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# Area-wide Integrated Management of Fruit Flies (Diptera: Tephritidae) Pest in Vegetables Cultivation

**Muhammad Sarwar***

Nuclear Institute for Food & Agriculture (NIFA), Peshawar, Khyber P. K. (KPK), Pakistan

## Abstract

Vegetable crops hold a key position in agricultural production worldwide, and the Asian regions such as East, Southeast and South are among the top regions for their exports and imports. However, many pests and diseases threaten the profitability of this agricultural sector, and improving the productivity and quality of vegetables can enhance food security, employment and trade opportunities. Fruit flies particularly melon fly *Bactrocera cucurbitae* (Coquillet) (Diptera: Tephritidae) are among the most important pests of solanaceous and cucurbit crops, and losses of as much as 100% of host harvests can be frequently observed without pest control. The melon fruit fly *B. cucurbitae* can successfully be managed over a local area by bagging fruits, field sanitation, protein baits, cue-lure traps, growing fruit fly-resistant genotypes, augmentation of biocontrol agents and insecticides. The control methods used independently have not been successful to effectively control tephritid fly populations. Therefore, the area wide management program involves the coordination of different characteristics of a fly eradication program (including local area options) over an entire area within a defensible perimeter and subsequently protected against reinvasion by quarantine controls. A more integrated approach is also required by taking into account the landscape habitats, especially wild plants, whose role must be considered within a framework of an agro-ecological management of these pest populations.

## Keywords

Vegetable, Tephritidae, Fruit Fly, *Bactrocera cucurbitae*, Pest Control, Control Method

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## 1. Introduction

Fruit fly species belonging to the Tephritidae family (Diptera) cause major damage to vegetable crops, while melon fruit fly *Bactrocera cucurbitae* (Coquillet) is among the most important pests on Cucurbitaceae and Solanaceae plants. It has been reported to damage 81 host plants, and is a major pest of cucurbitaceous vegetables, particularly the bitter gourd (*Momordica charantia*), muskmelon (*Cucumis melo*), snap melon (*C. melo* var. momordica) and snake gourd (*Trichosanthes anguina*). The extents of losses vary between 30 to 100%, depending on the cucurbit species and the season. Its abundance increases when the temperature falls below 32°C, and the relative humidity ranges between 60 to 70%. It prefers to infest young, green and soft-skinned fruits. It inserts the eggs 2 to 4 mm deep in the fruit tissues and the maggots feed inside the fruit (Sarwar, 2014 a; Allwood et al., 1999).

### 1.1. Life Cycle and Biology of Fruit Flies

The distribution of melon fly *B. cucurbitae* ranges from South Asia to many Pacific Islands and more recently the Africa, where it is currently spreading. Its biology is relatively well known and the species has been much studied in South-East Asia, which is a thermophilic species not commonly found at altitudes over 800 m (Dhillon et al., 2005).

* Corresponding author
E-mail address: drmsarwar64@yahoo.com

Adults of melon fly are typical strong fliers and they usually fly in the morning and afternoon. Most often they are found on low, leafy and succulent vegetation near cultivated areas. In hot weather they rest on the undersides of leaves and in shady areas. They usually feed on the juices of decaying fruit, nectar, plant sap and bird feces. The adult melon fly is about 6 to 8 mm in length. Distinctive characteristics include its wing pattern, long third antennal segment, the reddish yellow dorsum of the thorax with light yellow markings, yellowish head with black spots, large black spot at wing tip and black cross streak on the wing, and the medial vitta on the scutum. The female may lay as many as 1,000 eggs and these are generally laid in young vegetable, but are also laid in the succulent stems of host plants. The eggs are deposited in cavities created by the female using its sharp ovipositor. The egg is elliptical, about 2 mm long and pure white. It is almost flat on the ventral surface and more convex on the dorsal. Eggs are often somewhat longitudinally curved.

The first stage larvae or larvae that hatch initially are small and delicate. It is a cylindrical-maggot shape, elongated, with the anterior end narrowed and somewhat curved ventrally. It has anterior mouth hooks, ventral fusiform areas and a flattened caudal end. Last instar larvae range from 7.5 to 11.8 mm in length. The venter has fusiform areas on segments 2 through 11. The anterior buccal carinae are usually 18 to 20 in number. The anterior spiracles are slightly convex in lateral view, with relatively small tubules averaging 18 to 20 in number. They moult into slightly more robust second instar larvae, and these in turn moult into quite stout and tough third instar larvae. When the third instars have finished feeding, they leave the fruits, fall to the ground and crawl away to a sheltered spot usually in the soil where they pupate.

The pupation usually occurs in the soil and larval skin becomes barrel-shaped, tanned brown and hard, and is known as the puparium that ranges in color from dull red or brownish yellow to dull white, and is about 5 to 6 mm in length. The true pupa is formed inside this puparium shell and the pupa turns into an adult fly, which escapes from the puparium by splitting open the anterior end and squeezing out of it. Female flies do not lay eggs for several days after emergence and need a protein feed to be able to develop eggs. Most fruit flies are facultative breeders that will lay eggs whenever their hosts are available, so may have many generations per year depending on hosts availability and normally there may be as many as 8 to 10 generations in a year. Development period from egg to adult ranges from 12 to 28 days.

## 1.2. Fruit Fly Damage and Crop Losses

Fruit flies are the most serious insect pests with an ability to totally wipe out any marketable host. The damage starts when the female fruit fly punctures the fruit with its long and sharp ovipositor. They pierce the host and lay eggs, after hatching the fruit fly larvae or maggots feed inside the host causing sunken, discoloured patches, distortions and open cracks. It is assumed that some or may be all fruit fly females carry bacteria with them that they inject into the fruit at oviposition so that the fruit decays faster. Or else, the cracks made by long and sharp ovipositor serve as entry points for fungi and bacteria, and the fruit starts to decay causing host to rot. The larvae that hatch from the eggs feed on the decaying fruit tissue, and on the yeasts and bacteria that multiply in the host. Fruits with fruit fly larvae in them decay quickly thus making it more nutritious for the larvae.

The Fruit fly pests are present throughout the year, and their populations levels are fairly high and mainly distribute in the vegetables growing areas. Vegetables consumption in a state is mainly for domestic and export purposes, and though fruit flies are causing serious damage to crops, even then these are not causing quarantine problems. It is sometimes possible to cut out the damaged portion of host and then home consumption of the remaining part of the vegetable, but infested hosts are generally not saleable, and can certainly not be exported. Crop losses can vary from a few per cent up to 100%, and losses of 90% or over are more common (Sarwar, 2014 b).

Within vegetables, fruit flies are among the main pests for solanaceous crops, in particular field grown tomato *Lycopersicum esculentum* Mill, and cucurbits including cucumber (*Cucumis sativus* L.), zucchini (*Cucurbita pepo* L.), melon (*Cucumis melo* L.), etc. Losses of as much as 80% of tomato and 100% of cucurbit crop harvests have been frequently observed (Philippe et al., 2010). Host choice experiments have been done for fruit fly *B. cucurbitae* by using different vegetables. Host preference for oviposition has been determined by incubating vegetables to natural infestations by *Bactrocera* in the field, and their larvae reared and adults maintained in the laboratory. The vegetables, bitter gourd, brinjal, muskmelon and pumpkin have been tested for the relative host preference of fruit fly *B. cucurbitae*. The bitter gourd has been found as most preferred host demonstrating the maximum pupae formation (134.08), pupae weight obtained (4.91 mg) and percent adult emergence (82.64%) of fruit flies. Brinjal has been observed as moderately preferred host, while, muskmelon and pumpkin are sorted out as least preferred hosts. These results provide experimental support that flies can respond differently to the host experienced in the field and the hosts that are of advantageous to the pests may be more adapted. Results further imply that host preference of fruit flies can shift towards suitable hosts and if hosts which provide a proper breeding situation become scarce then alternative hosts are accepted. These findings confirm that the host choice and preference of the fruit flies have the impacts on both pre-harvest and post-harvest countermeasures of horticultural crops (Sarwar et al., 2013).

The *B. cucurbitae* has been found present through all the year and maximum numbers of adults are trapped during August (14.14/ trap/ week). Trap catches of *B. cucurbitae* have been significantly and positively correlated with relative humidity. Maximum and minimum temperature, RH (%), rainfall (mm), evaporation (mm) and wind speed (km/ h) collectively determined 44% of *B. cucurbitae* trap catches. Maximum fruit fly emergence of 494.64/ kg fruit has been found on bitter gourd (October) followed by cucumber (November), pickling cucumber (October) and ridge gourd (October) (Kumar et al., 2006).

### 1.3. Sampling for pre Harvest

Fruit samplings are useful to identify the hot spots or areas where breeding populations of flies persist. Sampling of the major vegetable fruits are undertaken periodically to assess the percentage of hosts infested by the respective species. The samples of fruits are randomly collected, mainly from the ground, weighed, counted and set up in bulk or individually in separate plastic containers. For analysing, they are held in laboratory, the healthy and damaged fruits are sorted, numbers of infested fruits are recorded and the percentage of fruits infested is determined. Alternately, near to crop harvest, 15-25 suspected vegetables fruits at random are selected from a field and grouped, thus each crop has enough fruits. These host fruits are brought to the laboratory and be placed in cages for ripening after which they are cut and percentage infestation is calculated based on the numbers of infested fruits. Flies are allowed to emerge and fed on water and sugar for about five days, killed, identified, counted, and the percentage of host infested is also determined.

### 1.4. Identification of the Commonly Occurring Fruit Fly

There are many kinds of fruit flies that can inflict damage to the vegetables. The loses from fruit flies can be caused by single species of fruit flies or as result of several species which attack the same plant at the same time. Understanding how to identify the species of fruit flies is the important issue for fruit flies management because the wrong identification may lead to mismanagement. Simple identification methods can be applied using a hand lens or binocular microscope. The identification can be made by examining the face mark, thorax and abdominal bands and marks on the wing. The scutellum of *B. cucurbitae* is yellow; wings with costal band complete, dark and expanded apically; other characters are costal band with large apical spot, almost covering apical part of cells r2+3 and r4+5; crossveins R-M and DM-Cu thickly infuscated; and have 3 frontal setae (Riaz and Sarwar, 2014; Shah et al., 2014).

## 2. Strategies for Integrated Management of Melon Fruit Fly

Through keeping in view the importance of the pest and crop, the melon fruit fly management could be done using local area management or area wide management. In some cases losses can be reduced by other treatments applied by the farmers in an area e.g., against another orchard pest or in another crop intercropped in the orchard. The various methods currently used can be summarized in ensuing lines.

### 2.1. Non-chemical Control

The control of fruit flies is still largely based on the use of insecticides, but the research issues already conducted on fruit flies have gradually turned towards alternative methods. The cucurbits and solanaceae fruits, of which the melon fly is a serious pest, are harvested at short intervals for self-consumption and marketing. Therefore, it is difficult to rely on insecticides as a means of controlling this pest.

#### 2.1.1. Monitoring and Monitoring Devices

Surveying fruits for infestation can give some indication of the severity of an infestation. Looking for maggots infesting fruit that has fallen from plant in late winter and spring is useful, as it can give some indication of overwintering fly numbers. Adult fruit flies can be monitored with McPhail or Yellow sticky traps. Plastic McPhail traps have proven to be more effective than yellow sticky traps in catching larger numbers of fruit flies and catching them earlier in the season. However, yellow sticky traps baited with a pheromone lure or ammonium bicarbonate may be easier to use. Males of *B. cucurbitae* are attracted to cue lure. Bottle trap using a plywood (3 cm x 3 cm x 1 cm) soaked in cue lure 6: 1 v: v (cue lure: malathion) can be suspended from the top of a plastic water bottle (capacity 1 litre). Each bottle may have four windows to facilitate pheromone dispersion and entry of fruit fly adults (Sarwar, 2015 a).

Place traps in the second tree row or further inside, to reduce dust accumulation in the traps. Hang the traps at mid-canopy, in the shade (north side of the tree), and in an open area avoid leaves blocking the trap. Usually record the numbers of flies trapped weekly. Although traps reduce damage, they are more useful as monitoring devices. Traps should not be used as a stand-alone treatment, in part because of their inconsistent ability to attract and trap adult flies and because traps cannot compete with fruits as the fruit becomes more attractive. Flies enter from the bottom of the trap through an opening and drown in the solution. Recommended baits to use in these traps are torula yeast or nuLure bait. The addition of pheromones in liquid traps does not increase trap catches. Torula yeast catches more flies earlier than ammonia-based lures. Normally, place two traps for each 5 to 10 acre block of trees to evaluate treatment efficacy. More traps per block are necessary to evaluate fly's activity or density. For mass trapping, place one trap in each tree, use 3 to 4 yeast tablets per trap and change monthly. To count the trapped flies, the trap contents are emptied into a sieve so that the liquid can drain out and the flies may be identified and counted (Sarwar, 2012; Sarwar et al., 2014 a).

Yellow sticky traps are baited with a sex pheromone, an ammonium bicarbonate attractant, or both. The sex pheromone attracts the males whereas ammonium bicarbonate attracts both males and females. Both lures can be combined in one trap, but pheromones may not increase trap catches. Sticky traps may be more difficult to use than McPhail traps. While there may be no relationship between fruit damage and the number of insects found in traps, surveying trap catches can evaluate treatment efficacy by comparing trap catches before and after treatment (Sarwar et al., 2014 b).

### 2.1.2. Cultural Control

Field sanitation is important in reducing overall fly densities. It is useful to remove old fruits remaining on plants following harvest and destroy all fruits that are on the ground by either burying at least 4 inches deep or taking to the landfill. Extremely high fly populations can occur in fruited varieties of landscape plants and in un-maintained ornamental situations. These can be a significant source for invasion of commercial groves. Prevent fruiting on landscape plants in spring by using a chemical such as naphthalene acetic acid (NAA) or destroy fruit on the ground in fall to reduce this invasion pathway. An area wide approach is needed to reduce fly's densities where commercial plantings are near ornamental or un-maintained trees. Fruit fly adults feed on honeydew and reducing black scale populations may reduce a food source needed during high summer temperature (Sarwar, 2015 b).

Traditionally, the vegetable fruits can tolerate damage up to 100% if the damage is caused by stings or tunnels in unripe fruit and there is less than 1% fruit rot. The most important aspect of damage levels for vegetables is that the fruit should be harvested early to avoid damage or rot. Vegetable damaged by fruit fly larvae can develop like ripe fruit flavours even when fruits are still green. This makes it possible to harvest fruit early, but still produces tasteful food (Sarwar, 2015 c).

### 2.1.3. Physical Control

Physical protection of crops via nets or screens to prevent insect egg-laying is a solution already employed on some crops such as vegetables and could be a very useful practice. Practices of individual fruit bagging using nets are sometimes employed in some countries where there is a low labour cost. It has been demonstrated that cucurbit flies do not enter open plastic tunnels housing crops, the openings of which are closed off by bird nets of mesh size around 3 cm, owing to the net that may disrupt the flight behaviour of the flies, thus preventing them from entering in spite of the large mesh size (Sarwar, 2015 d).

### 2.1.4. Biological Control

Fruit flies have a number of natural enemies, which generally attack the eggs or larvae; however these stages are more or less protected by the fruits hosting them, except when the larvae emerge from the host to pupate in the soil. They can then fall prey to various predators (including ants) and parasitoids. Native parasites have been observed attacking fruit fly pupae, but these wasps appear to be generalists that are only present when fly numbers are high. *Paphiopedilum concolor*, a non-native parasite that can be raised in culture has been released for other fruit flies including the Mediterranean fruit fly with limited success (Sarwar, 2015 e).

i. *Predators*: A group of organisms that is free-living throughout their entire life cycle consumes a number of pests called preys in its lifetime. Fruit fly predators may include spiders, ants, carabid beetles, assassin bugs, staphylinid beetles and probably others. Adults may be captured by weaver ants that are very efficient in protecting vegetable plants from pests like fruit flies. Generally, predators have little effect on fruit fly populations in vegetable production situation, but this aspect has still been little studied.

ii. *Parasitoids*: These are insects, mostly wasps and flies that lay eggs on or near insect pests of fruits and vegetables. Upon hatching, parasitoid larvae feed on hosts, either internally or externally and kill hosts during their development. Adult parasitoids feed mostly on flowers. The eggs inserted under the fruit skin can also be parasited fairly easily by Oophagous species, whereas only larvae near the edges of the fruit can be reached by other parasitoids. The most common parasitoids of fruit flies belong to the families Braconidae, Chalcididae and Eulophidae. Some examples are *Psyttalia fletcheri* Silvestri, *Diachasmimorpha kraussi* and *Diachasmimorpha longicaudata*.

iii. *Pathogens*: These are parasitic microorganisms used to control fruit flies commonly infesting fruits and vegetables. Some insect pathogens infecting fruit flies are viruses, bacteria and fungi. Both viruses and bacteria infect their hosts when are eaten. Endo-symbiotic bacteria of the genus *Wolbachia* are known to induce cytoplasmic incompatibility, thelytokous parthenogenesis and male-killing or feminization. Fungal pathogens can infect their hosts by penetrating directly through surfaces of host's body. Only a few species are recognized as beneficial, for example green (*Metarhizium anisopliae*) and white (*Beauveria bassiana*) muscardine fungi, but their effectiveness may or not always sufficient in economic terms.

#### 2.1.5. Sterile Insect Technique (SIT)

Sterile insect technique or birth control strategy involves releasing millions of sterile male flies over a wide area to mate with the native females present. Mating of released sterile males with native females leads to a decrease in the female's reproductive potential because their offspring do not survive. Ultimately, if males are released in sufficient numbers over a sufficient period, this leads to the local elimination or suppression of the pest population. It is a species-specific technique and has no effect on other non-target species, and therefore environmentally clean and sustainable. The SIT approaches are good at reducing low populations to very low levels in contrast to insecticides which are good at reducing high populations to low ones (Dyck et al., 2005). Since there is no natural boundary around control areas, the success of SIT is seriously jeopardized by the re-invasion of fertile flies. So, eradicating of fruit fly can be done in two stages, firstly, numbers may be reduced to a minimum by mass trapping using pheromone. Finally, the residual fruit flies can be eradicated using the SIT technique, so it would be a worthwhile investment (Sarwar, 2015 g; 2015 h).

### 2.2. Chemical Control

The farmers apply foliar insecticides to vegetables in order to control either adults present in the crop directly via contact or inhalation, or adults arriving at the field subsequently via a residual or repellent effect. These applications have no effect on larvae survival, which are protected inside the hosts. Observations of daytime activities of some fruit fly species have demonstrated that only females enter the field to lay eggs, whereas males or immature females remain located in the immediate surroundings of fields (e.g., hedges) to feed, mate or rest. Hence, treatments applied to the field at best will only affect a part of the adult population.

In situations where chemical control of melon fruit fly becomes necessary, one has to rely on soft insecticides with low residual toxicity and short waiting periods. Certain insecticides or toxicants in baits are applied to fruit flies or sprays applied to crops. Chemical control of the melon fruit fly is relatively ineffective; however, insecticides such as malathion, dichlorvos, phosphamidon, and endosulfan are moderately effective against the melon fly. Attract and kill traps attract flies with a food lure on every trap and sex pheromone on every fourth trap. The trap containing a pyrethroid insecticide, kills the flies when they land. The traps are designed to be effective for about five months. For mass trapping, large numbers of traps are needed (up to one trap per tree). They are most effective when fly numbers are very low and where orchards are isolated from nearby untreated trees. Research indicates that bait and deterrent sprays are very effective in managing of fruit fly. Both spray treatments provide consistent damage reduction and can be used as a sole management tool (Sarwar et al., 2015).

#### 2.2.1. Male Annihilation Technique (MAT)

This technique aims to reduce the male fruit fly population to such a low level that no mating occurs with females. This may be achieved by distributing a carrier containing a male lure plus a toxicant, at regular intervals over a wide area. The effectiveness of the MAT may be severely reduced if the carrier loses its attractiveness or toxicity before the end of the interval selected. Traps are installed in the field and mostly four traps are installed per acre. In traps, pheromone is used as attractant and Diptrex is used as a killer. The technical product naled mixed with pheromone in two ratios of 1: 2 and 2: 3 can be used successfully in male annihilation technique and needs renewed every two months (Todd et al., 2007). The pheromone-fentrithion mixture at 100% of attractant showed that the weekly mean numbers of captured males all over 10 successive weeks are significantly higher than those obtained at 75, 50, 25 and 10% when diluted with paraffin oil (Nabil et al., 2010; Sarwar, 2015 i).

#### 2.2.2. Bait Application Technique (BAT)

The principle of BAT uses the nutritional need of female fruit flies for protein before they are capable of laying viable eggs. Female flies do not lay eggs for several days after emergence and need a protein feed to be able to develop eggs. Sexually immature female flies actively seek protein sources such as bacteria and other exudates on the leaf and fruit surfaces of the host plants. This is why protein baits mixed with insecticide are an effective control method. Moreover, male and sexually mature female flies also feed on protein. Adding a toxicant to the protein and applying the mixture in large droplets or spots to the underside of leaves in host trees is a very effective method of controlling fruit flies by killing female flies before they reach the egg-laying stage. As a dietary source of protein material, protein hydrolysate bait spray are used to control adult population of both sexes. A mixture of water (carrier), protein hydrolysate (a food attractant) and malathion 57 EC (insecticide) in the ratio of

98.6: 0.7: 0.7 is used, at a rate of less than 2 l mixture per hectare (including < 8 gm of malathion/ hectare) (Ghanim, 2013; Sarwar, 2015 j).

## 3. Integrated Pest Management (IPM)

Finally, it is needed to take into account the integrated management practices of fruit fly pests control. It is found that spraying of chemical insecticides is somewhat worthless in fruit fly management options. Therefore, future efforts should be made to find ways to reduce the cost of application of pesticides to make vegetable cultivations a profitable business, and to protect environment and life. Consequently, new management techniques and tools such as field sanitation, crop netting, application of locally made botanical pesticides, using the entomopathogenic fungus *Beauveria bassiana,* efficient and environmentally sound insecticides, cost-effective method of biocontrol, BAT, MAT and SIT are needed to reduced infestation of fruit fly to increase size and quality of vegetables (Sarwar, 2013).

## 4. Conclusions

The technologies for eradication of many pest species are available, but the best technology is only as good as the technical and management commitment and support. The key lessons learnt during this eradication exercise are that there must have early warning systems and a well-documented various methods such as preventive measures (sanitation), physical control, biotechnical control, coloured traps, chemical control, Male Annihilation Technique (MAT), Bait Application Technique (BAT)], and biological control in the event of an incursion of an local or exotic fly pests. Also, by keeping in view the importance of the pest and crop, the melon fruit fly can be managed or suppressed locally at the grower fields using any of the option combinations available including, bagging of fruits, cue-lure traps, spray of protein baits with toxicants, growing of fruit fly-resistant genotypes, augmentative releases of biological control agents and insecticides. On the other hand, the incorporation of a number of different techniques including the sterile insect technique, transgene based embryo-specific lethality system and quarantine, in addition to the available local area management options, could be exploited for better results in an area wide management of melon fruit fly. The local area management aims mainly at suppression, rather than eradication and use of area wide management can subsequently protect against reinvasion by quarantine controls. Although, sterile insect programs have been successfully used in area-wide approaches, more sophisticated and powerful technologies should be used in their eradication program such as insect transgenesis, which could be deployed over wide areas. The use of a geographical information system could also be used as an IPM tool to mark site-specific locations of traps, host plants roads, land use areas and fruit fly populations within a specified operational region.

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