MANAGEMENT OF FRUIT FLIES: AN INTEGRATED APPROACH

Abstract

Fruit flies are the most notorious pests of horticultural commmodities throughout the world. Being ubiquitous in distribution, these flies are reported from almonst all agroclimatic conditions of the world and are regarded as pests of international significance. The high reproductive potential, polyphagous nature and ability to adapt to varied clinmatic conditions has made fruit flies a very difficult pest to manage. A single management tactic does not provide effective control of the pest, hence different methods need to be integrated to achieve desired level of contol. The present chapter provides information on different management options available along with the level of control achieved with each option.

Fruit flies belong to one of the largest family Tephritidae of the order Diptera. The fruit flies are ubiquitous in distribution occupying regions from tropical, subtropical to temperate regions of the world. There are nearly 4500 species of fruit flies under the family Tephritidae reported throughout the world with 400 species of fruit flies under the genus Bactrocera (David and Ramani, 2011). The tephritidits are identified by the three costal breaks in the wing at the humeral subcostal and costal vein. The size of the fruit flies differs and is affected by the host (Sharma and Gupta 2018b). Fruit flies belonging to the genus Bactrocera are the most devastating pests of fruit and agricultural commodities throughout the world. The change in the climatic conditions has provided adaptive advantage to these fruit flies resulting in frequent outbreaks in various fruit crops (Sultana et al., 2017). Fruit flies affect the quality and quanity of the fruits therby affecting their production and market potential and leading to about 40- 80 percent crops losses (Kibira et al 2015).

Keywords: Fruit flies integrated approach

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Fruit flies are responsible for more restrictions on produce movement than any other pest. These are most widely distributed, there are a number of different species that raise quarantine concerns.Since they can be easily transpoted across the nations through contaminated fruit commodities, countries harbouring these pests invest great amounts to control the pest and also has trade sanctions imposed (Sharma and Thakur, 2007; Sharma et al, 2009).

The European union and US has imposed restriction on the import of fresh fruits from fruit fly reported countries and fruits from such countries can only be imported after nuclear irradiation and strict quarantine inspection (Dhami et al 2016; Rastogi and Deodhar 2008; Reddy et al 2010). The fruit flies are a very difficult pest to mange as the damaging stages remain hidden in the fruit nad the full grown larvae fall to the ground for pupation thus escaping the insecticide contact (Heve et al, 2017). Moreover most of the countries have imposed ban oin the earlier effective broads spectrum insecticides used for fuit fly mangement. (Bockmann et al, 2014). The increasing concern among the people and enviornmentalists for pesticidfree food has compeled the scientists and researchers to serach for alternative fruit fly mangement options (Navarro-llopis et al, 2011).

The high adaptation potential, polyphagous nature and higher reproductive potential makes it a very diffficult pest to manage and cannot be dependent on a single option but requires the integration of various management options. Therefore the chapter highlights the impotant integrated fruit fly mangemnt options for reducing the menance of fruit flies.

I. BIOLOGY OF THE PEST AND CORRECT TAXONOMIC IDENTIFICATION

The effective management of fruit flies require the proper knowledge pertaning to the biology of the pest so that the weak links in the life cycle of the pest can be targeted. The fruit flies makes punctutre in the fruit with the help of its ovipositor and deposits the eggs in the fruits. The maggots after completion of the incubation hatch from the eggs and statrt feeding. The maggots during the first instar are delicate and with the help of the mouth hooks feed on the fruit pulp. After completion of the second instar the maggots moult into the third instar, which is the major feeding stage of the pest. Once these third instar maggots becomes fully feed they leave the rotting fruit and fall to the ground for pupation. The larval skin of the third instar becomes hard to form the puparium in which the maggots pupates. The adult flies emerge from the puparium by cutting a hole in it. Several generations are completed in a year depending on the host availability and favourable conditions (Sharma, 2018). Identification of the fruit fly species is an important aspect of fruit fly mangement as the fruit flies infesting the vegetables are attracted to cuelure whereas those found in fruits are generally trapped using methyl eugenal. The monitoring and identification are most important aspect in the mangement of fruit flies (Aluja, 1999). Monitoring of fruit fly population helps us to determine the population of fruit flies present and evaluate effectiveness of different mangement strategies (Eliopoulos, 2007).

The different management strategies for fruit fly control are mentioned as under :

1. **Cultural Control:** Managing of fallen fruits is the first and foremost step for controlling the fruit fly infestation. The fallen fruits should in collected and dumped in a pit 50 cm deep and should be covered with soil to ensure cleanliness. The fallen fruits on the ground

severe as a breeding site for the multiplication of the fruit flies. These fallen fruits can also be placed in plastic bags and exposed to sunlight (Reddy, 2020). Higher density of *B. invadens* was found on fallen fruits than from the fruits on the tree, which highlights the importance of orchard santitation practises for effective fruit fly management (Rwomushana, 2008). The use of black plastic bags has also shown much importance in mangemet of fruit flies. The fallen fruits were placed in black plastic bags and were hung in sun until the fruits rot and the maggots dies. This method was found effective for the mangement of *B. zonata* in Egypt (Mohamed and El-wakkad, 2003). The varying temperature regimes and internal conditions were studied in mango crop, it was observed that the damaged mango fruits in the shade favoured better internal conditons for the growth of the larvae than the mangoes which were present in the sun (Jenkins et al, 2008).

Since fruit flies prefer semi-ripened fruits for egg laying, early harvesting of fruits can also help in lowering the pest population. The harvesting of fruits like banana, mango and oranges should be done at an early stage to avoid damage caused by fruit flies (Badii et al 2015; Sidique et al, 2017). The selection of variety can also have impact in reduction of fruit infestation. Since the maximum infestation by fruit flies was recorded in late summer and autumn maturing varieties hence selection of early maturing varieties can help to manage the attack (Sidique et al, 2017). Further a well managed orchard has less infestation in comparison to an unmanged ones as the intercultural operations can be easily carried out. When effect of pruning from May to Sptember in guava was conducted and was compared with orchards with no pruning, it was observed that minimum fruit infestation was observed in trees pruned in September (9.94%), being at par with infestation in trees pruned in August (11.87 %). Whereas, the maximum infestation was observed in unpruned tress (48.11 %) (Choudhary et al ,2022).

2. **Mechanical Control:** The mechnaical methods to prevent fruit infestation by the flies includes the use of protective covers such as screens and nets to avoid contact of fruit flies with the fruit. The method of wrapping of the fruits using protective coverings is more effective but wrapping of the fruits is a labour inntensive method and require more cost. Wrapping is usually carried out 1 month earlier to prevent the female fruit flies from laying eggs (Badii et al, 2015).

Behavioural Control: Behavioural control involves the methods which interfere with the normal behavioural aspects of the pest. This inclues use of Pheromones and Sterile insect Technique.

- **MAT:** The pheomones are used to attract the males of the fruit flies. The Male annihilation technique (MAT) is mostly used which is a strategy to kill the male flies by luring them with help of a chemical and killing the attracted males, thereby reducing the availability of the male to mate with the females. When combined with other control strategies MAT can result in eradication of the fruit flies (Dominiak and Nicol, 2012;Dominiak, 2019).

  Traps and lures have been used for the mangemnet of fruit flies from over a decade. The first attractant developed for the male fruit flies was Methyl Eugenal by Howlett in 1912 for attracting the males of *Bactrocera zonata* (Verghese et al, 2013). There after different lures were developed by various workers such as kerosene, Angelica seed oil and trimed lure for Mediterranean fruit fly, *Ceratitis capitata* management. Studies for attractiveness of Cuelure for the mangement of *Bactrocera cucurbitae* was demonstrated by Beroza and Green (1963).

The MAT blocks aree made up of materials such as pastic or wood (Lloyd et al, 1998, Thakur and Gupta, 2013). The tephritid fruit flies have been managed with the use of MAT for decades in various parts of the world. The eradication of *B. papayae* was carried out using Methyl eugenal based traps in Rota, Okinawa Islands and NorthQueesland (Steiner et al 1965; Koyama et al, 1984 and Lloyd et al, 1998). The peach fruit fly *B.zonata* was eradicated from Egypt (Ghanim et al, 2010) and *B. dorsalis* in Kenya (Ndlela et al, 2020) and the *Zeugodacus cucurbitae* from Hawaii (Spafford et al, 2018).

The MAT blacks are impregnated with the mixute consisting of alcohol, lure and insecticide. These blocks are then placed in a bottle of any contanier so that the flies attracted and killed are collected in the container. The chemical lures used to attract the males are Culure (CL) and Methyl eugenol (ME)(Bateman et al., 1966), whereas for a number of years Malathion has been used as a toxicant due to its long activity under field conditions (Lioyd et al 1998 and Thomas and Meats 1999), however due its toxicity and restricted use is being replaced by spinosad (Sharma, 2018 and Abrol et al, 2019). The effectiveness of the MAT is affected severly by decline in the effectiveness of lure or toxicant (Llyod et al, 1998; Vargas et al 2015; Manoukis et al, 2019). MAT fails to provide complete control of the fruit flies due to the lack of community participation and unwillingness among the farmers for installation of traps. Often the MAT is combined with other techniques such as the sterile insect release and protein baits where irradication is the main objective.

As the pheromones are unstable in nature and under go auto-oxidation, photo-oxidation and isomerization and volatility (Cok, 2004), the pheromones when used under field conditons need to be stable. One answer to this problem can be the use of nanogel immobilized pheromones. It was observed that the nanogel were quite effectivw in the control of fruit flies with higher residual activity and also were found effective during the unfavourable conditions (Bhagat et al., 2013).

- **SIT:** Sterile Insect Technique (SIT), according to the International Plant Protection Convention (FAO, 2005) is defined as a method of pest control using area-wide inundative releases of sterile insects to reduce fertility of field population of the same species. The technique involves the mass rearing of sterile insects and releasing the same in the enviornment for mating with the females in the wild. This will result in failure of production of off springs by the femlae. The SIT was successfullly used for the first time by Knipling in 1955 (Knipling, 1955) for the eradication of a cattle pest screwworm, *Cochliomyia hominivorax* Coqerel from North and Central America (Klassen and Curtis, 2005). Since then SIT has been used for the eradication of a number of agriculturally and veterinary pests from around the world. Since the 1950's this technique has been used for control of fruit flies from different parts of the world such as *Bactrocera cucurbitae* Coquillett from Japan (Kuba et al 1996) Queesland fruit fly *Bactrocera tyroni* Froggatt from Western Austrailia (Sproule et al, 1992), Mediterranean fruit fly,*Ceratitis capitata* from California and Florida, USA

(Dowell et al 2000; Barry et al, 2004), Hawaii (Steiner et al, 1970), Mexico (Hendrichs et al, 1983) and Chile (Gonzalez and Troncoso 2007).

SIT is a scientifically sound management technique which is used for the control of pests and can also be used to establish fruit fly free zones (Reddy et al 2016). With the advancement in technology, Artificial intenlegence is now being used for identification of the treated flies from the normal flies (Gonzalez-Lopez et al, 2022).

The favourable effect of the SIT program estimated in terms of the benefit cost ratio achieved was 150 in Mexico and US and as high as 1600 and 1900 : 1 in Chile and South California respectively (Lindquist and Enkerlin, 2000). It was only after the eradication of the melon fruit fly from Japan that it was able to export horticultural products in the international market (Kakazu, 2002). SIT is the only technique which provides high economic retuns.

II. BIOLOGICAL CONTROL

Parasitoids among the biological control strategy are mostly exploited for fruit fly mangement (Vargas et al 2012; Dias et al, 2018). The papasitoids in the Braconidae family includes *Diachasmimorpha longicaudata Diachasmimorpha longicaudata and Psyttallia* spp. Such as *P. concolor, P. fletcheri and P. ponerophaga*(Mohamed et al 2008; Montoya et al 2016; Ovruski and Schliserman, 2012). The parasitoid was also reported from the mango growing regions of Himachal Pradesh, India (Sharma, 2018). The ability of *D. longicaudata* to settle in diverse semiarid and tropical enviornments allowed the mangement of the pestiferous *Anastrepha*sp. in Brazil (Garcia et al, 2013). The parasitoid,*D. longicaudata* has also been used for the augmentative location-extensive release in various Mexican states (Montoya et al 2007; Montoya et al, 2020). *D. longicaudata* was also used in Peru for the control of *C. capitata* resulting in more than 50 per cent parasitism in 2 years (Gracia et al, 2020). Apart from these the egg- larval parasitiod *Fopius arisanus*, larval parasitoid *D. Tyroni, D. fullaway*i and the pupal parasitoid *Coptera silvestri* was also used for the management of fruit flies, especially *C capiata* (Clausen, 1978).

The entomopathogenic fungi have also been used for the mangemnt of fruit flies resulting in stimulating effects. *Beauveria bassiana, Metarhizium anisopliae* and *Isaria fumosorosea* resulted in 90-100 per cent motrtlaity of *Rhagoletis cerasi* (Daniel and Wyss, 2009). The foliar application of *B. bassiana* reduced the fruit fly species by 65 per cent. (Daniel and Wyss, 2010). The entomopathogenic species provided promising results for the management of *C. capitata*, *Bactrocera oleae*and Z. cucurbitae (Castillo et al, 200; Yousef et al, 2013; Toledo et al., 2017; Yousef et al., 2014; Sookar et al 2017). Recently, autoinoculative devices and sterile male vectors were tested using three strains of *B. bassiana* for the control of *C. capitata* in coffee (Toledo et al, 2017). The release of the male vectors was a better transmitting agent of the conidial spores.

EPNs have also been used under laboratory conditions like Steinernema carpocapsae Weiser (Neoaplectana carpocapsae) was found to cause significant mortality in melon fruit fly after 6 days of exposure at 5000–5,000,000 nematodes/cup, and an average of 87.1% mortality in the field when applied at 500 infective juveniles/cm2 of soil (Lindegren, 1990).

Table 1 summarizes the natural enemies of fruit flies and the stages that are affected. The two main species used for the mangement of fruit flies include Heterorhabditis spp. (Rhabditida: Heterorhabditidae) and Steinernema spp. (Rhabditida: Steinernematidae). The entompthoagenic nematodes have been successfully used for the mangement of *A. fraterculus, A. ludens, A. suspensa Dacus ciliatus and R. cerasi* (Kamali et al 2013; Foelkel et al 2017; Have et al ,2016; Torrini et al, 2017). These workers suggested the mortality of fruit flies with EPNs ranged from 14-96 per cent and were also influenced by a number of factors.

III. CHEMICAL CONTROL OF FRUIT FLIES

The management of fruit flies with chemicals has been an age old practice and the most commonly followed practice by the farmers. The first chemical to be used for the fruit fly management was DDT and was slowly replaced by organophosphate insecticides Gupta and verma (1978).

In Bait Application technique (BAT), sprays consisting of mixture of Bait and insecticide are applied in the form of spot application. Baits such as protein solutions, fermented sugar solutions, vinegar and fruit juices have been used since 1918 for the capture of females (IAEA 2003).

The bait sprays are applied as spot application which is known to reduce the fruit fly population upto 90 per cent with a cost benefit ratio of 1:9.1 (Ekesi, 2016). This method is an advantageous alternative to the chemical application of insecticide cover sprays (Jenkins and Sheldy 1959; Allwood, 1989). The mixture of water, bait (protein hydrolysate) and insecticide are used in the ratio of 98.6, 0.7: 0.7. this technique is relatively save in comparison to the application of the insecticide alone and is less harmful to the non-target organisms. The combination of MAT and BAT provides added advantage for the mangmeent of fruit flies (Patel and Mondal, 2011). Both MAT and BAT cannot control the damage caused by fruit flies, they can only be effective when used with other control methods. The MAT when used with Sterile insect Technique has been found effective in irradication of fruit flies from various islands.

The mangement of fruti flies using either baits or as cover spray both can result in the development of resitance. The development of resitnce in insect can result either from mutations of the tatget site due to the detoxification of the insecticide molecule. B. cucrbitae and B. dorsalis were reported to show resitance to DDT nad methoxy chlor from Hawaii. Additionally, *B. oleae, B. dorsalis and C. capitata* have shown resistance to organophosphate insecticides (Nigg et al 2008; Vontas 2018; Hsu et al, 2008). Nigg et al (2008) also reported the resistance of A, suspensa to malathion from Taiwan, similarly *C. capitata* was also reported to be resistance to malathion from Spain (Magana et al, 2008).

Quarantine Treatments

1. **Cold Storage:** Cold storage is commonly used as a quarantine treatment for fruit crops against fruit flies. Temperatures under 3°C are required for 2 weeks or more. This limits use on chilling sensitive vegetables.

2. **Heat Treatments:** Heat treatments are used as a quarantine treatment against fruit flies in chilling sensitive fruit crops.

3. **Fumigation:** There are a number of different fumigants, of which methyl bromide is still widely accepted. It is cheap to apply, fast and can be used as a generic treatment against a range of pests.

4. **Irradiation:** it is fast, accepted as a generic treatment for fruit fly and leaves no residue.

IV. NEW INSECTICIDES

The high degree of resistance to popularly used insecticides has compeled the researchers to search for alternatives. Spinosad has provided efffective control of the fruit flies in mango (Sharma and Gupta 2018a, Sharma 2018). Rahman et al (2019) also reported the effectiveness of spinosad andabamectin in fruit fly management. In addition, botanical based pesticides not only provide effective control of the fruit flies (Singh 2003; Silvia et al 2013) but can also be integrated with other parasitoids (Alvarenga et al, 2012). The utilization of spinosad in bait sprays has also provided good control of fruit flies (Michaud, 2003; Flores et al, 2011). Alam and Khan (2021) suggested the efficacy of spinosad in amangement of cucurbit fruit fly in bottle gourd. El-Gendy et al (2021) suggested the efficacy of abamectin as soil treatment for the control of peach fruit fly, *B. zonata*. Sharma and Gupta(2018) reported better efficacy of spinosad than the popularliy used insecticide malathion and azadirachtin in mangement of *B. dorsalis and B. zonata*. Jagarat et al (2023) also reporteed the efficacy of spinosad in management of fruit flies in bitter gourd.

V. CONCLUSION

Studies on fruit flies which started from as early as 1950's even continue till date as management of this pest is not only difficult but the threat of its introduction to new regions is a cause of concern. The dependance on a sole management tactic cannot control the pest hence integration of diffferent methods needs to be done. Moreover, the scientist will keep searching for alternatives and integration of different management options until the management of the female fruit flies is achieved.

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