanicals and bioagents in food baits in the laboratory.

3.3.1 Rearing of *B. dorsalis* in the Laboratory

The infested fruits were collected and rearing of flies was done as per the procedure given in para 3.1.2.

3.3.2 Selection of most effective treatments in BAT

Laboratory evaluation was conducted to select the most promising treatments for the management of mango fruit fly.

Design : CRD

Treatments : 12

Replication : 3

The following were the treatments used for the study. Details of the insecticides used are given in Table 5.

T1 Deltamethrin 0.04%

T2 Deltamethrin 0.02%

T3 Lambda cyhalothrin 0.005%

T4 Lambda cyhalothrin 0.0025%

T5 Chlorantraniliprole 0.006%

T6 Chlorantraniliprole 0.003%

T7 Spinosad 0.02%

T8 Spinosad 0.01%

T9 Malathion 0.1%

T10 Azadirachtin 0.003%

T11 *B. bassiana* (ITCC 6063) WP 2%

T12 *P. lilacinus* (ITCC 6064) WP 2%

3.3.3 Preparation of Bait Traps

The food bait used was 10 per cent jaggery. The insecticides, botanicals and bioagents at different concentrations were added to 100 ml jaggery solution. It was taken in 1L plastic bottles consisting of three rectangular windows of size 2 x 3 cm.

3.3.4 Testing the effect of treatments on adult

Ten freshly emerged adult flies were used for the study. Flies were introduced into cages of size 50 x 50 x 50 cm (Plate 3). The bait traps prepared as per the procedure 3.3.3 were kept inside the cages.

Observations on the mortality of flies were taken each day after treatment for a period of seven days. The time taken for the death of flies was also recorded and the most promising three treatments were selected for field evaluation.

3.4 EVALUATION OF EFFICACY OF THE CHEMICALS IN MALE ANNIHILATION TECHNIQUE IN THE LABORATORY

A cage experiment was conducted in the laboratory for testing the efficacy of traps using alcohol, methyl eugenol and insecticides on V: V: V basis.

Plate 2. Methyl eugenol traps kept in homesteads

Plate 3. Cage used for the experiment

3.4.1 Rearing of *B. dorsalis* in the Laboratory

The infested fruits were collected and rearing of flies was done as per the procedure given in 3.1.2.

3.4.2 Selection of most effective treatments in MAT

Laboratory evaluation was conducted to select the most promising treatments for the management of mango fruit fly.

Design : CRD

Treatments : 9

Replication : 3

The efficacy of insecticides were tested as per the following method. Plywood blocks soaked in alcohol: methyleugenol: insecticide (V: V: V) mixture in respective ratios (Table 5) were used for the study. The treatments are as follows.

T1 Deltamethrin 6:4:0.04

T2 Deltamethrin 6:4:0.4

T3 Lambda cyhalothrin 6:4:0.005

T4 Lambda cyhalothrin 6:4:0.05

T5 Spinosad 6:4:0.02

T6 Spinosad 6:4:0.2

T7 Imidacloprid 6:4:0.005

T8 Imidacloprid 6:4:0.05

T9 Malathion 6:4:1

3.4.3 Preparation of Pheromone Traps

Plywood blocks of size 4 x 6 cm was taken and tied using a rope. Blocks were soaked in alcohol, methyl eugenol and insecticides in respective ratios for seven days and were shade dried for two days. It was tied well to plastic bottles consisting of windows of 2 cm diameter on all four sides.

Table 5. Insecticides used for laboratory evaluation of BAT and MAT

Sl. No.	Details of insecticides				
	Chemical name	**Trade name**	**Chemical group**	**Mode of action as per IRAC, 2014**	**Manufacturers**
1	Deltamethrin	Decis 2.8 EC	Synthetic pyrethroid	Sodium channel modulators	Bayer crop science
2	Lambda cyhalothrin	Karate 5 EC	Synthetic pyrethroid	Sodium channel modulators	Syngenta India Ltd.
3	Chlorantraniliprole	Coragen 18.5 SC	Diamides	Ryanodine receptor modulators	Dupont
4	Spinosad	Tracer 45 SC	Spinosyns	Nicotinic acetylchloline receptor (allosteric) activators	Dow AgroScience Ltd.
5	Malathion	Killer 50 EC	Organophosphates	Acetylcholine esterase inhibitors	Bayer crop science
6	Azadirachtin	Nimbecidine 0.03 EC	Neem based	Ecdysone agonists / moulting	T Stanes and company Ltd.
7	Imidacloprid	Confidor 17.8 SL	Neonicotinoids	Nicotinic acetylchloline receptor agonists	Bayer crop science

3.4.4 Testing the Effect of Treatments on Adult

Ten freshly emerged adult male flies were used for the study. Flies were introduced into cages of 50 x 50 x 50 cm. The pheromone traps prepared as per the procedure 3.4.3 were kept inside the cages.

Observations on the mortality count of flies were taken each day after treatment for a period of seven days. The time taken for the death of flies was also recorded and the most promising three treatments were selected for field evaluation

3.5 PEAK TIME ACTIVITY OF FRUIT FLIES

A field study was conducted to document peak time activity during day time of the mango fruit fly in mango trees. The experiment was laid out in Completely Randomised Design with ten replications. Fruit fly activity was determined by trapping flies using methyl eugenol traps at an interval of two hours for a period of one week during the month of April 2015. The following were the time interval selected for the study: 6-8 am, 8-10 am, 10-12 am, 12-2 pm, 2-4 pm and 4-6 pm.

3.5.1 Preparation of traps

Methyl eugenol traps were prepared as per the procedure described in para 3.4.3 and kept in ten identified mango trees at a height of 1.5 m from ground.

3.5.2 Determination of effect of time on fruit fly activity

Observations on the number of fruit flies were recorded from each trap. The number of *B. dorsalis* and other fruit fly species was sorted out and recorded separately. To avoid trap catches after the time interval of 4-6 pm, traps were covered with a polythene cover and the cover was removed at morning 6.00 am on each day.

3.6 EVALUATION OF BAIT APPLICATION TECHNIQUE IN FIELD

A field trial was conducted to evaluate the effectiveness of promising treatments that were found to be effective from the experiment 3.3 against *B. dorsalis* in the preliminary trial conducted in the laboratory. The experiment was conducted in Completely Randomised Design with four treatments and six replications. The following were the treatments.

T1 Lambda cyhalothrin 0.005%
T2 Lambda cyhalothrin 0.0025%
T3 Spinosad 0.02%
T4 Malathion 0.1%

3.6.1 Evaluation of Promising treatments under field conditions

The promising treatments identified were tested under field conditions. The field evaluation was conducted in the homesteads of Balaramapuram panchayath during the peak fruiting season of mango.

3.6.2 Preparation of bait traps

The bait traps were prepared as per the procedure described in para 3.3.3. The traps were hung on the trees at canopy level at the rate of one per tree. The bait material in the trap was replaced every week.

3.6.3 Assessment of efficacy of treatments

The efficacy of treatments was determined by taking the number of flies in the trap on each day. The fruit fly count was recorded by brushing out the trapped flies. The time taken for the death of flies as well as daily trap catches for a period of two weeks from each trap was recorded. Male, female and total number of fruit flies was also taken from each trap.

3.7 EVALUATION OF MALE ANNIHILATION TECHNIQUE IN FIELD

The promising treatments identified from laboratory trial (para 3.4) were further evaluated in field for their efficacy in controlling *B. dorsalis*. The experiment was conducted in Completely Randomised Design comprising of four treatments with six replications.

T1 Spinosad 6: 4: 0.02
T2 Spinosad 6: 4: 0.02
T3 Deltamethrin 6: 4: 0.04
T4 Malathion 6: 4: 1

3.7.1 Evaluation of promising treatments under field conditions

The promising treatments identified from laboratory experiments were selected for the study. The field evaluation was conducted in the homesteads of Balaramapuram panchayath.

3.7.2 Preparation of pheromone traps

Traps were prepared as per the procedure described in para 3.4.3 and were evaluated under field conditions. Traps were set up in identified mango trees at a height of 1.5 m from ground.

3.7.3 Assessment of efficacy of treatments

Observations on the efficacy of treatments were recorded for a period of three months. Trap count was taken at fortnightly intervals. Different fruit fly species caught in the traps were identified and quantified.

3.7.4 Duration of effective trap catch

Persistence of insecticides in field was also evaluated by recording the total fly catch and duration of effective trap catch. Mortality of flies at fortnightly intervals was recorded.

3.8 STATISTIAL ANALYSIS

Data of each experiment were subjected to suitable statistical methods of analysis. The statistical methods followed in the experiments are Analysis of Variance (ANOVA) technique (Panse and Sukhame, 1967) and 't' test (Snedecor and Cochran, 1989). Transformation of data was done wherever necessary.

RESULTS

4. RESULTS

The mango fruit fly, *B. dorsalis* is a destructive polyphagous pest, posing threat to various fruit crops. A survey was conducted in homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani during 2014-15 in order to study the pest incidence, population dynamics and host range of *B. dorsalis*. Laboratory and field experiments were conducted to standardize the use of newer molecules of insecticides in BAT and MAT to manage the pest. The results of the study are presented here.

4.1 POPULATION DYNAMICS AND HOST RANGE OF FRUIT FLIES

4.1.1 Documentation of pest incidence

Incidence of fruit fly in mango, guava and banana was observed during the survey conducted in homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani. No infestation was observed on papaya and sapota.

4.1.1.1 Incidence of fruit fly in mango

Infestation and damage caused by fruit flies in mango were studied during the peak fruiting season (Plate 4). The peak season was observed during April 2014, May 2014, June 2014 and July 2014 and the percentage infestation was recorded from the homesteads and Instructional Farm.

4.1.1.1.2 Infestation during peak season of mango

Infestation of *B. dorsalis* was seen in mango during April 2014– July 2014. The percentage of fruit damage caused by pest in mango in homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani during April 2014 to July 2014 was recorded (Table 6).

Plate 4a. Gummy exudation from oviposition puncture

Plate 4b. Development of brown patch

Plate 4c. Maggots feeding on fruit pulp

Plate 4d. Damage in mango

Plate 4. Incidence of fruit fly in mango

The damage caused by *B. dorsalis* to mango in homesteads ranged from 7.92 to 63.35 per cent. The lowest damage (7.92 %) was recorded during April 2014 and it was statistically on par with the damage observed (9.19 %) in July 2014. Significantly higher damage was recorded during June 2014 (63.35 %) and it was followed by May 2014 (51.21 %).

The damage to fruits caused by *B. dorsalis* in Instructional Farm, Vellayani was significantly different from each other during April - July months. Significantly higher damage was recorded in June 2014 (59.98 %). This was followed by May 2014 (47.34 %) and July 2013 (18.58 %). The damage of fruits during April 2014 was significantly lower (5.70 %).

The mean per cent damage caused by *B. dorsalis* to mango during fruiting months (April 2014 – May 2014) ranged from 6.77 to 61.68 per cent. The lowest damage was in April 2014 (6.77 %) and it was statistically on par with that in July 2014 (13.53 %). Incidence of fruit fly infestation was higher in June 2014 (61.68 %) and it was on par with the damage recorded during May 2014 (49.28 %).

4.1.1.2 Incidence of *B. dorsalis* in guava

Infestation and damage caused by fruit flies were studied during peak season of fruiting in guava (Plate 5). Peak season was observed during June, July, August and September. The percentage infestation was recorded for these months in homesteads and Instructional Farm, Vellayani.

4.1.1.2.1 Infestation during peak season of guava

Infestation of *B. dorsalis* was seen in guava during peak fruiting months of guava (June - September). The percentage of fruit fly infestation in guava in homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani during June to September 2014 is presented in the Table 7.

The damage caused by *B. dorsalis* to the fruits of guava in homesteads ranged from 11.48 to 85.64 per cent. Higher damage was observed during July 2014 (85.64

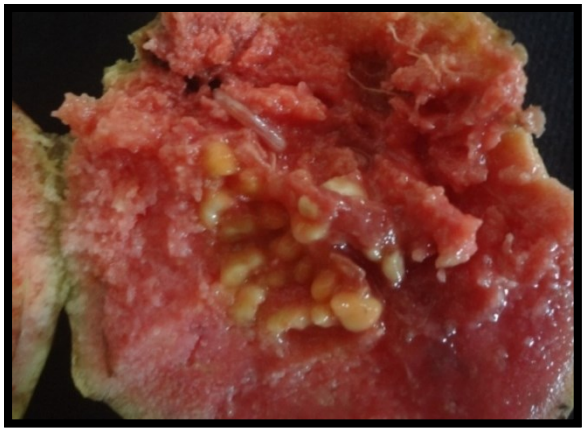
Table 6. Infestation of fruit fly in mango during April to July 2014

Month	Percentage infestation*		
	Homestead	**Instructional Farm**	**Mean**
April 2014	7.92 (16.34)	5.70 (13.81)	6.77 (15.09)
May 2014	51.21 (45.70)	47.34 (43.48)	49.28 (44.58)
June 2014	63.35 (52.74)	59.98 (50.75)	61.68 (51.74)
July 2014	9.19 (17.64)	18.58 (25.53)	13.53 (21.59)
CD (0.05)	**(3.560)**	**(3.206)**	**(12.585)**

*Mean of 20 replications

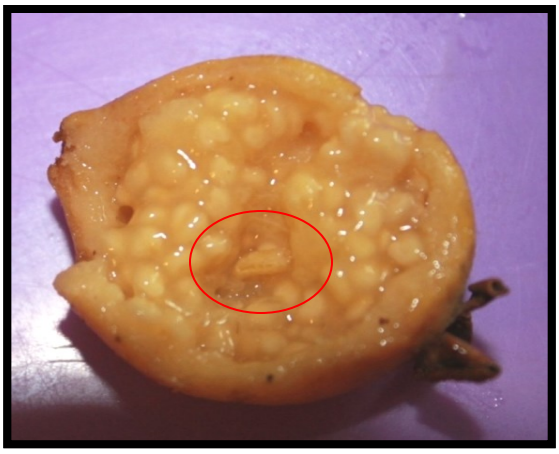
Figures in parentheses are angular transformed values

5a. White fleshed variety



5b. Pink fleshed variety

5c. Strawberry guava (small fruited)



5d. Maggots in straw berry guava

Plate 5. Incidence of fruit fly in guava

%) and it was statistically on par with that of August 2014 (78.20 %). This was followed by June 2014 with a percentage infestation of 34.09. Fruit fly incidence was found to be less during the month of September 2014 (11.48 %).

Significantly higher damage was recorded in July 2014 (81.81 %) in the Instructional Farm, Vellayani. However, this was on par with August 2014 (71.49 %). The damage of fruits during September 2014 was significantly lower (16.67) and was on par with that of June 2014 (23.23 %).

The mean percentage damage caused by *B. dorsalis* to guava during fruiting months (June-September 2014) ranged from 13.97 to 83.78 per cent. Incidence of fruit fly infestation was higher in July 2014 with a mean percentage infestation of 83.78. However, it was on par with the damage recorded during August 2014 (74.91 %). The lowest damage was observed in September 2014 (13.97 %).

4.1.1.3 Incidence of fruit fly in other hosts

In addition to the infestation of *B. dorsalis* in mango, guava and banana, infestation was also recorded from soursop. In banana, incidence of fruit fly was observed in red banana and palayamkodan (Plate 6a and b). Infestation by other species of fruit fly was also recorded from rose apple (Plate 7a and b) and solanaceous vegetables such as brinjal and tomato (Plate 8a, b and c). Rose apple was found to be infested by *Bactrocera syzigi* (Tsuruta and White) (Plate 7c). Brinjal and tomato were infested by solanum fruit fly, *Bactrocera latifrons* (Hendel) (Plate 8d).

4.1.2 Assessment of pest status

4.1.2.1 Population of maggot during peak season of mango

The average number of maggots per infested fruits during the different fruiting months of mango (April-May) was recorded (Table 8). The average number

Table 7. Infestation of fruit fly in guava during June to September 2014

Month	Percentage infestation*		
	Homestead	**Instructional farm**	**Mean**
June 2014	34.09 (35.72)	23.23 (28.81)	28.50 (32.27)
July 2014	85.64 (67.73)	81.81 (64.75)	83.78 (66.24)
August 2014	78.20 (62.17)	71.49 (57.72)	74.91 (59.94)
September 2014	11.48 (19.80)	16.67 (24.09)	13.97 (21.94)
CD (0.05)	**(12.649)**	**(11.947)**	**(8.455)**

*Mean of 20 replications

Figures in parentheses are angular transformed values

Plate 6a. Maggots in Red banana

Plate 6b. Maggots in Palayankodan

Plate 6. Incidence of fruit fly in banana

Plate 7a. Infested fruits

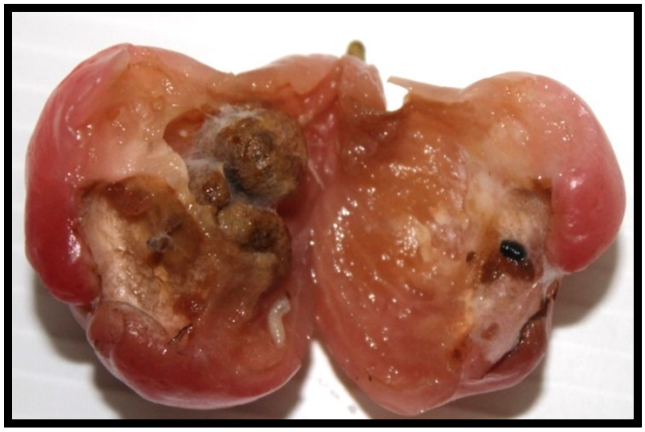


Plate 7b. Maggots in rose apple

Plate 7c. *B. syzigi*

Plate 7. Incidence of fruit fly in Rose apple

Plate 8a. Oviposition punctures on brinjal fruit

Plate 8b. Maggots in brinjal

Plate 8c. Maggots in tomato

Plate 8d. *B. latifrons*

Plate 8. Incidence of fruit fly in brinjal and tomato

of maggots during fruiting periods ranged from 33.22 to 82.49. The maximum number of maggots per infested fruit was recorded during June 2014 (82.49) but it was statistically on par with that in May 2014 (71.26). The lowest number of maggots per infested fruits was observed in April 2014 (33.22) and had no significant difference with July 2014 (36.99).

4.1.2.3 Species emerged from mango

The mean number of different fruit fly species emerged from infested fruits was recorded (Table 9). Different species of fruit flies emerged from infested fruits were *B. dorsalis* (Plate 9a and b) and *B. caryeae* (Plate 9c and d). The computed t-value of 2.024 revealed that there is a significant difference between the mean number of *B. dorsalis* (42.00) and *B. caryeae* (16.80) emerged during rearing.

4.1.3 Reaction of mango and guava varieties against fruit fly attack

4.1.3.1 Incidence of fruit fly in different mango varieties

4.1.3.1.1 Fruit fly infestation in different mango varieties

The results (Table 10) revealed that the variety Bangalora showed significantly higher per cent fruit infestation (99.69 %). This was followed by the varieties Vellayani Local (97.43 %), Neelum (93.38 %), Kappa (86.95 %) and Kalapady (77.75 %) and is statistically different from each other. However, the varieties Vellari (70.30 %), Mulgoa (66.78 %) and Neelamundappa (63.04 %) did not differ significantly. No fruit damage was observed for the local variety Kottukonam Varikka. Significantly moderate per cent infestation was observed in Alphonso (46.12 %) and Kasthoori (43.67 %).

Based on the percentage infestation, Neelum, Mulgoa, Bangalora, Vellari, Kalapady, Vellayani Local, Neelamundappa and Kappa were categorized as highly

Table 8. Population of maggot during peak season of mango

Month	No. of maggots per infested fruit*
April 2014	33.22 (5.85)
May 2014	71.26 (8.50)
June 2014	82.49 (9.13)
July 2014	36.99 (6.17)
CD (0.05)	**(1.676)**

*Mean of 20 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

Table 9. Fruit fly species emerged from mango

Fruit fly species	No. of flies emerged*
B. dorsalis	42.00
B. caryeae	16.80
t- value (0.05)	**2.024**

*Mean of 20 replications

Plate 9a. *B. dorsalis*- dorsal view

Plate 9b. *B. dorsalis*- ventral view

Plate 9c. *B. caryeae*- dorsal view

Plate 9d. *B. caryeae*- ventral view

Plate 9. Species emerged from mango

susceptible varieties whereas Kasthoori and Alphonso were susceptible. The variety Kottukonam Varikka was ranked as totally immune.

4.1.3.1.2 Population of maggot in different mango varieties

The variety Bangalora recorded the highest number of maggots per fruit (117.20) and was significantly different from the other varieties (Table 10). This was closely followed by the varieties Kalapady (86.79), Kasthoori (84.30) and Mulgoa (84.13) and they were statistically on par with each other. No maggots were seen in the fruits of local variety Kottukonam Varikka. The number of maggots was significantly low in variety Vellayani local (44.22). The mean number of maggots in the variety Neelamundappa (65.97) was on par with the variety Neelum (70.47) and Alphonso (64.27). This was followed by the variety Vellari (50.85).

4.1.3.1.3 Fruit fly emergence from different mango varieties

Two species of fruit flies were reared out from different mango varieties viz., *B. dorsalis* and *B. caryeae*. The variety Bangalora recorded the highest number (75.50) of *B. dorsalis* emergence (Table 11). No flies emerged from the variety Kottukonam Varikka. The lowest number of flies emerged from the variety Vellayani Local (28.33) and it was on par with the variety Vellari (29.87). The varieties Kasthoori (55.90) and Kalapady (51.55) were observed to be statistically on par with the varieties Kappa (53.65), Mulgoa (53.35) and Neelum (47.89). These were followed by the varieties Alphonso (40.67) and Neelamundappa (40.58) which were on par with each other.

The highest number of *B. caryeae* emerged from the variety Kalapady (26.39). However, it was statistically on par with the varieties Kasthoori (25.00), Kappa (21.20), Bangalora (21.01) and Neelum (20.99). These were followed by the varieties Mulgoa (14.22), Neelamundappa (13.90), Vellayani Local (12.01) and Vellari (10.01), respectively and were statistically on par. The minimum number of

Table 10. Occurrence of fruit fly infestation in different mango varieties

Variety	Percentage infestation*	Maggots per fruit**	Category
Neelum	93.38 (75.09)	70.47 (8.45)	HS
Mulgoa	66.78 (54.80)	84.13 (9.22)	HS
Bangalora	99.69 (86.77)	117.2 (10.88)	HS
Vellari	70.30 (56.98)	50.85 (7.20)	HS
Kalapady	77.75 (61.85)	86.79 (9.37)	HS
Kasthoori	43.67 (41.37)	84.30 (9.23)	S
Vellayani Local	97.43 (80.79)	44.22 (6.72)	HS
Neelamundappa	63.04 (52.55)	65.97 (8.19)	HS
Kottukonam Varikka	0.00 (1.00)	0.00 (1.00)	TI
Alphonso	46.12 (42.78)	64.27 (8.08)	S
Kappa	86.95 (68.82)	83.89 (9.21)	HS
CD (0.05)	**(4.621)**	**(0.351)**	

*Figures in parentheses are angular transformed values

**Figures in parentheses are $\sqrt{x+1}$ transformed values

TI- Totally immuneHS- Highly susceptible S- Susceptible

B. caryeae was emerged from the variety Alphonso and the variety Kottukonam Varikka recorded no fruit fly emergence.

4.1.3.2 Incidence of fruit fly in different guava varieties

Percentage infestation, population of maggot and species emerged from different varieties of guava are given in Table 12.

4.1.3.2.1 Fruit fly infestation in different guava varieties

Pink fleshed varieties of guava were more susceptible to attack of *B. dorsalis* with an infestation of 14.50 per cent. This was followed by white fleshed varieties (14.00 %) and the small fruited variety, strawberry guava (8.75 %).

4.1.3.2.2 Population of maggot in guava varieties

The white fleshed variety recorded the highest number of maggots per fruit (25.00). However, it was statistically on par with pink fleshed varieties (24.35). The number of maggots was significantly lower in strawberry guava (1.30).

4.1.3.2.3 Species emerged from guava

The white fleshed variety recorded the maximum emergence of *B. dorsalis* (19.20). This was followed by pink fleshed varieties (18.35). Significantly lower fruit fly emergence was observed in strawberry guava (1.25).

4.1.4 Natural enemies

A predatory spider, lynx spider (*Oxyopes* sp.) (Plate 10a) and a larval-pupal parasitoid, *Opius* sp. (Hymenoptera: Braconidae) (Plate 10b) were observed in the field during the survey.

Table 11. Effect of varieties on the emergence of fruit fly

Variety	Number of fruit fly emerged per fruit*	
	B. dorsalis	***B. caryeae***
Neelum	47.89 (6.99)	20.99 (4.69)
Mulgoa	53.35 (7.38)	14.22 (3.90)
Bangalora	75.50 (8.74)	21.01 (4.70)
Vellari	29.87 (5.55)	10.01 (3.31)
Kalapady	51.55 (7.24)	26.39 (5.23)
Kasthoori	55.90 (7.54)	25.00 (5.10)
Vellayani Local	28.33 (5.41)	12.01 (3.60)
Neelamundappa	40.58 (6.44)	13.90 (3.87)
KottukonamVarikka	0.00 (1.00)	0.00 (1.00)
Alphonso	40.67 (6.45)	4.49 (2.34)
Kappa	53.65 (7.40)	21.20 (4.71)
CD (0.05)	**(0.375)**	**(0.750)**

*Mean of 20 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

Table 12. Infestation of fruit fly in guava varieties

Variety	Fruit infestation* (%)	No. of maggots per fruit*	No. of *B. dorsalis* emerged per fruit*
White fleshed variety	14.00	25.00	19.20
Pink fleshed variety	14.50	24.35	18.35
Strawberry guava	8.75	1.30	1.25
CD (0.05)	**0.310**	**0.663**	**0.532**

*Mean of 20 replications

Plate 10a. *Oxyopes* sp.

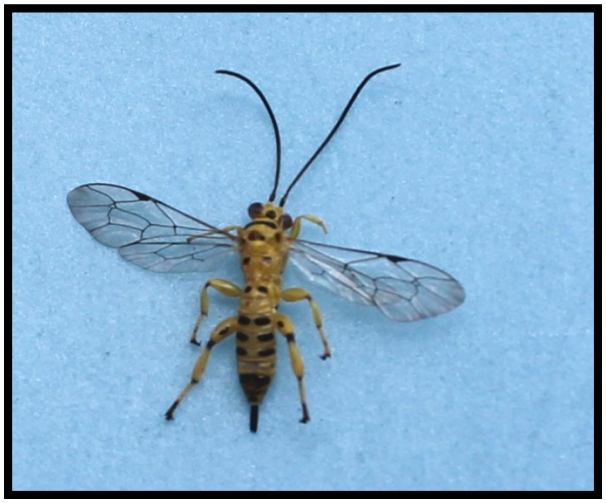


Plate 10b. *Opius* sp.

Plate 10. Natural enemies observed in field

4.1.5 Population dynamics of fruit flies

The species of fruit flies captured in the traps include four species *viz., B. dorsalis, B. caryeae, Bactrocera correcta* (Bezzi) (Plate 11a and b) and *Bactrocera zonata* (Saunders) (Plate 11c and d).

4.1.5.2 Species dominance

Population of *B. caryeae* (2447.85) was significantly higher than the population of other species of fruit flies (Table 13). This was followed by *B. dorsalis* with a mean population of 1141.54. The population of *B. correcta* and *B. zonata* were statistically on par with a mean of 66.35 and 1.93, respectively.

4.1.5.3 Population fluctuation of different species of fruit flies

Population fluctuation of *B. dorsalis*, *B. caryeae*, *B. correcta* and *B. zonata* were studied for a period of one year (Table 14).

4.1.5.3.1 Population of *B. dorsalis*

B. dorsalis recorded a significantly higher population during June 2014 (124.82). This was followed by May 2014 (86.75) which was on par with July 2014 (70.93). The lowest catch of *B. dorsalis* was during the month of December 2014 (21.98). However, it was statistically on par with the trap catches recorded for November 2014 (30.63) and January 2015 (28.08).

4.1.5.3.2 Population of *B. caryeae*

Significantly higher catch of *B. caryeae* was during the month of June 2014 (278.91). It was on par with the catch during the month of May 2014 (197.97). The population of *B. caryeae* was the lowest during the month of February 2015 (15.50). However, it was statistically on par with the population recorded during November 2014 (42.48), December 2014 (28.82) and January 2015 (16.70).

Table 13.Occurrence of different species of fruit flies in the field

Species of fruit fly	**Population* (No. of flies per trap)**
B. dorsalis	1141.54 (33.80)
B. caryeae	2447.85 (49.48)
B. correcta	66.35 (8.20)
B. zonata	1.93 (1.71)
CD (0.05)	**(15.411)**

*Mean of 15 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

Plate 11a. ***B. correcta***

Plate 11b. Antennal spot fusing in ***B. correcta***

Plate 11c. ***B. zonata***

Plate 11d. Antennal spot not fusing in ***B. zonata***

Plate 11. Species collected from traps other than ***B. dorsalis*** **and** ***B. caryeae***

4.1.5.3.3 Population of *B. correcta*

The highest population level of *B. correcta* was recorded during July 2014 (9.27). This was followed by the population during the month of June 2014 (6.87) and August 2014 (4.97). The lowest catch of *B. correcta* was observed during December 2014 (2.07) but was on par with September 2014 (3.30), February 2015 (2.88), March 2014 (2.82), January 2015 (2.80), October 2014 (2.77) and November 2014 (2.20).

4.1.5.3.4 Population of *B. zonata*

Population level of *B. zonata* was very low and did not differ significantly between the months throughout the year. The maximum catch of *B. zonata* was recorded during April 2014 (0.50). This was followed by June 2014 (0.40), May 2014 (0.34), October 2014 (0.13) and February 2015 (0.13). No fly catch was recorded during March 2014, August 2014, September 2014, November 2014, December 2014 and January 2015.

4.1.5.4 Correlation between different species of fruit fly population with weather parameters

The average of the monthly weather data *viz.,* rainfall, maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, average relative humidity and sunshine hours were worked out (Table 15). The monthly weather parameters were correlated with the population of different species of fruit flies during 2014-15 and correlation coefficients were studied (Table 16).

4.1.5.4.1 *B. dorsalis*

Correlation coefficients between the population of *B. dorsalis* and weather parameters revealed that the population had a negative correlation with rainfall, but the relationship was not significant. However, maximum temperature, minimum

Table 14. Monthly catch of fruit flies in methyl eugenol traps

Month	Monthly trap catch*(No. of flies per trap)			
	B. dorsalis	***B. caryeae***	***B. correcta***	***B. zonata***
Mar-14	48.99 (7.08)	186.52 (13.70)	2.82 (1.95)	0.00 (1.00)
Apr-14	60.43 (7.83)	157.54 (12.60)	4.23 (2.29)	0.50 (1.22)
May-14	86.75 (9.37)	197.97 (14.10)	4.50 (2.34)	0.34 (1.19)
Jun-14	124.82 (11.21)	278.91 (16.73)	6.87 (2.80)	0.40 (1.19)
Jul-14	70.93 (8.48)	132.35 (11.54)	9.27 (3.20)	0.29 (1.13)
Aug-14	44.21 (6.72)	75.97 (8.78)	4.97 (2.44)	0.00 (1.00)
Sep-14	45.40 (6.81)	63.60 (8.03)	3.30 (2.08)	0.00 (1.00)
Oct-14	38.50 (6.29)	53.19 (7.37)	2.77 (1.94)	0.13 (1.07)
Nov-14	30.63 (5.62)	42.48 (6.60)	2.20 (1.78)	0.00 (1.00)
Dec-14	21.98 (4.80)	28.82 (5.47)	2.07 (1.75)	0.00 (1.00)
Jan-15	28.08 (5.40)	16.70 (4.20)	2.80 (1.94)	0.00 (1.00)
Feb-15	36.02 (6.09)	15.50 (4.07)	2.88 (1.97)	0.13 (1.07)
CD (0.05)	**(1.172)**	**(2.902)**	**(0.392)**	**NS**

*Mean of 15 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

Table 15. Weather parameters during study period March 2014 to February 2015

Month	Monthly mean weather parameter						
	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Morning relative humidity (%)	Evening relative humidity (%)	Average relative humidity (%)	Rainfall (mm)	Sun shine (hour)
Mar-14	30.91	21.53	91.90	66.54	79.22	9.50	8.82
Apr-14	31.61	22.32	91.20	73.60	82.40	7.00	9.31
May-14	32.41	22.88	90.03	78.45	84.24	7.88	11.69
Jun-14	32.77	24.48	92.47	79.17	85.82	9.58	9.02
Jul-14	31.94	24.73	91.90	77.59	84.74	21.56	8.69
Aug-14	30.91	23.18	90.78	81.22	86.00	3.14	8.98
Sep-14	29.99	24.30	90.8	78.97	84.88	5.83	3.81
Oct-14	29.55	23.74	82.41	86.93	84.67	31.55	5.37
Nov-14	30.21	24.19	93.47	77.23	85.35	16.88	4.15
Dec-14	30.52	23.82	91.25	74.87	83.06	12.11	4.15
Jan-15	30.60	21.56	93.87	63.41	79.43	0.25	9.15
Feb-15	31.56	22.34	91.78	64.71	78.25	0.00	9.35

temperature, evening relative humidity, average relative humidity and sunshine hours showed a significant positive correlation with the population of *B. dorsalis*. The morning relative humidity did not show any effect on fruit fly population. It showed a positive correlation but the relationship was not significant with population of *B. dorsalis*.

4.1.5.4.2 *B. caryeae*

The population of *B. caryeae* had a significant positive correlation with maximum temperature, average relative humidity and sun shine hours. However, the population was negatively correlated with rainfall but was not significant. Minimum temperature, morning relative humidity and evening relative humidity showed a positive correlation but the association was not enough to get statistical significance.

4.1.5.4.3 *B. correcta*

The population had a significant positive correlation with maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, average relative humidity and sunshine hours.

4.1.5.4.4 *B. zonata*

Population build up was observed to be negatively correlated with minimum temperature, morning relative humidity and average relative humidity. The correlation coefficients were -0.0076, -0.5790 and -0.1446, respectively but did not vary significantly. Rainfall, maximum temperature and sunshine hours were positively correlated with population growth of *B. zonata* and was significant.

4.1.5.4.5 Total fruit fly population

The total fruit fly population was negatively correlated with rainfall. However, it shows a significant positive correlation with maximum temperature and sunshine hours. The correlation coefficients expressed a positive association of the

Table 16. Correlation of population of different fruit fly species with weather parameters

Weather parameters	*B. dorsalis*	*B. caryeae*	*B. correcta*	*B. zonata*	Total fly
Rainfall (mm)	-0.0005	-0.0080	0.1007	0.2719**	-0.0054
Maximum temperature(^{0}C)	0.8199**	0.7459**	0.7630**	0.1829**	0.7769**
Minimum temperature(^{0}C)	0.2513**	0.0096	0.3347**	-0.0076	0.06744
Morning RH (%)	0.0874	0.1033	0.1569*	-0.5790	0.1022
Evening RH (%)	0.2461**	0.1181	0.2219**	0.1421	0.1502
Average RH (%)	0.3420**	0.1823**	0.3511**	-0.1446	0.2234
Sun shine (hour)	0.5273**	0.5561**	0.5543**	0.2263**	0.5602**

*Significant at 1% level

**Significant at 5% level

population with minimum temperature, morning relative humidity, evening relative humidity and average relative humidity, but were not statistically significant.

4.2 BIOLOGY OF MANGO FRUIT FLY

The duration of different stages of *B. dorsalis* (Plate 12) was studied in different mango varieties and hosts under laboratory conditions.

4.2.1 Biology of *B. dorsalis* in different mango varieties

Analysis of results (Table 17) revealed that the egg period and larval period did not differ significantly with each other. However, the pupal period was longer (11.40 ± 1.18) in the variety Bangalora. It was significantly different from other varieties. The duration of pupa on the varieties Mulgoa (10.10 ± 1.38), Neelum (9.80 ± 0.63) and Vellari (9.70 ± 0.82) were statistically on par.

Significantly higher adult longevity (20.70 ± 2.31) was recorded for the variety Bangalora and it was statistically similar with the variety Mulgoa (19.60 ± 2.88) and on par with the variety Neelum (17.90 ± 2.02). A significantly shorter duration in adult longevity was seen in Vellari (17.70 ± 1.82), compared with other varieties.

4.2.2 Comparative biology of *B. dorsalis* in different hosts

The results on the duration of life stages of *B. dorsalis* in different hosts are presented in Table 18. The egg period in different hosts was not significantly different with each other. The highest larval duration (12.90 ± 1.85) was observed in banana. The larval period in mango, papaya and sapota was found to be 11.60 ± 1.71, 11.50 ± 1.59 and 10.80 ± 1.22 days, respectively. Larva has a shorter duration (9.70 ± 0.82) in guava and it was on par with sapota.

A longer pupal period was observed in banana (10.30 ± 1.33) which was statistically on par with mango (10.20 ± 0.91) and papaya (10.00 ± 1.05), followed by

Plate 12a. Egg cluster

Plate 12b. Larva

Plate 12c. Pupa

Plate 12d. Adult

Plate 12. Life stages of mango fruit fly, *B. dorsalis*

guava (9.10 ± 0.73). A significant shorter duration (8.30 ± 1.15) of pupa was observed in sapota. Pupal period was found to be significantly minimum in sapota than other hosts.

Maximum duration of adult longevity (19.70 ± 2.40) was observed in mango. However, it was statistically similar with papaya (19.10 ± 1.67) and guava (19.00 ± 2.17). Duration of adult was observed to be significantly shorter in sapota (16.80 ± 2.09) and was on par with banana (18.00 ± 2.27).

4.3 EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIOAGENTS IN FOOD BAIT IN THE LABORATORY

The data on efficacy of freshly emerged adults of *B. dorsalis* treated with different new generation insecticides, botanicals and bioagents were depicted in Table 19.

4.3.1 Effect of different treatments on the adults of *B. dorsalis*

Mortality of adult flies recorded on the first day after treatment showed the superiority of synthetic pyrethroid, lambda cyhalothrin 0.005% (T_3) with higher mortality of 56.70 per cent. However, it was on par with malathion 0.1% (T_9) (50.00 %) and spinosad 0.02% (T_7) (39.85 %) was observed to be equally effective as that of malathion 0.1%.

Considering the mortality on the second day after treatment, none of the treatments was superior to lambda cyhalothrin 0.005% (T_3) (98.85 %). The treatments malathion 0.1% (T_9) and spinosad 0.02% (T_7) were equally effective with 70.33 and 67.09 per cent respectively.

At the end of the third day, lambda cyhalothrin 0.005% (T_3) recorded cent per cent mortality and was on par with malathion 0.1% (T_9) (98.85 %). This was followed by spinosad 0.02% (T_7) with 90.00 per cent mortality.

Table 17. Biology of *B. dorsalis* in different mango varieties

Varieties	Duration of different stages in days (Mean ± SD)*			
	Egg	**Larva**	**Pupa**	**Adult**
Neelum	2.20 ± 0.79	11.50 ± 1.78	9.80 ± 0.63	17.90 ± 2.02
Mulgoa	2.60 ± 0.84	11.20 ± 1.54	10.10 ± 1.38	19.60 ± 2.88
Bangalora	2.30 ± 0.82	9.80 ± 1.03	11.40 ± 1.18	20.70 ± 2.31
Vellari	2.90 ± 0.73	10.80 ± 1.48	9.70 ± 0.82	17.70 ± 1.82
CD (0.05)	**NS**	**NS**	**0.785**	**1.731**

*Mean of ten replications

Table 18. Comparative biology of *B. dorsalis* in different hosts

Hosts	Duration of different stages in days (Mean ± SD)*			
	Egg	**Larva**	**Pupa**	**Adult**
Mango	2.60 ± 0.97	11.60 ± 1.71	10.20 ± 0.91	19.70 ± 2.40
Guava	2.50 ± 1.09	9.70 ± 0.82	9.10 ± 0.73	19.00 ± 2.17
Banana	2.60 ± 0.84	12.90 ± 1.85	10.30 ± 1.33	18.00 ± 2.27
Papaya	2.90 ± 0.73	11.50 ± 1.59	10.00 ± 1.05	19.10 ± 1.67
Sapota	2.50 ± 0.70	10.80 ± 1.22	8.30 ± 1.15	16.80 ± 2.09
CD (0.05)	**NS**	**1.116**	**0.798**	**1.601**

*Mean of ten replications

Observations recorded on the fourth day showed 100 per cent mortality for malathion 0.1% (T_9) and spinosad 0.02% (T_7). The treatment lambda cyhalothrin 0.0025% (T_4) recorded a mortality percentage of 98.85 per cent.

After the fifth day, lambda cyhalothrin 0.0025% (T_4) showed 100 per cent mortality of flies. The mortality observed with deltamethrin 0.04% (T_1) and spinosad 0.01% (T_8) increased to 83.64 and 80.69, respectively. Significantly lower percentage of mortality of flies were recorded for *B. bassiana* (ITCC 6063) WP 2% (T_{11}) and *P. lilacinus* (ITCC 6064) WP 2% (T_{12}) with 36.60 and 40.00 per cent mortality, respectively and are statistically on par.

On the sixth day after treatment, spinosad 0.01% (T_8) also recorded 100 per cent mortality and the mortality observed with deltamethrin 0.04% (T_1) and chlorantraniliprole 0.006% (T_5) increased to 95.47 and 93.30 per cent, respectively. This was followed by deltamethrin 0.02% (T_2), chlorantraniliprole 0.003% (T_6) and azadirachtin 0.003% (T_{10}) which was on par, mortality being 83.64 per cent each.

At the end of the seventh day, all the insecticides were found to be equally effective with their mortality ranging from 98.85 to 100 per cent. The botanical insecticide, azadirachtin 0.003% (T_{10}) (95.47 %) was on par with insecticides *viz.,* deltamethrin 0.02% (T_2), chlorantraniliprole 0.006% (T_5) and chlorantraniliprole 0.003% (T_6) with 98.85 per cent mortality each. Lower mortality per cent was recorded for *B. bassiana* (ITCC 6063) WP 2% (T_{11}) and *P. lilacinus* (ITCC 6064) WP 2% (T_{12}) with 53.35 and 60.00 per cent, respectively and were on par.

Based on the above observations under laboratory conditions, all the insecticides were equally effective after seven days of treatment, even though significant variations were noticed during the early hours of treatment. Therefore, the superiority of treatments was tested based on the time taken to cause 50 per cent mortality (LT_{50}). LT_{50} values of the above mentioned treatments are given in Table 20.

Table 19. Cumulative per cent mortality of adult flies in bait application technique (BAT) under laboratory conditions

TREATMENTS	Days after treatment*						
	1	**2**	**3**	**4**	**5**	**6**	**7**
T1- Deltamethrin 0.04%	19.31 (26.08)	29.67 (33.00)	43.17 (41.08)	60.14 (50.85)	83.64 (66.14)	95.47 (77.71)	100.00 (90.00)
T2- Deltamethrin 0.02%	13.01 (21.14)	28.79 (23.17)	36.60 (37.22)	53.35 (46.92)	73.49 (54.00)	83.64 (66.14)	98.85 (83.85)
T3- Lambda cyhalothrin 0.005%	56.70 (48.84)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
T4- Lambda cyhalothrin 0.0025%	33.25 (35.21)	46.64 (43.08)	63.40 (52.78)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
T5- Chlorantraniliprole 0.006%	13.01 (21.14)	26.51 (30.99)	40.00 (39.23)	56.70 (48.84)	70.33 (63.92)	93.30 (75.00)	98.85 (83.85)
T6- Chlorantraniliprole 0.003%	10.00 (18.43)	20.00 (26.56)	39.85 (39.14)	56.70 (48.84)	70.33 (63.92)	83.64 (66.14)	98.85 (83.85)
T7- Spinosad 0.02%	39.85 (39.14)	67.09 (54.99)	90.00 (71.57)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
T8- Spinosad 0.01%	16.35 (23.85)	29.67 (33.00)	43.17 (41.08)	67.22 (55.08)	80.69 (63.929)	100.00 (90.00)	100.00 (90.00)
T9- Malathion 0.1%	50.00 (45.00)	70.33 (56.99)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
T10- Azadirachtin 0.003%	13.01 (21.14)	26.20 (30.78)	39.85 (39.14)	63.40 (52.78)	73.49 (59.00)	83.64 (66.14)	95.47 (77.71)
T11- *B. bassiana* (ITCC 6063) WP 2%	0.00 (0.00)	4.53 (12.29)	16.35 (23.85)	29.67 (33.00)	36.60 (37.22)	46.64 (43.08)	53.35 (46.92)
T12- *P. lilacinus* (ITCC 6064) WP 2%	0.00 (0.00)	10.00 (18.43)	23.18 (28.79)	36.90 (37.22)	40.00 (39.21)	53.35 (46.92)	60.00 (50.77)
CD (0.05)	**(6.170)**	**(8.967)**	**(7.396)**	**(7.356)**	**(6.034)**	**(7.931)**	**(8.689)**

Figures in parentheses are angular transformed values

Analysis of LT_{50} values showed that, the time taken for 50 per cent mortality was the lowest in lambda cyhalothrin 0.005% (T_3) (0.63 day) and malathion 0.1% (1.12 days) (T_9) which were on par. This was followed by lambda cyhalothrin 0.0025% (T_4) (1.70 days) and spinosad 0.02% (T_7) (1.29 days) and was statistically on par. Other treatments with insecticides recorded LT_{50} value more than two days. The time taken for mortality was significantly higher for *B. bassiana* (ITCC 6063) WP 2% (T_{11}) with LT_{50} value of 6.28 days.

4.4 EVALUATION OF EFFICACY OF THE CHEMICALS IN MALE ANNIHILATION TECHNIQUE IN THE LABORATORY

The freshly emerged adult male flies of *B. dorsalis* treated with different new generation insecticides were observed for mortality on each day for a period of seven days (Table 21).

4.4.1 Effect of new generation insecticides on the adult male flies of *B. dorsalis*

A higher mortality percentage of 39.85 were recorded for spinosad 6: 4: 0.2 (T_6) which was on par with malathion 6: 4:1 (T_9) with a percentage mortality of 33.25 on the first day.

At the end of the second day, spinosad 6: 4: 0.2 (T_6) and malathion 6: 4: 1(T_9) were equally effective and the mortality observed was 53.35 per cent. This was followed by deltamethrin 6: 4: 0.4 (T_2) and spinosad 6: 4: 0.02 (T_5) with 36.60 and 32.91 per cent, respectively and were on par. A similar trend was observed at the end of the third day also.

On the fourth day, spinosad 6: 4: 0.2 (T_6) showed 100 per cent mortality of flies and was statistically same with malathion 6: 4: 1 (T_9) (98.85 per cent). Deltamethrin 6: 4: 0.4 (T_2) and spinosad 6: 4: 0.02 (T_5) recorded 77.84 and 76.82 per cent mortality, respectively and were on par. The mortality observed with imidacloprid 6: 4: 0.05 (T_8), imidacloprid 6: 4: 0.005 (T_7) and lambda cyhalothrin 6:

Table 20. Efficacy of treatments in bait application technique based on LT_{50} values

Treatments	Quantity used per 100ml	LT_{50} (days)
T1- Deltamethrin 0.04%	1.42 ml	2.62
T2- Deltamethrin 0.02%	0.71 ml	3.09
T3- Lambda cyhalothrin 0.005%	0.10 ml	0.63
T4- Lambda cyhalothrin 0.0025%	0.05 ml	1.70
T5- Chlorantraniliprole 0.006%	0.032 ml	3.05
T6- Chlorantraniliprole 0.003%	0.01 ml	3.24
T7- Spinosad 0.02%	0.044 ml	1.29
T8- Spinosad 0.01%	0.02 ml	2.62
T9- Malathion 0.1%	0.2 ml	1.12
T10- Azadirachtin 0.003%	10 ml	3.01
T11- *B. bassiana* (ITCC 6063) WP 2%	2 gm	6.28
T12- *P. lilacinus*(ITCC 6064) WP 2%	2 gm	5.62
CD (0.05)		**0.525**

Table 21. Cumulative per cent mortality of adult flies in MAT under laboratory conditions

TREATMENTS (Alcohol: Methyl Eugenol: Insecticides) (V: V: V)	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
T1 Deltamethrin 6: 4: 0.04	1.14 (6.14)	13.01 (21.14)	23.17 (28.79)	36.60 (37.22)	60.14 (50.85)	80.69 (63.92)	93.30 (75.00)
T2 Deltamethrin 6: 4: 0.4	19.31 (26.08)	36.60 (37.22)	53.35 (46.92)	77.84 (61.92)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)
T3 Lambda cyhalothrin 6: 4: 0.005	0.00 (0.00)	1.14 (6.14)	19.31 (26.08)	36.60 (37.22)	50.00 (45.00)	60.14 (50.85)	73.49 (59.00)
T4 Lambda cyhalothrin 6: 4: 0.05	4.53 (12.29)	13.01 (21.14)	26.51 c (30.99)	39.85 (39.14)	56.83 (48.92)	73.49 (59.00)	83.64 (66.14)
T5 Spinosad 6: 4: 0.02	19.31 (26.07)	32.91 (35.00)	56.70 b (48.84)	76.82 (61.21)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)
T6 Spinosad 6: 4: 0.2	39.85 (39.14)	53.35 (46.92)	80.00 (63.43)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
T7 Imidacloprid 6: 4: 0.005	1.14 (6.14)	13.01 (21.14)	29.67 (33.00)	46.64 (43.08)	70.33 (56.99)	77.54 (61.71)	90.74 (72.29)
T8 Imidacloprid 6: 4: 0.05	19.31 (26.08)	16.35 (23.85)	29.67 (33.002)	50.00 (45.00)	76.82 (61.21)	93.30 (75.00)	98.85 (83.85)
T9 Malathion 6: 4: 1	33.25 (35.21)	53.35 (46.92)	76.82 (61.21)	98.85 (83.85)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
CD (0.05)	**11.651**	**8.474**	**7.229**	**8.716**	**9.388**	**8.982**	**11.272**

Figures in parentheses are angular transformed values

4: 0.05 (T_4) too increased to 50.00, 46.64 and 39.85 per cent, respectively and are equally effective. This was followed by lambda cyhalothrin 6: 4: 0.005 (T_3) and deltamethrin 6: 4: 0.04 (T_1) which were on par, mortality being 36.60 per cent.

After the fifth day, malathion 6: 4: 1 (T_9) showed 100 per cent mortality and was found to be statistically on par with spinosad 6: 4: 0.02 (T_5) and deltamethrin 6: 4: 0.4 (T_2) with 98.85 per cent mortality. Significantly lower mortality was observed with lambda cyhalothrin 6: 4: 0.05 (T_4) and lambda cyhalothrin 6: 4: 0.005 (T_3) (56.83 and 50.00, respectively).

Observations recorded on the sixth day showed 100 per cent mortality for spinosad 6: 4: 0.02 (T_5) and deltamethrin 6: 4: 0.4 (T_2). The mortality observed for imidacloprid 6: 4: 0.05 (T_8) and deltamethrin 6: 4: 0.04 (T_1) increased to 93.30 and 80.69 per cent, respectively.

At the end of the seventh day, all the insecticides were equally effective with the mortality ranging from 90.74 to 100.00 per cent except lambda cyhalothrin 6: 4: 0.005 (T_3) and lambda cyhalothrin 6: 4: 0.05 (T_4) (83.64 %). However, a significantly lower mortality was observed for lambda cyhalothrin 6: 4: 0.005 (T_3) (73.49 %).

Based on the above observations under laboratory conditions, all insecticides were equally effective after seven days of treatment. Promising insecticides were selected based on the time taken to cause 50 per cent mortality (LT_{50}). LT_{50} values of the above mentioned treatments are presented in Table 22.

LT_{50} values of spinosad 6: 4: 0.2 (T_6) and malathion 6: 4: 1 (T_9) were observed to be 1.43 and 1.57 days, respectively and were on par. This was followed by spinosad 6: 4: 0.02 (T_5) (2.21 days) and deltamethrin 6: 4: 0.4 (T_2) (2.22 days). Other treatment recorded LT_{50} values more than three days with significantly higher LT_{50} value of 5.03 days for lambda cyhalothrin 6: 4: 0.005 (T_3).

Table 22. Efficacy of insecticides in male annihilation technique based on LT_{50} values

Treatments (Alcohol: Methyl Eugenol: Insecticides) (V: V: V)	Quantity used per 100ml	LT_{50} (days)
T1- Deltamethrin 6: 4: 0.04	0.40 ml	4.11
T2- Deltamethrin 6: 4: 0.4	3.84 ml	2.22
T3- Lambda cyhalothrin 6: 4: 0.005	0.05 ml	5.03
T4- Lambda cyhalothrin 6: 4: 0.05	0.5 ml	4.22
T5- Spinosad 6: 4: 0.02	0.05 ml	2.21
T6- Spinosad 6: 4: 0.2	0.5 ml	1.43
T7- Imidacloprid 6: 4: 0.005	0.20 ml	3.90
T8- Imidacloprid 6: 4: 0.05	2 ml	3.41
T9- Malathion 6: 4: 1	9 ml	1.57
CD (0.05)		**0.676**

4.5 PEAK TIME ACTIVITY OF FRUIT FLIES

The peak time activity of different species of fruit flies in mango during April 2014 using methyl eugenol traps is presented in Table 23. The species of fruit flies captured in the traps are *B. dorsalis, B. caryeae* and *B. correcta*.

4.5.1 Effect of time of the day on the diurnal activity of fruit flies

The mean maximum catch (6.92) of *B. dorsalis* was during early morning hours, 6-8 am. This was followed by 8-10 am (3.29) and 4-6 pm (2.94). A similar trend was also observed in the case of *B. caryeae* with maximum catch (6.64) during 6-8 am followed by 8-10 am (2.94). Population of *B. correcta* was more active during the evening hours 4-6 pm (0.94). This was followed by 2-4 pm (0.68) and 6-8 am (0.54). The mean minimum number of flies captured was during noon hours 12-2 pm with 1.89, 1.10 and 0.48 flies per trap for *B. dorsalis*, *B. caryeae* and *B. correcta*, respectively.

4.6 EVALUATION OF BAIT APPLICATION TECHNIQUE IN THE FIELD

Results of the laboratory studies revealed the efficacy of four promising treatments in BAT for field evaluation. The treatments were selected based on the per cent mortality of flies and LT_{50} values. The treatments included for field study were lambda cyhalothrin 0.005% (T_1), spinosad 0.02% (T_2), lambda cyhalothrin 0.0025% (T_3) and malathion 0.1% (T_4). Field evaluation was conducted during the fruiting season of mango, May 2015.

4.6.1 Effect of insecticides on population of fruit fly

The results of male, female and total fly catch recorded are given in Table 24.

4.6.1.1 Male fly catch

Observations recorded one week after treatment indicated that spinosad 0.02% (T_2) showed higher male catch (10.50) and it was on par with the treatments lambda

Table 23. Peak time activity of fruit flies

Time interval	Trap catch* (No. of flies/ trap/ day)		
	B. dorsalis	***B. caryeae***	***B. correcta***
6-8 am	6.92	6.64	0.54
8-10 am	3.29	2.94	0.51
10-12 am	2.12	1.71	0.51
12-2 pm	1.89	1.10	0.48
2-4 pm	2.09	1.12	0.68
4-6 pm	2.94	1.12	0.94
CD (0.05)	**0.894**	**0.726**	**0.149**

*Mean of ten replications

cyhalothrin 0.005% (T_1) (8.50) and malathion 0.1% (T_4) (8.33). Significantly lower male catch was recorded for the treatment lambda cyhalothrin 0.0025% (T_3) (5.67).

A similar trend was also observed at the second week after treatment. The treatments spinosad 0.02% (T_2) (10.17), lambda cyhalothrin 0.005% (T_1) and malathion 0.1% (T_4) with catch being 9.17 flies each, did not differ significantly. Population of male flies trapped was significantly lower in lambda cyhalothrin 0.0025% (T_3) (2.50).

4.6.1.2 Female fly catch

On the first week after treatment, the female count was maximum for spinosad 0.02% (T_2) and malathion 0.1% (T_4) with 21.00 flies per trap and were statistically on par with that of lambda cyhalothrin 0.005% (T_1) (20.33). Minimum female catch was recorded for lambda cyhalothrin 0.0025% (T_3) (12.00).

After the second week, spinosad 0.02% (T_2) showed higher female catch of 21.50 flies per trap and did not differ statistically with malathion 0.1% (T_4) (21.17) and lambda cyhalothrin 0.005% (T_1) (18.67). Female count was significantly lower in lambda cyhalothrin 0.0025% (T_3) (13.83).

4.6.1.3 Total fruit fly catch

On the first week after treatment, the treatments involving food bait with spinosad 0.02% (T_2), malathion 0.1% (T_4) and lambda cyhalothrin 0.005% (T_1) recorded higher total fruit fly count of 31.50, 29.67 and 28.83, respectively and were on par. Total fly catch was the lowest for lambda cyhalothrin 0.0025% (T_3) (17.67).

Observations recorded on second week also revealed that spinosad 0.02% (T_2), malathion 0.1% (T_4) and lambda cyhalothrin 0.005% (T_1) were statistically on

Table 24. Effect of insecticides on the population of fruit flies in bait application technique

Treatments	Mean number per trap at weekly intervals*						
	1			2			
	Male	Female	Total	Male	Female	Total	Mean
T1- Lambda cyhalothrin 0.005%	8.50	20.33	28.83	9.17	18.67	27.83	56.67
T2- Spinosad 0.02%	10.50	21.00	31.50	10.17	21.50	31.67	63.17
T3- Lambda cyhalothrin 0.0025%	5.67	12.00	17.67	2.50	13.83	16.33	34.00
T4- Malathion 0.1%	8.33	21.00	29.67	9.17	21.17	29.67	59.33
CD (0.05)	**2.304**	**4.254**	**2.270**	**3.578**	**4.163**	**7.159**	**9.246**

*Mean of six replications

par with 31.67, 29.67 and 27.83, respectively. Significantly lower catch was observed for lambda cyhalothrin 0.0025% (T_3) (16.33). A similar trend was also observed for mean fruit fly catch.

4.7 EVALUATION OF MALE ANNIHILATION TECHNIQUE IN THE FIELD

Field study using promising insecticides selected from laboratory experiments were conducted during February 2015 - May 2015 for a period of three months. The treatments selected for field evaluation were spinosad 6: 4: 0.02 (T_1), spinosad 6: 4: 0.2 (T_2), deltamethrin 6: 4: 0.4 (T_3) and malathion 6: 4: 1 (T_4).

4.7.1 Effect of insecticides on population of fruit fly

The results of the field study on the efficacy of selected insecticides taken at fortnightly intervals are presented in Table 25.

4.7.1.1 Fruit fly catch

Data on the second week after treatment revealed that the treatments spinosad 6: 4: 0.2 (T_2) (123.81), spinosad 6: 4: 0.02 (T_1) (113.28) and malathion 6: 4: 1 (T_4) (112.89) did not differ significantly. The treatment deltamethrin 6: 4: 0.4 (T_3) (35.14) was significantly inferior to all other treatments.

On the fourth week after treatment, spinosad 6: 4: 0.2 (T_2) recorded higher fly catch (179.74) and was significantly different from all other treatments. This was followed by malathion 6: 4: 1 (T_4) (120.34) and spinosad 6: 4: 0.02 (T_1) (118.91) and was statistically on par. The fruit fly catch was significantly lower in deltamethrin 6: 4: 0.4 (T_3) (32.27). A similar trend was observed thereafter up to the fourteenth week after treatment with spinosad 6: 4: 0.2 as the superior treatment than all other treatments.

Table 25. Effect of insecticides on the population of fruit flies in male annihilation technique

Treatments (Alcohol: Methyl Eugenol: Insecticides) (V: V: V)	Mean number per trap at fortnightly intervals*						
	2	**4**	**6**	**8**	**10**	**12**	**14**
T1 Spinosad 6:4:0.02	113.28 (10.70)	118.91 (10.95)	122.38 (11.10)	139.58 (11.85)	164.80 (12.88)	133.70 (11.60)	129.40 (11.41)
T2 Spinosad 6:4:0.2	123.81 (11.17)	179.74 (13.44)	219.65 (14.85)	272.48 (16.53)	273.34 (16.57)	226.65 (15.09)	208.05 (14.45)
T3 Deltamethrin 6:4:0.4	35.14 (6.01)	32.27 (5.77)	39.09 (6.33)	52.34 (7.30)	42.80 (6.61)	41.64 (6.53)	39.83 (6.39)
T4 Malathion 6:4:1	112.89 (10.68)	120.34 (11.01)	137.80 (11.79)	147.29 (12.18)	168.21 (13.00)	154.20 (12.45)	138.24 (11.80)
CD (0.05)	**(1.131)**	**(2.082)**	**(2.162)**	**(2.264)**	**(1.633)**	**(1.558)**	**(1.865)**

*Mean of six replications

Figures in parentheses $\sqrt{x+1}$ transformed values

4.7.1.2 Duration of effective trap catch

Persistence of insecticides in field was assessed by recording the total fly catch and duration of effective trap catch (Table 26).

The results of the persistent toxicity of insecticides against fruit fly are presented in Table 25. The results revealed that spinosad 6: 4: 0.2 (T_2) recorded significantly higher total fruit fly catch (1371.08) followed by malathion 6: 4: 1 (T_4) (882.02) and spinosad 6: 4: 0.02 (T_1) (823.91) and were equally effective. Deltamethrin 6: 4: 0.4 (T_3) was the inferior treatment with a total fruit fly catch of 240.52 flies per trap.

Duration of effective trap catch was significantly higher for spinosad 6: 4: 0.2 (T_2) (108.68) and it was on par with treatments malathion 6: 4: 1 (T_4) (105.00) and spinosad 6: 4: 0.02 (T_1) (104.83). Significantly lesser duration of effective trap catch was observed for deltamethrin 6: 4: 0.4 (T_3) (91.83).

By considering the total fruit fly catch and duration of effective trap catch, spinosad 6: 4: 0.2 (T_2) was identified as the best treatment in the field.

Table 26. Persistent toxicity of insecticides against fruit flies

Treatments (Alcohol: Methyl Eugenol: Insecticides) (V: V: V)	Total fruit fly catch* (No. of flies/ trap)	Effective trap catches (days)
T1 Spinosad 6:4:0.02	823.91 (28.72)	104.83
T2 Spinosad 6:4:0.2	1371.08 (37.04	108.68
T3 Deltamethrin 6:4:0.4	240.52 (15.54)	91.83
T4 Malathion 6:4:1	882.02 (29.71)	105.00
CD (0.05)	**(3.798)**	**9.606**

*Mean of six replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

DISCUSSION

5. DISCUSSION

Mango is one of the most popular seasonal fruit crops well adapted to both tropics and subtropics with high potential for export (Litz *et al.,* 1995). The Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is a serious pest of fruit crops, especially that of mango because of its wide host range, destructiveness and distribution. Verghese *et al.* (2002) reported that the loss caused by mango fruit fly in India ranged from 1.00 to 31.00 per cent. Mango growers adopt chemical measures against fruit flies, including insecticide cover sprays, bait sprays, etc. Injudicious use of toxic chemicals causes health issues and pesticide residue problems. Pesticide load in the environment can be reduced by the use of eco-friendly management measures like bait application technique (BAT) and male annihilation technique (MAT). Present recommendation for BAT and MAT includes a conventional organophosphate insecticide, malathion (KAU, 2011). An attempt was made to standardize the use of new generation insecticides which are safe, target specific and required in lower dosages.

Pest status is influenced by the availability of hosts and climatic changes over the season. Hence, the changing pest scenario warrants a thorough knowledge on the economic significance of the pest in terms of its population dynamics and relationship with weather parameters. As a prerequisite for developing a control strategy, the study of host range, nature of damage, level of injury caused by the pest is essential. Hence a survey was conducted in the homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani during 2013-2015 to document the host range, incidence and population dynamics of mango fruit fly in different fruit crops. Laboratory and field evaluation to standardize the use of newer molecules in BAT and MAT were undertaken in the Department of Agricultural Entomology, College of Agriculture, Vellayani and homesteads of Balaramapuarm panchayath, respectively. The results of the study are discussed below.

5.1 POPULATION DYNAMICS AND HOST RANGE OF FRUIT FLIES

5.1.1 Documentation of pest incidence

Survey conducted revealed the incidence of *B. dorsalis* in three fruit crops *viz.,* mango, guava and banana, out of the five selected. No infestation was recorded from papaya and sapota from the field. This showed that both papaya and sapota were less acceptable hosts for fruit flies in Kerala. Since the present study was confined to a single panchayath of the Thiruvananthapuram district, definite conclusions could not be drawn from the data. Further studies are needed for confirmation of the results. Sapota is not commonly grown in the homesteads of Kerala. Hence its availability in the field is less, compared to mango, guava and banana. This can be another reason for the no preference of sapota by fruit flies in Kerala. It was also observed that *B. dorsalis* prefers soursop as one of its host. In recent days cultivation of soursop has increased to commercial level because of its anti-cancerous property. Further it was revealed that in addition to infestation by *B. dorsalis*, many other species of fruit flies are also attacking fruit crops and vegetables. In the survey, incidence of *Bactrocera syzigi* (Tsuruta and White) in rose apple and solanum fruit fly, *Bactrocera latifrons* (Hendel) in solanaceous vegetables *viz.,* brinjal and tomato was recorded. Fruit fly infestation in brinjal and tomato are new reports from Kerala. Koyama (1989) reported that *B. dorsalis* occured on a wide range of fruit crops in China and Japan on custard apple, apple, carambola, bananas, capsicum, guava, mango, orange, papaya, peach, plum and tomato. Survey conducted by Tsuruta and White (1997) in Srilanka revealed the occurrence of *B. dorsalis* in cashew, custard apple, bread fruit, wild guava, papaya, garcinia, mango, avacado, guava, pomegranate, golden apple, wild mango, strychnos, rose apple and almond. The wide host range of this pest was reported by several authors (Chu and Chen, 1985; Allwood *et al.,* 1999). *B. latifrons* was identified as a host of 59 plant species from 14 plant families. It is considered as a pest of crops such as chilli,

tomato and brinjal (Liquido *et al.,* 1994). It was primarily of Asian distribution including Pakistan, India, Sri Lanka, Myanmar, China, Thailand, Laos, Vietnam, Malaysia, Singapore, Brunei and Taiwan (Carroll *et al.,* 2004). This wide distribution of *B. latifrons* pattern might be the reason for its occurrence in Kerala.

5.1.1.1 Incidence of fruit fly

The mean extent of infestation caused by fruit flies to mango during the fruiting months (April-June) ranged from 6.77 to 61.68 per cent with peak infestation during June (61.68 %) and May (49.28 %) and minimum fruit damage during the month of April (6.77 %) (Table 6). The findings of the present study are in agreement with that of Nasiruddin (1991). He reported peak incidence of mango fruit fly in mango in May and the lowest in April. The studies conducted by Patel *et al.* (2013) at Navsari Agricultural University are also in accordance with the present findings. They reported higher fruit fly infestation of more than 30 per cent during peak fruiting season of mango in May-June.

The mean percentage infestation in guava during fruiting months (June-September) ranged from 13.97 to 83.78 with maximum damage during the month of July (83.78), followed by August (74.91) (Table 7). The highest loss of 80 per cent in guava fruit was reported by Kafi (1986) and Ishtiaque *et al.* (1999). Jalaluddin *et al.* (1999) also reported a yield loss of 60-80 per cent in guava. Studies carried out by Kakar *et al.* (2014) in guava orchards during 2010 and 2011 revealed that higher infestation was observed in mid August (49.67%), followed by early September (45.17%). It was contradictory to the findings of the present study and that might be due to the difference in fruiting season of guava and climatic conditions prevailing in the areas.

The infestation in banana was negligible as compared to mango and guava and the damage usually occurred during the unproductive season. As an adaptation

for better survival during the lean season of mango and guava, *B. dorsalis* might have opted for an available host like banana that too in ripened fruits. There are reports of infestation of *B. dorsalis* in banana (Rao, 1956; Ekanayake *et al.,* 2002).

5.1.2 Assessment of pest status

The study revealed that maggot population per fruit during fruiting periods of mango ranged from 23.11 to 78.75 with maximum during June and minimum during April (Fig 1). A gradual increase in maggot population was observed from April 2014 to June 2014 and thereafter a declining trend was found up to July 2014 (27.30). According to Barma and Jha (2013), the maggot population has a positive relationship with fruit damage. They reported that the highest population of 7.15 to 7.76 maggots/fruit and fruit damage (25-40%) occurred during first and second week of June in *B. cucurbitae*. In the present study also, the population of maggot was in close association with percentage infestation with the highest incidence of fruit fly and maggot population in June 2014.

Two species of fruit fly were found infesting mango. They are *B. dorsalis* and *B. caryeae* (Fig 2) with a species composition of 74.16 and 25.83 per cent, respectively. In guava, only infestation with *B. dorsalis* was observed. Jalaluddin *et al*. (1999) recorded *B. dorsalis* from guava fruits. Studies conducted by Ukey *et al.* (2013) also revealed that guava fruits were infested with four different fruit fly species. Among them, *B. dorsalis* was observed to be the dominant species with the highest mean number of flies (50.25) emerged out per cage.

5.1.3 Reaction of mango and guava varieties to fruit fly

The fruits are attacked by fruit flies in mango during April-June and the level of injury varies from variety to variety (Atwal and Dhaliwal, 1997). Eleven mango varieties were studied for natural infestation of fruit flies and observations were taken during peak fruiting season. All the varieties were found susceptible to fruit fly

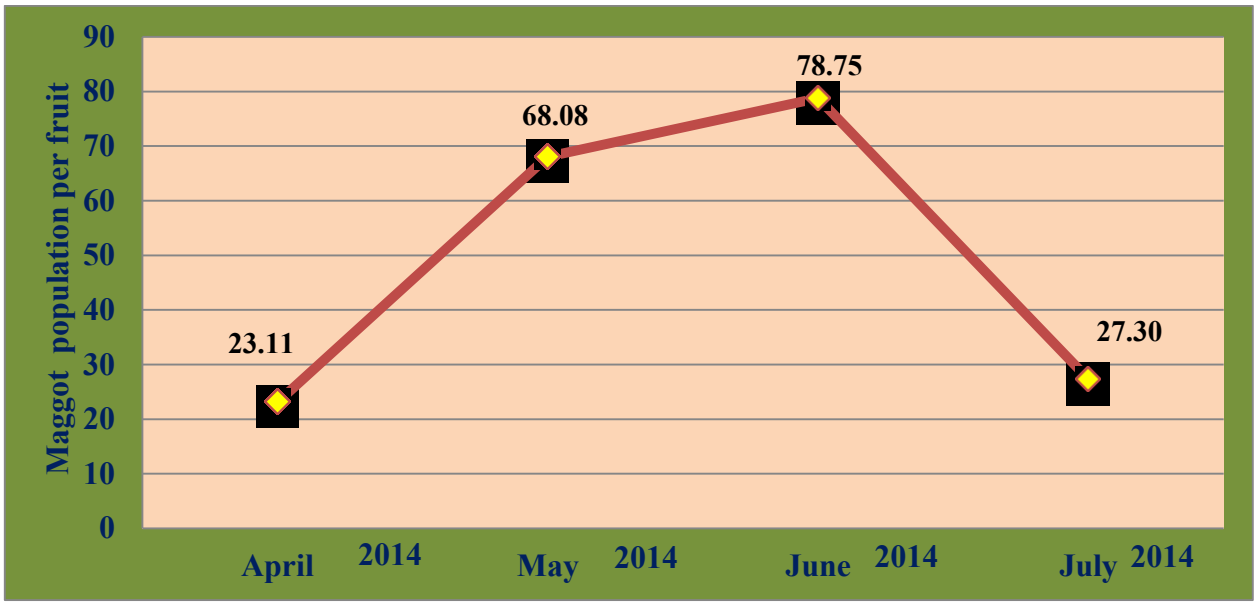


Fig 1. Population of maggot per mango

attack, except the variety Kottukonam Varikka and was categorized as immune. Peel thickness, fibre content and biochemical properties can be the reason for the non-preference of fruit flies for this variety. Studies by Balagawi *et al.* (2005) and Rattanapur *et al.* (2009) showed that peel firmness and thickness affected the oviposition preference of fruit flies. Rossetto *et al.* (2006) observed that resistant variety became susceptible when eggs of Mediterranean fruit fly, *C. capitata* were artificially inserted directly into fruit pulp. This indicated that peel thickness is the main mechanism of resistance among mango varieties to fruit flies. Sapota germplasm with thin fruit skin was susceptible to fruit fly damage, compared to those with thick fruit skin (Nandre and Shukla, 2014).

The percentage fruit infestation of varieties ranged from 0 to 99.69 (Table 10). The highest fruit damage was recorded in the varieties Bangalora (99.69 %), Vellayani Local (97.43 %) and Neelum (93.38 %). The least fruit damage was observed in the varieties Kasthoori (43.67 %) and Alphonso (46.12 %) and they were categorized as susceptible. Remaining varieties came under the category, highly susceptible. Verghese *et al.* (2002) screened eleven mango varieties *viz.,* Alphonso, Banganapalli, Bombay Green, Dashehari, Langra, Rumani, Suvarnarekha, Totapuri (Bangalora), Jahangir, Raspuri and Mulgoa in the mango orchards of IIHR, Bangalore. The study revealed that two varieties, Banganapalli and Totapuri recorded maximum mean percentage infestation of 46.0 and 59.0, respectively, followed by the variety Alphonso (26.0 %).

The present investigation revealed that the number of maggots per infested fruit ranged from 44.2 to 117.2 in different mango varieties. The maximum number of maggots was observed in the variety Bangalora and minimum in the variety Vellayani Local. This variation in number of maggots might be due to the difference in size of the fruit. Verghese *et al.* (2002) screened different mango varieties against

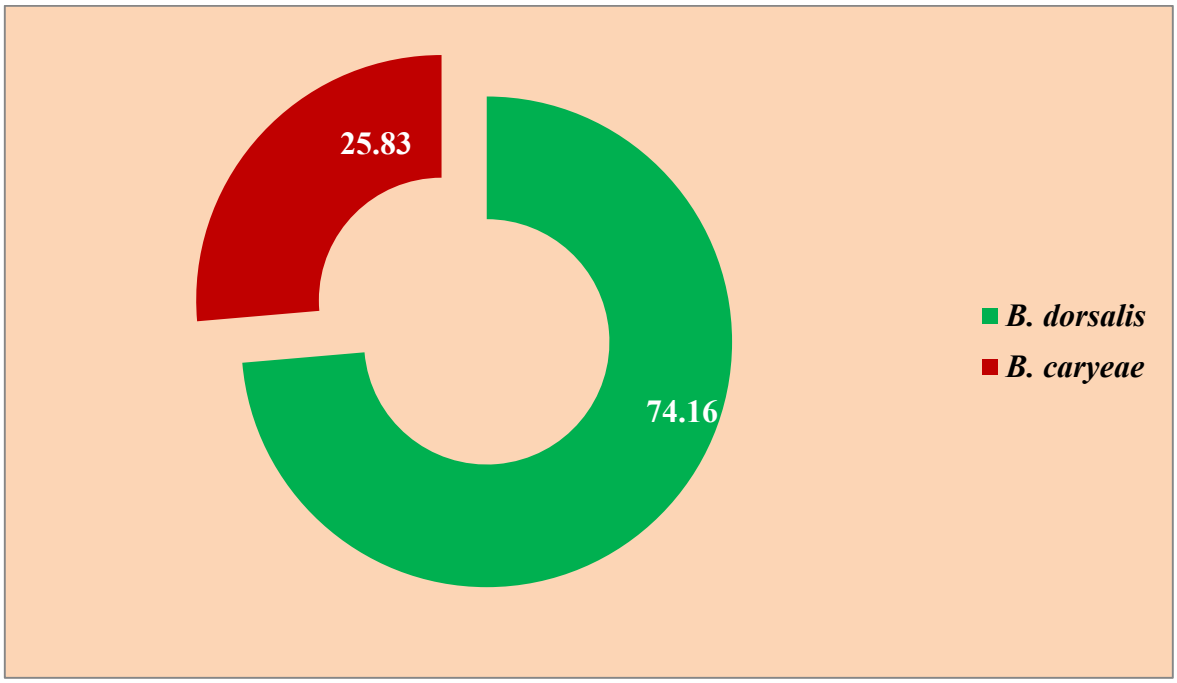


Fig 2. Species composition (%) of fruit flies from mango

fruit flies by counting mean number of maggots per hundred fruits. Susceptible varieties, Banganapalli and Totapuri (Bangalora) recorded higher number of maggots, compared to tolerant ones *viz.,* Alphonso, Suvarnarekha and Bombay Green.

In the present study, two species of fruit flies were found emerged from the mango varieties *viz*., *B. dorsalis* and *B. caryeae*. Population of *B. dorsalis* was the highest in the variety Bangalora; whereas population of *B. caryeae* was the highest in the variety Kalapady (Table 11). Species composition of fruit fly species revealed that the varieties Alphonso and Kalapady had higher composition of *B. dorsalis* (86.74 %) and *B. caryeae* (33.08 %), respectively (Fig 3).

The present study conducted on different guava varieties *viz*., white fleshed variety, pink fleshed variety and strawberry guava revealed that pink fleshed varieties were more susceptible to fruit fly attack than other varieties. Bhaskar *et al.* (2007) also observed that pink fleshed guava varieties were preferred by fruit flies with a percentage infestation of 28.67. The reason might be due to the biophysical and biochemical characteristics of the peel as well as the flesh of the fruit. Luximon-Ramma *et al.* (2003) reported that white pulp guava had higher ascorbic acid and total phenolics than pink pulp guava. They observed that the ascorbic acid content was 142.6 and 72.2 mg/100 g in white and pink pulp, respectively. The total phenolic content was 247.3 and 126.4 mg gallic acid equivalence/100 g in white and pink pulp, respectively. There are many reports showing the effect of biochemical characteristics in fruits and the level of fruit fly infestation. Biochemical parameters such as per cent total acids and total soluble solids (TSS) in fruit pulp also influenced the preference of fruit flies to a particular variety. High acidity and low free sugar content in some mango varieties negatively affect larval survival to pupation (Ibrahim and Rahman, 1982). Similar findings were also made by Kumar *et al.* (1994) and Hennessey and Schnell (2001). Studies conducted by Nandre and Shukla (2014) on

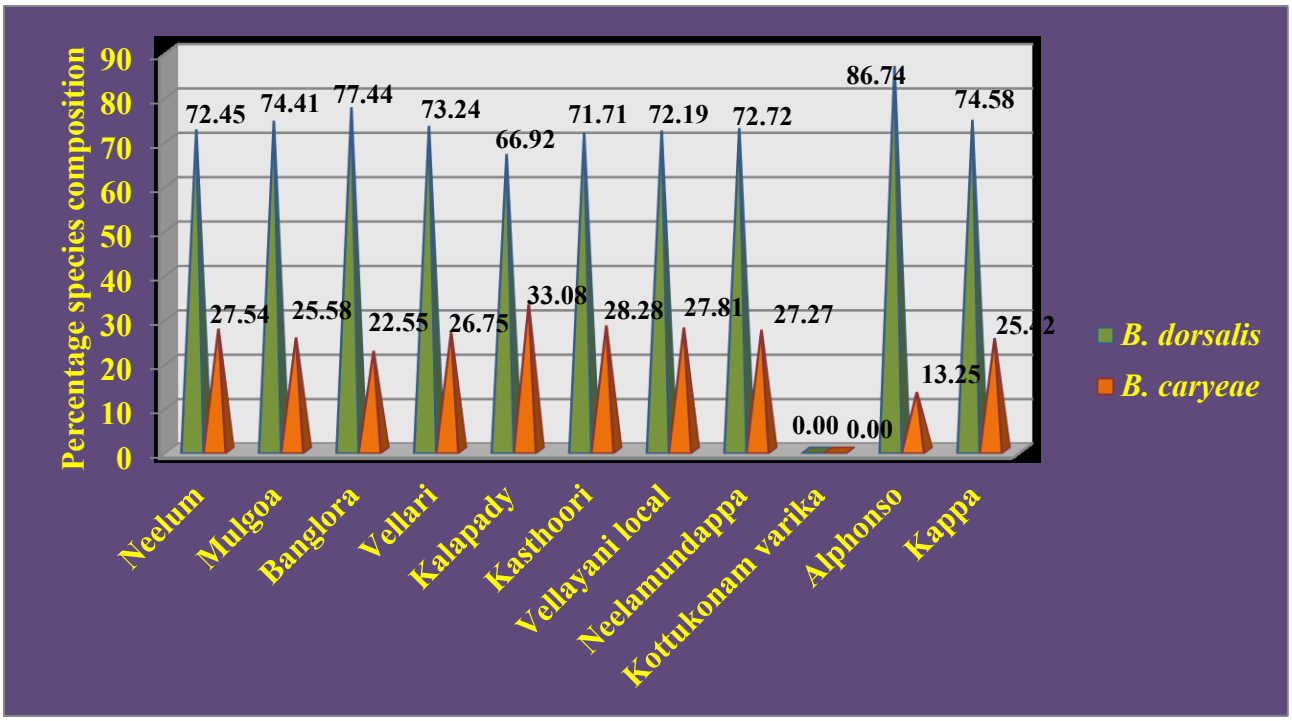


Fig 3. Species composition (%) of fruit flies in different mango varieties

the effect of chemical constituents of fifteen sapota germplasm collections against fruit fly infestation revealed that the infestation was maximum in sapota varieties with higher TSS and total sugar content. Similarly, high TSS and total sugar content in guava showed susceptibility to *B. dorsalis* (Arora *et al*., 2000).

The present investigation also revealed that the number of maggots and number of *B. dorsalis* emerged from guava were maximum for white fleshed varieties. However, it was statistically on par with pink fleshed varieties. The white fleshed varieties recorded the maximum emergence of *B. dorsalis* than pink fleshed varieties and strawberry guava.

From the study, it can be suggested that use of varietal resistance can be incorporated in integrated pest management strategies for the successful management of fruit flies as it is easy to use, economical and compatible with other methods of control (Kumar, 1984).

5.1.4 Natural enemies

Natural enemies play a key role in the control of a pest within an agro ecosystem. Identification of potential natural enemies will provide a novel tool in confronting the pest. Studies indicated that only a few natural enemies have been reported for fruit flies. Attempts were also made during the survey to locate the natural enemies of fruit fly. A predatory spider of *B. dorsalis*, lynx spider, *Oxyopes* sp. (Plate 10a) and a larval pupal parasitoid of *B. dorsalis*, *Opius* sp. were observed in the field (Plate 10b). *Opius* sp. was reported as a potential larval-pupal parasitoid of fruit flies by Nishida and Bess (1957), Narayanan and Chawla (1962), Wharton and Gilstrap (1983) and Nair (1995).

5.1.5 Population dynamics of fruit flies

Studies on population dynamics is of great value in IPM decision making and implementation, especially for the polyphagous pests like fruit flies. Fruit fly detection by trapping is a practical method that helps to track altering pest scenario, thereby providing information for ecologically sustainable measures against fruit flies. Survey conducted in ten homesteads of Kalliyoor panchayath and Instructional Farm, Vellayani during 2014-15 revealed the prevalence of four *Bactrocera spp. viz., B. dorsalis*, *B. caryeae*, *B. correcta* and *B. zonata*. Occurrence of different species of fruit flies was also recorded by several workers. Verghese and Jayanthi (2001) reported the catches of *B. dorsalis* and *B. correcta* in the methyl eugenol traps. Madhura and Viraktamath (2003) recorded five species of fruit flies *viz., B. dorsalis*, *B. correcta*, *B. verbascifoliae*, *B. affinis* and *B. zonata* which were attracted to methyl eugenol traps located at Bangalore. Morde (2003) observed *B. caryeae*, *B. dorsalis* and *B. zonata* in the trap installed in guava orchard in Konkan area. Kawashita *et al.* (2004) reported catches of *B. correcta*, *B. dorsalis* and *B. zonata* in methyl eugenol and *B. cucurbitae* in cue lure. Satarkar *et al.* (2009) reported four fruit flies species *viz., B. caryeae*, *B. zonata*, *B. affinis* and *B. correcta* attracted to the methyl eugenol trap in coastal region of Goa.

Results of the present investigation revealed that *B. caryeae* occurred predominantly in all months, except January 2015 and February 2015, contributing to 69.85 per cent of the total population while the occurrence of *B. dorsalis* was 28.74 per cent. *B. correcta* and *B. zonata* were found relatively in few numbers contributing to 1.38 and 0.02 per cent of the total population, indicating that they were only minor species (Fig 4).

The population fluctuation of fruit flies throughout the year was observed (Fig 5). The population of *B. caryeae* and *B. dorsalis* which was low in March-April

2014 increased slowly and steadily reached the peak level in June 2014. It was also observed that there was 2.23 times increase in population of *B. caryeae* than *B. dorsalis* during that month. It was in accordance with the findings made by Kumar *et al.* (1997) that fruit fly population increased from March and reached the peak during June. It was also confirmed by the observations of Singh (1989) that a peak population of *B. dorsalis* (580 flies/ trap) occurred in the month of June in mango orchards at Pantnagar. The study by Lutap *et al*., (2009) also revealed a peak population of fruit flies during May- June, when monitored using methyl eugenol traps. In the present study, a gradual decline was observed in the population of *B. caryeae* and *B. dorsalis* after June 2014. However, the population of *B. dorsalis* started to build up again in August 2014 and then declined and then built up again in January 2015. The population of *B. dorsalis* was found to be higher than that of *B. caryeae* during January - February 2015. The population suppression of *B. dorsalis* by other species of fruit flies was reported by many workers. Field experiments were conducted by Agarwal *et al.* (1999) at Pusa in Bihar during April to August. They trapped adult males of *B. dorsalis* and *B. zonata* using methyl eugenol, bait (protein hydrolysate) and malathion. They observed that population of *B. zonata* was higher than that of *B. dorsalis* with an average of 39.94 and 134.92 flies per trap per week, respectively. They concluded that the mean population of *B. zonata* was 3.38 times greater than that of *B. dorsalis*, which indicated the population suppression of *B. dorsalis* by *B. zonata*.

The month wise occurrence of different species of fruit flies is illustrated in Fig 6. *B. caryeae* constituted the major share of fruit fly population with maximum occurrence during March 2014 (82.57 %) and minimum during February 2015 (27.31 %). Species composition of *B. dorsalis* was the highest during the month of February 2015 (69.30 %) and the lowest during March 2014 (16.79 %). The occurrence of *B. correcta* and *B. zonata* was below 5 and 1 per cent, respectively. Similar study was

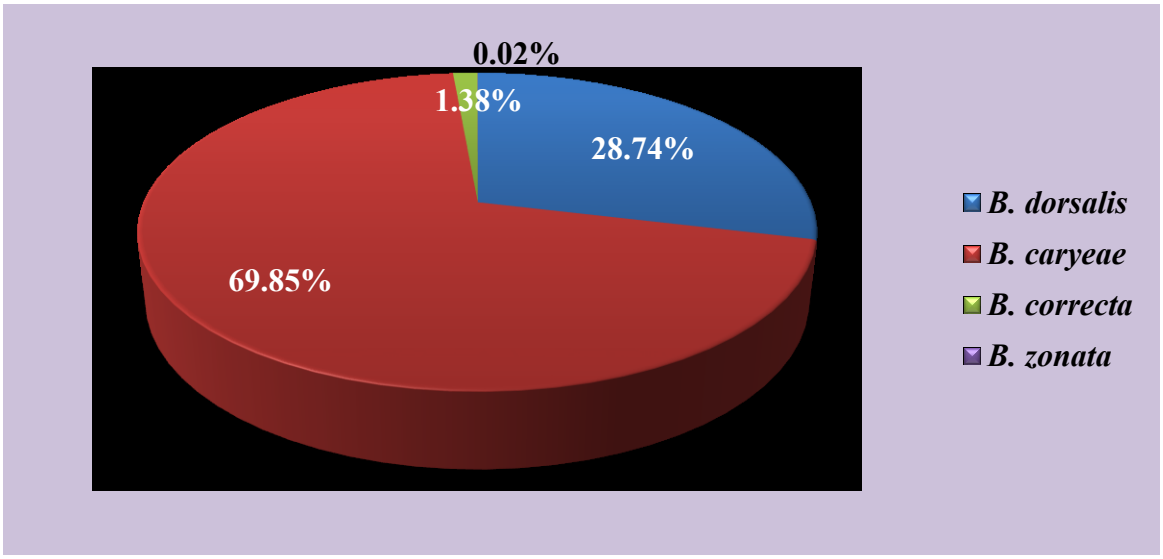


Fig 4. Mean percentage species composition of fruit flies in traps

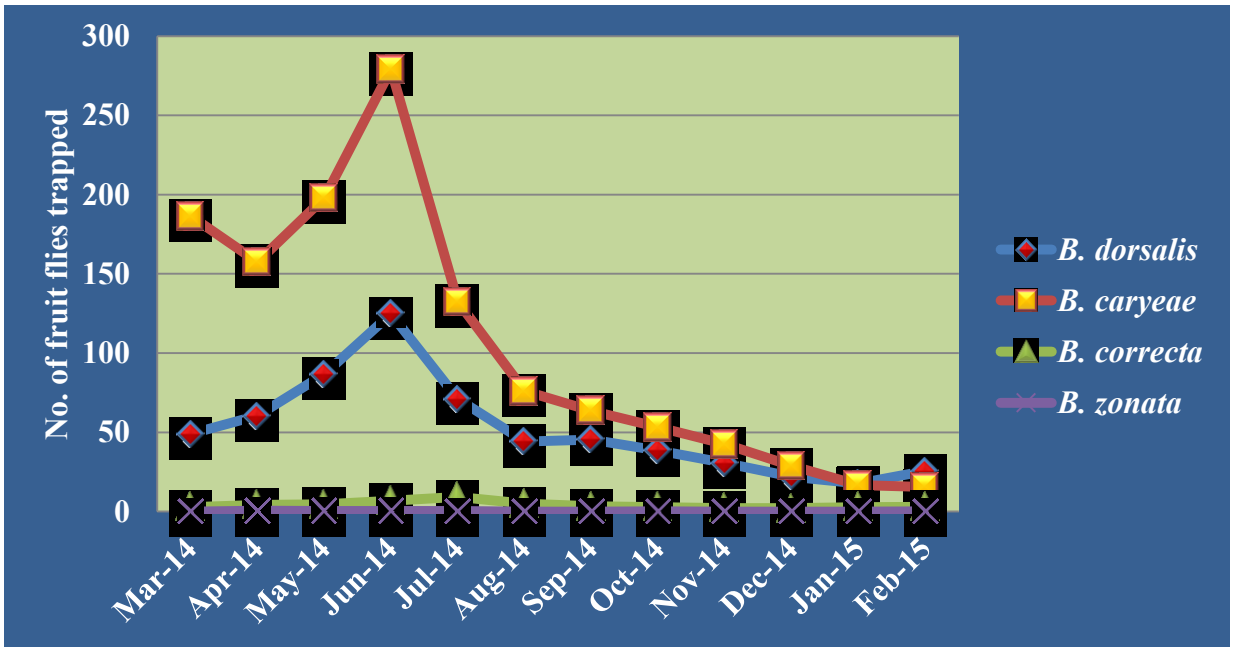


Fig 5. Population fluctuation of fruit flies during 2014-15

conducted by Jiji *et al.* (2008) in different locations for monitoring the population of *B. caryeae* in Kerala and Tamilnadu during the year 2007. They observed that population of *B. dorsalis* was the highest, ranged from 55.90 to 84.10 per cent and *B. caryeae* from 10.1 to 20.4 per cent. This was contradictory to the present findings. However, it shows the trend in population growth of *B. caryeae* as compared to other species of fruit flies. It shows *B. caryeae* has developed better adaptation for the survival in the ecosystem. It had attained a population which can succeed the existing fruit fly species.

5.1.5.1 Population dynamics of fruit fly in relation to host

One of the key determinants of fruit fly abundance is host availability (Shukla and Prasad, 1985). The adult fly catches of different species showed wide fluctuation in the populations. Even though the mean population of *B caryeae* was higher in fruiting season of mango than *B. dorsalis*, the emergence of *B. dorsalis* was found to be higher than *B. caryeae* from infested fruits. Since *B. caryeae* belongs to *B. dorsalis* complex with mango as the most preferred host (Ramani, 1998), it resulted in high levels of competition between the two members for survival. Larval competition between the species within the host might have occurred as they share nutritional resources also. Larval competition can occur by direct interference or exploitation. The impact of competition depends both on the density of larvae within a particular fruit and the relative abundance of each species (Liendo *et al.*, 2014). They studied the competition between *C. capitata* and *Anastrepha fraterculus* and observed both intra-specific as well as inter-specific larval competitions. The reason for higher population of *B. caryeae* in traps could be also due to their survival in some wild host plants which was unnoticed during the survey. *B. caryeae* has been reported from guava, mango, avocado, roseapple, Indian bael, white sapota and citrus (Drew and Hancock, 1994; Drew and Raghu, 2002). The only wild host for *B. caryeae* reported was patana oak (*Careya arborea*) (Kapoor, 1971). There are also

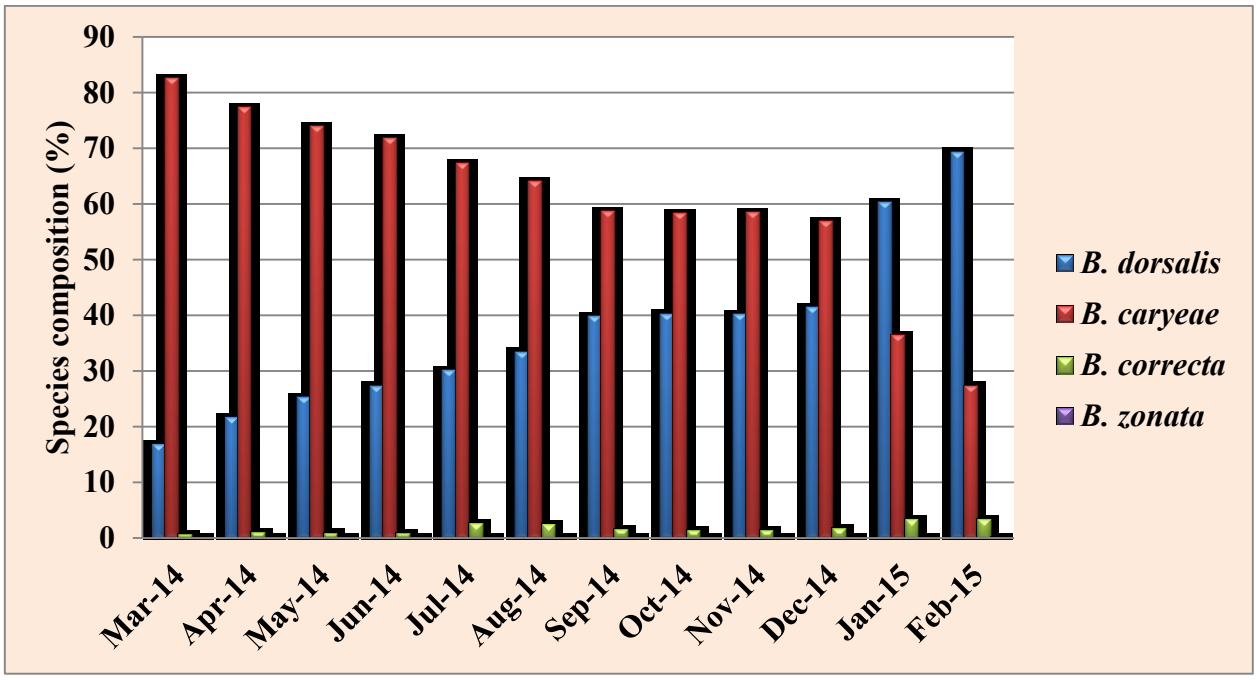


Fig 6. Species composition (%) of different species of fruit flies in traps

evidences for the replacement of indigenous species with invading species. Ekesi *et al.* (2009) documented the process of displacement of *Ceratitis cosyra* by *Bactrocera invadens* on mango in an eight year study in Kenya. Study indicated the dominance of *B. invadens* and its gradual trend in displacing the indigenous species, *C. cosyra*. In the present study, it was clear that *B. caryeae* has a tendency to replace the population of *B. dorsalis*. Hence, continuous surveying and monitoring has to be done to confirm the results.

Three population peaks of *B. dorsalis* were observed during June 2014, August 2014 and February 2015. These distinct peaks of *B. dorsalis* in this region may be due to the ready availability of ripened mango, guava and other host plants across the season. The findings were supported by Mohanraj *et al.* (2009) who also observed three population peaks of *B. dorsalis* during July, September and May-June which coincided with fruiting season of different fruit crops including mango and guava. However in the present study, only one distinct peak was observed for *B. caryeae* during June 2014 which coincided with the peak fruiting season of mango. This hike in June might be due to high preference of *B. caryeae* for mango.

The population of *B. correcta* was low, compared to *B. caryeae* and *B. dorsalis*. However, it reached the peak during July 2014 which coincided with the fruiting season of guava. The population of *B. zonata* was found to be negligible with maximum population occurred in association with the fruiting season of mango.

Mango and guava were the most preferred hosts recorded from the survey. Therefore, their fruiting period exerted essential effects on the population fluctuation of fruit flies. It is clear from the data that peak population of fruit flies coincided with the peak fruiting seasons of the host. Chang and Lee (1985) and Chiu and Chu (1986) indicated a positive relationship between peak fly population and ripening of

guava in Taiwan. It was also supported by the observations made by Amin (1995) who reported high population incidence at the ripening stage of mango. The findings were also in accordance with Reji Rani *et al.* (2012) with peak fruit fly catch observed during the fruit maturity stage (April- May).

5.1.5.2 Population dynamics of fruit fly in relation to weather parameters

Weather is one of the important factors that influence the fluctuations in fruit fly population (Ye and Liu, 2005). Attempts were carried out to study the population dynamics of the pest in relation to weather parameters (Table 16). During 2014-15, strong positive correlation was observed between the population of *B. dorsalis* with maximum temperature, minimum temperature, evening relative humidity, average relative humidity and sunshine hours.

The population of *B. caryeae* showed a significant positive correlation with maximum temperature, average relative humidity and sunshine hours. The present results are in conformity with the works of Bagle and Prasad (1983) and Agarwal and Kumar (2005) who observed significant positive correlation of fruit fly with maximum temperature on mango crop. Kumar *et al.* (1997) also reported similar results, where population of fruit flies had a significant positive correlation with average relative humidity in sapota. Both *B. dorsalis* and *B. caryeae* showed negative correlation with rainfall but had no significant relationship with population. The present results did not corroborate with the findings of Rai *et al.* (2008), who reported that fruit fly population had positive but non significant correlation with total rainfall in guava at Jammu. However, the results were supported by Boopathi *et al.* (2013) that rainy days and rainfall are negatively correlated with population of *B. dorsalis*. It might be due to the variation in climatic conditions other than rain fall and topographic conditions prevailing in that area compared with the area surveyed during the study. However, *B. correcta* and *B. zonata* showed a positive association with rainfall, the latter being significant. An incongruity was observed with the

findings made by Nair (1995) who found that the peak population of fruit fly in India was during rainy months of July and August and in cold months of January and February.

The population of *B. correcta* expressed a significant positive correlation with mean maximum temperature and minimum temperature. This was in agreement with findings made by Jalaluddin *et al.* (2001). Results with respect to *B. zonata* are in accordance with the reports of Agarwal and Kumar (1999) and Babu (2002). They observed a strong significant positive correlation in the population of *B. zonata* with maximum temperature.

The correlation of each weather parameters varied between different species of fruit flies. Total fruit fly population had a positive correlation with maximum temperature and sunshine hours. However, rainfall, minimum temperature, morning relative humidity, evening relative humidity and average relative humidity showed no relationship with the total fruit fly population.

It is strongly evident from the above observations that fluctuation of population is governed by both biotic factors like host availability and abiotic factors such as temperature, relative humidity, rainfall and sunshine hour. In nature, the population build up of a pest is determined by the combined action of two or more factors.

5.2 BIOLOGY OF MANGO FRUIT FLY

The research works on the biology of mango fruit fly in different varieties and hosts is meagre. The egg period and larval period of *B. dorsalis* were same in the different mango varieties *viz.,* Bangalora, Mulgoa, Neelum and Vellari (Table 10). The pupal period (11.40 ± 1.18 days) and adult longevity (20.70 ± 2.31 days) was longer in the variety Bangalora than in other varieties. Biology of *B. dorsalis* in

different hosts *viz.,* mango, guava, banana, papaya and sapota revealed that the duration of egg stage was similar in all hosts. The larval period (12.90 ± 1.85 days) and pupal period (10.30 ± 1.33 days) were higher in banana with longer adult longevity (19.70 ± 2.40 days) in mango. According to Vasuki (1979), incubation period of eggs ranged from 24-48 hours with an average of 36 hours. He also observed that duration of three larval instars is 2.16, 4.83 and 5.25 days, respectively. Laboratory assessment of duration in days of the developmental stages of *B. dorsalis* on mango varieties *viz.,* Neelum and Bangalora was studied by Jiji *et al.* (2006a). They reported that pupal period and adult longevity of *B. dorsalis* in the variety Neelum was 10.50 and 16.50 days, respectively. In case of the variety Bangalora, larval period, pupal period and adult longevity was 8.4,0 12.75 and 20.30 days, respectively.

Since there was not much variation in duration of life stages of *B. dorsalis* among different hosts, any one of the host crop is sufficient for its multiplication in off seasons and can serve as an inoculum in the field. This also indicated the reason for the severity of the pest.

5.3 EVALUATION OF EFFICACY OF INSECTICIDES, BOTANICALS AND BIOAGENTS IN FOOD BAIT IN THE LABORATORY

The efficacy of different treatments *viz*., deltamethrin (0.04% and 0.02%), lambda cyhalothrin (0.005% and 0.0025%), chlorantraniliprole (0.006% and 0.003%), spinosad (0.02% and 0.01%), malathion (0.1%), azadirachtin (0.003%), *B. bassiana* (ITCC 6063) WP (2%) and *P. lilacinus* (ITCC 6063) WP (2%) in BAT were assessed under laboratory conditions (Table 18). The synthetic pyrethroid, lambda cyhalothrin 0.005% (T_3) recorded cent per cent mortality at the third day after treatment, followed by a conventional organophosphate insecticide, malathion 0.1% (T_9) and a microbial insecticide, spinosad 0.02% (T_7) at the fourth day after treatment

and lambda cyhalothrin 0.0025% (T_4) at the fifth day after treatment. The botanical insecticide, azadirachtin 0.003% (T_{10}) needed seven days to yield a mortality rate of 95.47 per cent. The use of biocontrol agents, *B. bassiana* (T_{11}) and *P. lilacinus* (T_{12}) were less effective, compared to other treatments. However, the mortality rates increased from 0 to 53.35 and 60.00 per cent, respectively. The superiority of the treatments was determined using LT_{50} values (time taken to cause 50 per cent mortality) (Table 15). The LT_{50} values recorded for the treatments lambda cyhalothrin 0.005%, malathion 0.1%, spinosad 0.02% and lambda cyhalothrin 0.0025% were 0.63, 1.12, 1.29 and 1.70 days, respectively. All other treatments showed LT_{50} values above two days. Hence, the above mentioned four insecticides were selected for further field trials to standardize the insecticides in BAT. Many of the preceding studies revealed the efficacy of these promising insecticides in managing fruit flies under laboratory conditions. Barry and Polavarapu (2005) reported high toxicity of fipronil and spinosad at 40 ppm on protein baits against blueberry maggot flies causing 37.50 and 35.00 per cent mortality, respectively, after 48 h of treatment. Similar observations were also made by Reissig (2003) and Barry *et al.* (2005). Yee and Alston (2006) observed cent per cent mortality in spinosad bait, compared to other treatments including neonicotinoids *viz.,* imidacloprid and thiacloprid in laboratory against western cherry fruit fly. Radwan (2012) recorded higher relative toxicity of lambda cyhalothrin, spinosad and imidacloprid, compared to malathion against *B. zonata*. Jimmie and Micheal (1996) reported that relative low concentrations of spinosad combined with sugar-yeast hydrolysate mixture was effective as a bait spray on female and male adults of the Caribbean fruit fly, *Anastrepha suspensa* (Loew). El-Aw *et al.* (2008) observed that 120 ppm of spinosad resulted in 90 per cent mortality of adult flies of *B. zonata.*

5.4 EVALUATION OF EFFICACY OF THE CHEMICALS IN MALE ANNIHILATION TECHNIQUE IN THE LABORATORY

Under laboratory conditions, the synthetic insecticides *viz*., deltamethrin 6: 4: 0.04 and 0.4, lambda cyhalothrin 6: 4: 0.005 and 0.05 and spinosad 6: 4: 0.02 and 0.2, imidacloprid 6: 4: 0.005 and 0.05 and malathion 6: 4: 1 were tested (Table 16). The treatments spinosad 6: 4: 0.2 (T_6) recorded 100 per cent mortality at the end of the fourth day followed by malathion 6: 4: 1 (T_9) on the fifth day and spinosad 6: 4: 0.02 (T_5) and deltamethrin 6: 4: 0.4 (T_2) after the sixth day. But, all the treatments were equally effective, causing 90.74 to 100 per cent mortality after seven days of treatment, except both higher (T_3) and lower (T_4) concentrations of lambda cyhalothrin. The selection of superior treatments was based on the LT_{50} values (Table 17). The treatments spinosad 6: 4: 0.2, malathion 6: 4: 1, spinosad 6: 4: 0.02 and deltamethrin 6: 4: 0.4 were selected for field evaluation having LT_{50} values 1.43, 1.57, 2.21 and 2.22 days, respectively. These findings fall in line with the results of previous workers. Vargas *et al.* (2008) observed that specialised pheromone and lure application technology (SPLAT) using methyl eugenol and cue lure along with spinosad was very effective. Bioassay tests conducted by Mahmoudvand *et al.* (2011) revealed the toxicity of spinosad, deltamethrin and malathion against male flies of *D. ciliatus* under laboratory conditions.

5.5 PEAK TIME ACTIVITY OF FRUIT FLIES

The maximum activity of *B. dorsalis* and *B. caryeae* was observed during early morning hours (6-8 am), followed by morning hours (8-10 am) (Fig 7). However, the population of *B. correcta* was more influenced by evening hours (4-6 pm) resulting in high activity. Fruit flies were found to be less active during noon hours 12-2 pm. Stageman *et al.* (1979) observed that adult fruit flies were attracted to specific lure during the day time and peak attraction and population occurred in the day during summer, than in spring season. Siddiqui *et al.* (2003) recorded maximum

fly catch of *B. zonata* (4.49 flies per trap per hour) during early morning 5-7 h followed by 2.12 and 1.29 during 7-9 h and 9-11 h, respectively. The minimum number of flies (0.64) per trap per hour was captured during noon (11-13 h). The studies conducted by Jiji *et al.* (2006b) on peak time of activity of *B. dorsalis* also revealed that the diurnal activity was more during morning hours and less during noon hours. Thus, the findings of this study are in conformity with the results reported by these workers. Therefore, it was evident that fruit flies exhibited a wide range of diurnal activities and the measures to control the pest should be adopted during the morning or evening hours.

5.6 EVALUATION OF BAIT APPLICATION TECHNIQUE IN THE FIELD

The effective insecticides identified from the preliminary screening trials in BAT under laboratory conditions were further evaluated in the field to assess their overall efficacy against fruit flies. Four promising treatments *viz.,* lambda cyhalothrin 0.005%, malathion 0.1%, spinosad 0.02% and lambda cyhalothrin 0.0025% were selected. The results indicated that spinosad 0.02%, malathion 0.1% and lambda cyhalothrin 0.005% were equally effective in field with a mean total fly catch of 63.17, 59.33 and 56.67, respectively (Fig 8). The treatment lambda cyhalothrin 0.0025% was inferior with a mean total fly catch of 34.00 flies. In Hawaii and Florida (Adan *et al.,* 1996; King and Hennessey, 1996; Peck and McQuate, 2000), field tests demonstrated that spinosad based baits provided significant control of *C. capitata* and *Anastrepha ludens* (Leow). Spinosad gave high mortality in field population of fruit flies in the present study. The results are also in conformity with the findings of Raga and Sato (2006), Burns *et al.* (2001), Magana *et al*. (2007) and El-Aw *et al.* (2008) who found spinosad to be highly effective against *B. cucurbitae*, *B. dorsalis* and *C. capitata.* Vargas and Prokopy (2006) suggested that spinosad was a promising substitute for organophosphate insecticides like malathion in BAT for control of *B. dorsalis* and *B. cucurbitae*. Oke (2008)

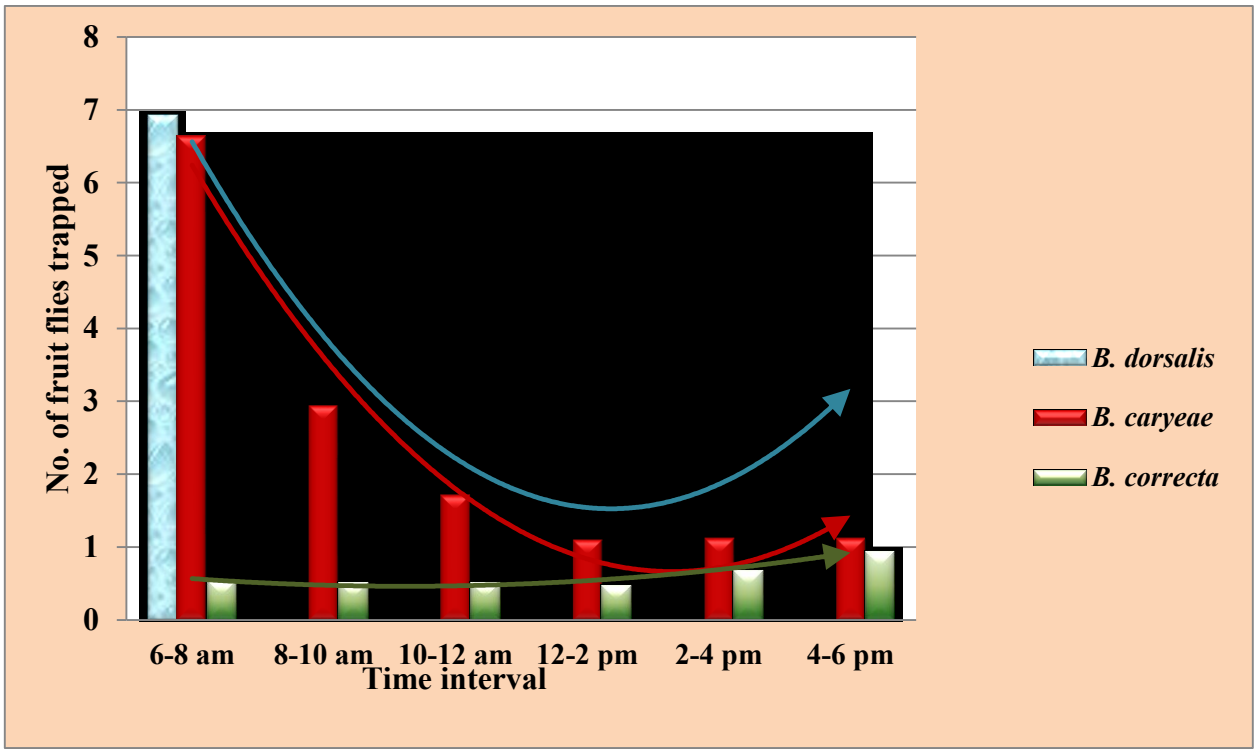


Fig 7. Effect of time of the day on activity of fruit flies

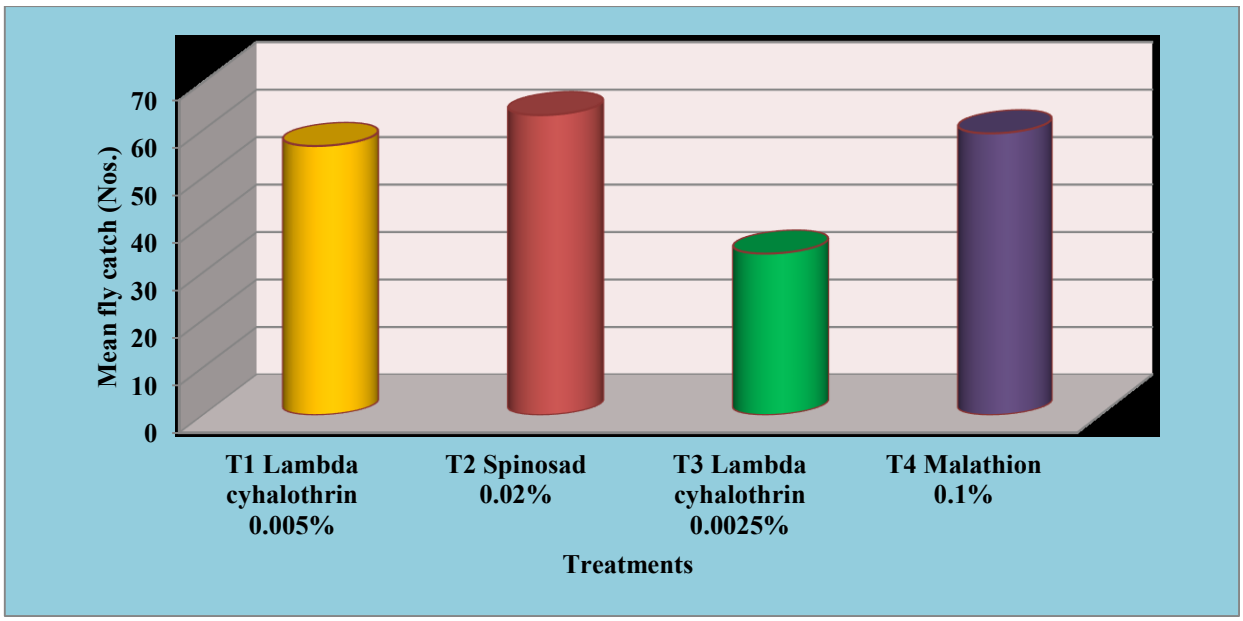


Fig 8. Effect of insecticides on the population of fruit flies

observed reduction in pupae of *B. cucurbitae* with the spray of lambda cyhalothrin on cucumber and was found to be more effective than deltamethrin. Spinosad based protein bait sprays in combination with good sanitation also reduced infestation by *B. dorsalis* in papaya orchards (Pinero *et al.*, 2009).

The percentage occurrence of male and female fruit flies was worked out (Fig 9). Female flies were more attractive to food bait traps than male flies. Among the treatments, spinosad 0.02% recorded higher male and female catch of 32.71 and 67.29 per cent, respectively. This was followed by malathion 0.1% (male- 29.50 % and female- 71.07 %) and lambda cyhalothrin 0.005% (male- 24.01 % and female- 75.99 %).

Food bait (jaggery 10%) with insecticides attracted pests other than fruit flies including lepidopteran pests *viz.,* adults of butter fly caterpillar (*Euthalia garuda* Moore), blue butterfly (*Rapala manea* Hewitson), fruit moths (*Othereis* sp.), palm butter fly (*Elymnias caudata* Butler) and castor butter fly (*Ariadne merione* Cramer) and coleopteran pests including flower beetles (*Oxycetonia* sp.). This indicated that food bait traps can also be exploited as an effective control measure for other pests. Further studies are to be carried out to standardize their use for the management of other pests. Vidya *et al.* (2005) reported the presence of lepidopteran pests such as snakegourd caterpillar, hairy caterpillar and fruit moths in bait traps. Catch of non target insects in traps was reported by Uchida *et al.* (2006) and Nboyine *et al.* (2012).

5.7 EVALUATION OF MALE ANNIHILATION TECHNIQUE IN THE FIELD

A field experiment was laid out to evaluate the efficacy of the best four treatments selected from the study conducted in the laboratory *viz.,* spinosad 6: 4: 0.2, malathion 6: 4: 1, spinosad 6: 4: 0.02 and deltamethrin 6: 4: 0.4. The treatment spinosad 6: 4: 0.2 recorded maximum total fly catch of 1371.08 flies per trap and was identified as the superior treatment compared with other treatments (Fig 10). The

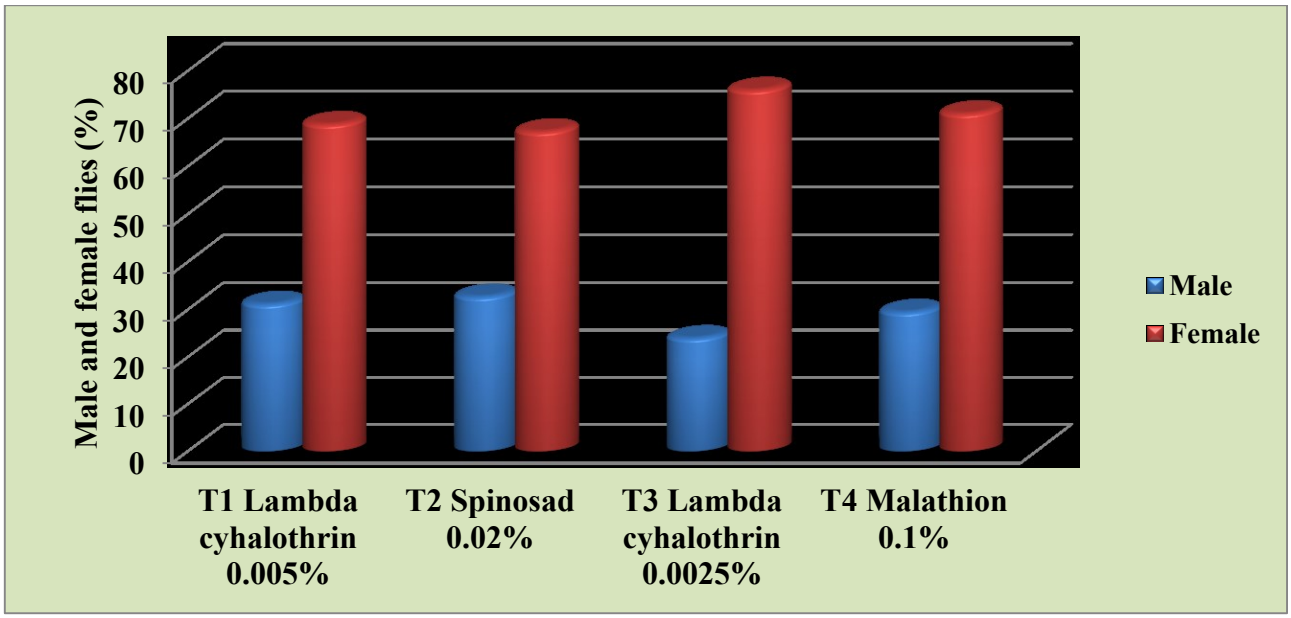


Fig 9. Effect of insecticides on the occurrence of male and female flies in BAT

treatments malathion 6: 4: 1 and spinosad 6: 4: 0.02 resulted in a total fly catch of 882.02 and 823.91 flies, respectively and were equally effective. With respect to the duration of effective trap catch, spinosad at higher concentration recorded maximum effective days (108.68 days) (Fig 11). This was followed by malathion 6: 4: 1 and spinosad 6: 4: 0.02 with 105.00 and 104.83 days, respectively. Days of effective trap catches were found to be less in deltamethrin 6: 4: 0.4 (91.83). This may be due to the less persistence of deltamethrin in the environment. The present findings were in agreement with Vargas *et al.* (2003) who reported that effectiveness of spinosad was equal to conventional organophosphate insecticides, malathion whereas the synthetic pyrethroid, permethrin recorded the lowest catch of *B. dorsalis*. They also observed that catch of *B. dorsalis* at week 20 was greater than or equal to week 5. Hence, attract and kill dispensers containing spinosad was found as promising substitute for current liquid organophosphate formulation used for area wide suppression of *B. dorsalis* and *B. cucurbitae* (Vargas *et al*., 2008; 2009). The effect of spinosad in field as well as under green house conditions against *B. dorsalis* in Taiwan was assessed by Hsu *et al.* (2010). They reported that spinosad recorded high mortality of flies in green house and field.

The results of the present investigation clearly showed that the host range of *B. dorsalis* is expanding, posing great threat to fruit crops including mango, guava, banana and soursop. In addition to *B. dorsalis*, many other species of fruit flies *viz., B. caryeae*, *B. correcta*, *B. zonata*, *B. syzigi* and *B. latifrons* are also emerging as potential pests for crops. BAT and MAT is an effective tool in integrated management of mango fruit fly. The findings emphasized the need for standardization of new generation insecticides in BAT and MAT. The results indicated that spinosad 0.02% and alcohol, lure and spinosad (6: 4: 0.2 v: v: v) could be used as an alternative chemical for the conventional organophosphate insecticide, malathion in BAT and MAT, respectively.

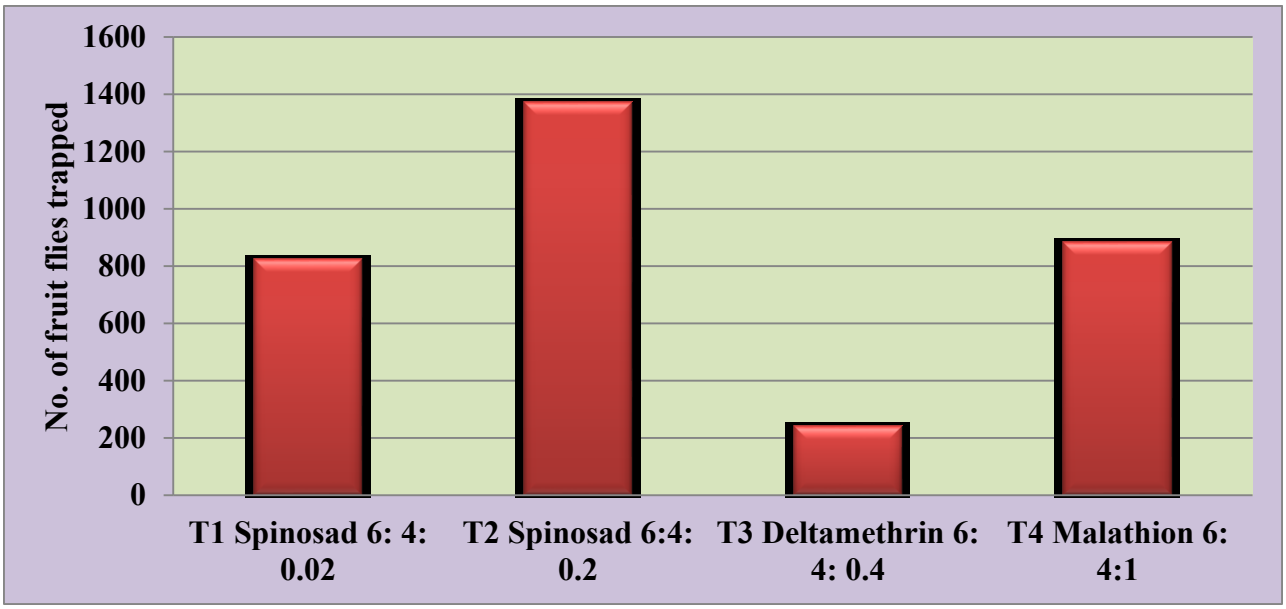


Fig 10. Effect of insecticides on trap catch in MAT under field conditions

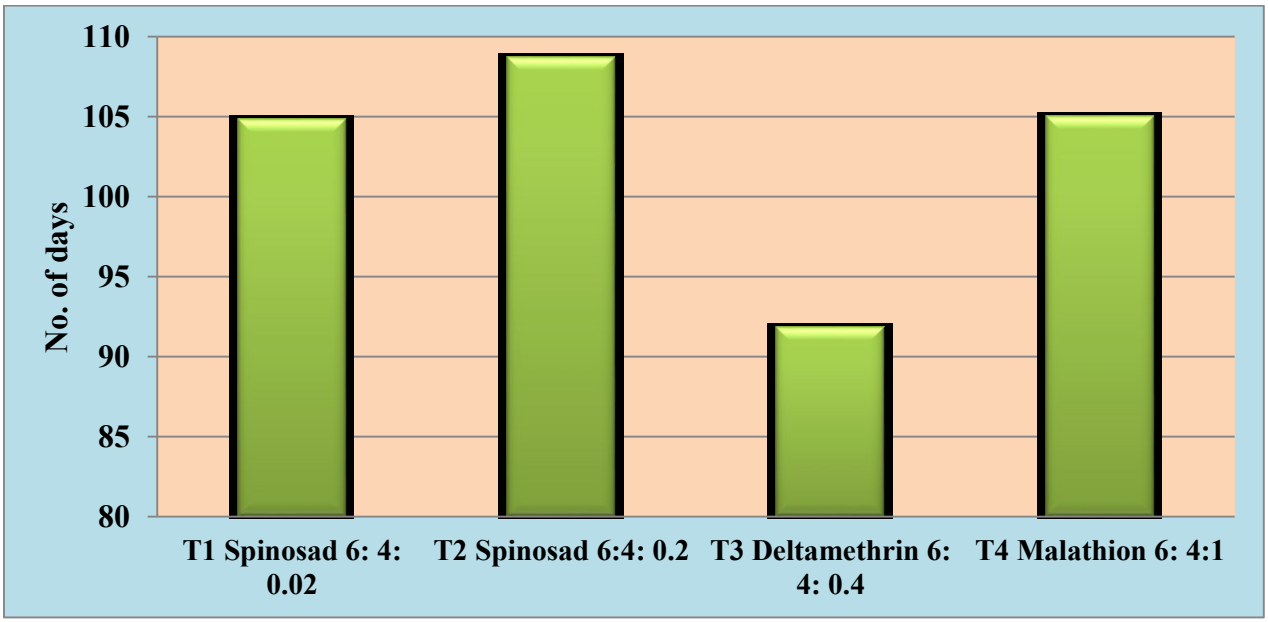


Fig 11. Effect of insecticides on effective trap catch in days in MAT under field conditions

SUMMARY

6. SUMMARY

Mango (*Mangifera indica* L.) is one of the most important fruit crops of the tropical and subtropical regions of the world. The oriental fruit fly, *Bactrocera dorsalis* (Hendel), is a very destructive pest of fruit crops, especially that of mango, causing considerable loss. Farmers depend on chemical control measures such as cover sprays, bait sprays, etc. Indiscriminate use of pesticides leads to environmental and health hazards. The direct application of pesticides needs to be minimized, as fruits are mostly consumed fresh. Currently, eco-friendly pest management methods including bait application technique (BAT) using food baits and male annihilation technique (MAT) using methyl eugenol as attractant are recommended with conventional organophsphate insecticide, malathion as the only insecticide. Hence an alternative chemical for malathion has to be standardized and popularized among the farmers for fruit fly management. The present investigation was undertaken to study the host range and population dynamics and to standardize the use of new generation insecticides in BAT and MAT against fruit flies. The major findings of the study are summarised below.

A survey was conducted in twenty homesteads of Kalliyoor panchayath and the Instructional Farm, Vellayani during 2014-2015 to assess the pest incidence, extent of damage and diversity of fruit flies in different hosts. Study revealed the incidence of the *B. dorsalis* in three fruit crops *viz.,* mango, guava and banana, out of the five selected. No infestation was observed in papaya and sapota from the field. *B. dorsalis* preferred soursop as one of its hosts. In addition to the infestation by *B. dorsalis*, many other species of fruit flies are also attacking fruit crops and vegetables. In the survey, incidence of *B. syzigi* in rose apple and solanum fruit fly, *B. latifrons* in solanaceous vegetables *viz.,* brinjal and tomato was recorded. Fruit fly infestation in brinjal and tomato are new reports from Kerala. A predatory spider, lynx spider (*Oxyopes* sp.) and a larval pupal parasitoid, *Opius* sp. (Hymenoptera: Braconidae) were observed in the field during the survey.

The mean extent of infestation caused by fruit flies to mango during the fruiting months (April-June) ranged from 6.77 to 61.68 per cent with peak infestation during June (61.68 %) and minimum fruit damage during the month of April (6.77 %). The maggot population per fruit during fruiting periods of mango ranged from 23.11 to 78.75 with maximum during June and minimum during April. Two species of fruit fly were found infesting mango. They were *B. dorsalis* and *B. caryeae*, with a species composition of 74.16 and 25.83 per cent, respectively.

The mean percentage infestation in guava during fruiting months (June-September) ranged from 13.97 to 83.78 with maximum damage during the month of July (83.78), followed by August (74.91). The infestation of fruit fly in banana was observed in Red banana and Palayamkodan. In guava and banana, only infestation of *B. dorsalis* was observed.

Study on the occurrence of fruit fly infestation in eleven mango varieties *viz.,* Neelum, Mulgoa, Bangalora, Vellari, Kalapady, Kasthoori, Vellayani Local, Neelamundappa, Kottukonam Varikka, Alphonso and Kappa showed that all the varieties were susceptible to fruit fly attack, except Kottukonam Varikka. The highest fruit damage was recorded in Bangalora (99.68 %), Vellayani Local (97.43 %) and Neelum (93.38 %). The least fruit damage was observed in Kasthoori (43.67 %) and Alphonso (46.12 %). Bangalora recorded the highest number of maggots per fruit (117.20); while the lowest was in Vellayani Local (44.22). Two species of fruit flies *viz*., *B. dorsalis* and *B. caryeae* were reared out from different mango varieties. Population of *B. dorsalis* was the highest (75.50) in the variety Bangalora; whereas population of *B. caryeae* was the highest (26.39) in the variety Kalapady.

Varietal variation in susceptibility to fruit flies among different varieties of guava was studied. Pink fleshed varieties were more susceptible to fruit fly attack

with an infestation of 14.50 per cent. The maximum number of maggots in guava was from white fleshed varieties (25.00) than pink fleshed and strawberry guava varieties. The white fleshed varieties recorded the maximum emergence of *B. dorsalis* (19.20) than pink fleshed varieties and strawberry guava.

Studies were conducted at ten homesteads of Kalliyoor panchayath and the Instructional Farm, Vellayani to monitor the population fluctuation and species diversity of fruit flies using methyl eugenol traps during 2014-2015. Prevalence of four *Bactrocera spp. viz., B. dorsalis*, *B. caryeae*, *B. correcta* and *B. zonata* was observed. *B. caryeae* occurred predominantly in all months, except in January 2015 and February 2015, contributing to 69.85 per cent of the total population. Occurrence of *B. dorsalis* was 28.74 per cent. *B. correcta* and *B. zonata* were relatively in few numbers, contributing to 1.38 and 0.02 per cent of the total population. The population of *B. caryeae* and *B. dorsalis* which was low in March-April 2014 increased slowly and steadily reached the peak level in June 2014, coinciding with the peak fruiting season of mango. The population of *B. correcta* was low, compared to *B. caryeae* and *B. dorsalis*. However, it reached the peak during July 2014, coinciding with the fruiting season of guava. Mango and guava were the most preferred hosts, as observed in the survey. Therefore, their fruiting period exerted essential effects on the population fluctuation of fruit flies.

Studies on correlation with weather parameters showed that the population of *B. dorsalis* expressed a strong positive correlation with maximum temperature, minimum temperature, evening relative humidity, average relative humidity and sunshine hours. The population of *B. caryeae* had a significant positive correlation with maximum temperature, average relative humidity and sunshine hours. The correlation of each weather parameters varied among different species of fruit flies. It is evident from the study that fluctuation of population is governed by both biotic

factors like host availability and abiotic factors such as temperature, relative humidity, rainfall and sunshine hour.

The biology of *B. dorsalis* in different mango varieties *viz.,* Bangalora, Mulgoa, Neelum and Vellari and different hosts *viz.,* mango, guava, banana, papaya and sapota was studied. There was not much variation in egg period and larval period in mango varieties while the pupal period (11.40 ± 1.18 days) and adult longevity (20.70 ± 2.31 days) were longer in Bangalora than in other varieties. Duration of egg stage was the same in all hosts. The larval period and pupal period were higher in banana, with longer adult longevity in mango.

A field trial was conducted to assess the peak time of activity of fruit flies. Methyl eugenol traps were used to document the diurnal activity of fruit flies. The maximum activity of *B. dorsalis* and *B. caryeae* was recorded during early morning hours (6-8 am), morning hours (8-10 am) and evening hours (4-6 pm). However, the population of *B. correcta* was more influenced by evening hours (4-6 pm) which resulted in high activity. Fruit flies were less active during noon hours (12-2 pm). This study suggested the adoption of control measures against fruit flies during morning or evening hours.

Preliminary screening of new generation insecticides, botanicals and bioagents in BAT on the adult of mango fruit fly was conducted under laboratory conditions in cages. Based on the per cent mortality and LT_{50} values, 10 percent jaggery along with lambda cyhalothrin 0.005%, 10 percent jaggery along with spinosad 0.02%, 10 percent jaggery along with malathion 0.1% and 10 percent jaggery along with lambda cyhalothrin 0.0025% were selected as promising treatments for field studies.

Overall observations on the efficacy of new generation insecticides in MAT on adults of mango fruit fly revealed that alcohol, lure and spinosad (6: 4: 0.2 v: v: v), alcohol, lure and malathion (6: 4: 1 v: v: v), alcohol, lure and spinosad (6: 4: 0.02 v: v: v) and alcohol, lure and deltamethrin (6: 4: 0.4 v: v: v) were effective under cage conditions. These were selected for field trials.

The promising treatments in BAT and MAT were evaluated under field conditions. The results indicated that 10 percent jaggery along with spinosad 0.02%, 10 percent jaggery along with malathion 0.1% and 10 percent jaggery along with lambda cyhalothrin 0.005% were equally effective in BAT. However, 10 percent jaggery along with spinosad 0.02% was selected considering the environmental factors. The superior treatment identified from MAT in the field was alcohol, lure and spinosad (6: 4: 0.2 v: v: v).

The study revealed that the host range of *B. dorsalis* is expanding, posing great threat to fruit crops including mango, guava, banana and soursop. In addition to *B. dorsalis*, many other species of fruit flies *viz., B. caryeae*, *B. correcta*, *B. zonata*, *B. syzigi* and *B. latifrons* were also causing considerable crop damage. Laboratory and field experiments for the standardization of new generation insecticides indicated that 10 per cent jaggery along with spinosad 0.02% and alcohol, lure and spinosad (6: 4: 0.2 v: v: v) could be affectively used for the management of fruit flies. So spinosad can be used as an alternative chemical for the conventional organophosphate insecticide, malathion in BAT and MAT.

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*Originals not seen

Population Dynamics and Management of Mango Fruit Fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)

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ABSTRACT

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ABSTRACT

The investigation entitled "Population dynamics and management of mango fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)" was conducted at the College of Agriculture, Vellayani during 2013-2015. The main objective of the work was to study the host range and population dynamics of mango fruit fly and to standardize the use of alternate chemicals in Bait Application Technique (BAT) and Male Annihilation Technique (MAT) for its management.

A survey was conducted in twenty homesteads of Kalliyoor panchayath having at least 25 cents and the Instructional Farm, Vellayani during 2013-2015 to study the pest incidence, extent of damage and host range of mango fruit fly. Study revealed the incidence of the *B. dorsalis* in three fruit crops *viz.,* mango, guava and banana, out of the five selected. No infestation was observed in papaya and sapota. *B. dorsalis* preferred soursop as one of its hosts. The species emerged from mango were identified as *B. dorsalis* and *B. caryeae* (Kapoor). In guava and banana, only infestation by *B. dorsalis* was recorded. Infestation by other species of fruit fly was also recorded from rose apple and solanaceous vegetables *viz.,* brinjal and tomato and the species were identified as *B. syzigi* and *B. latifrons* (Hendel), respectively. Fruit fly infestation in brinjal and tomato are new reports from Kerala. The percentage infestation in mango was higher in peak fruiting season during May (49.28) to June (61.68) and the maximum number of maggots was observed during June 2014 (82.49).

Studies were conducted at ten homesteads of Kalliyoor panchayath and the Instructional Farm, Vellayani to monitor the population fluctuation and species diversity of fruit flies using methyl eugenol traps during 2014-15. It revealed the prevalence of four *Bactrocera spp. viz., B. dorsalis*, *B. caryeae*, *B. correcta* (Bezzi) and *B. zonata* (Saunders) with a species composition of 28.74, 69.85, 1.38 and 0.02 per cent, respectively. The population of *B. caryeae* (278.91) and *B. dorsalis*

(124.82) reached the peak level in June 2014 which coincided with the peak fruiting season of mango. Studies on correlation with weather parameters revealed that the maximum temperature, average relative humidity and sunshine hours had a significant positive correlation with the population of *B. dorsalis* and *B. caryeae*.

The biology of *B. dorsalis* in different mango varieties and hosts was studied. Longer pupal period (11.40 days) and maximum adult longevity (20.70 days) were observed in the mango variety Bangalora. Among the different hosts, the highest larval (12.90 days) and pupal periods (10.30 days) were recorded in banana. However, the highest adult longevity (19.70 days) was observed in mango. Field studies indicated that the activity of *B. dorsalis* was more (6.92 flies per trap) during 6.00 to 8.00 am.

Based on the percentage mortality and LT_{50} values, 10 per cent jaggery along with lambda cyhalothrin 0.005%, 10 per cent jaggery along with spinosad 0.02%, 10 per cent jaggery along with malathion 0.1% and 10 per cent jaggery along with lambda cyhalothrin 0.0025% in BAT and alcohol, lure and spinosad (6: 4: 0.2 v: v: v), alcohol, lure and malathion (6: 4: 1 v: v: v), alcohol, lure and spinosad (6: 4: 0.02 v: v: v) and alcohol, lure and deltamethrin (6: 4: 0.4 v: v: v) in MAT were selected for field evaluation. Field studies conducted in homesteads of Balaramapuram panchayath using the above promising insecticides revealed that 10 per cent jaggery along with spinosad 0.02% was effective in BAT and alcohol, lure and spinosad (6: 4: 0.2 v: v: v) was the best treatment in MAT.

The study revealed that in addition to *B. dorsalis*, *B. correcta* and *B. zonata* and many other fruit fly species including *B. caryeae*, *B. syzigi* and *B. latifrons* are also becoming a great threat to crops. Considering the environmental factors, spinosad can be selected as an alternative chemical for the conventional organophosphate insecticide, malathion.