Comprehensive Approaches to Fruit Fly Management in Vegetable Crops

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Fruit flies are significant agricultural pests that attack on vegetable crops. Fruit flies eat and deposit their eggs on crops, causing significant harm. These pests are considered crucial key pests due to the devastation they create. Fruit flies are hard to control since their eggs are laid inside the fruit. Controlling them is extremely difficult due to their polyphagous behaviour, strong reproductive potential, and adaptability to many environments. Therefore, suitable action needs to be made to manage this pest in a sustainable manner. Since one approach will not suffice to manage this pest, a combination of approaches, including mechanical, cultural, behavioural, chemical, and biological control, as well as host plant resistance mechanisms and quarantine, can be employed. We talk about each of these approaches to suppress the pest population and to minimize the damage level to the lowest extent.

Keywords: *Fruit fly, Vegetable crops, IPM, Environmental sustainability, Eco-friendly management*

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Introduction

Pests and diseases of crops pose a significant threat to food security (Bebber et al., 2014). Fruit flies, which are classified as economically significant pests under the families Tephritidae and order Diptera, with over 4000 species spread among 481 genera (Reddy et al., 2020). Out of these species, about 5% are found to occur in India (Ganie et al., 2013; Mariadoss et al., 2020). These can be found in any habitat with suitable life on the planet, ranging from rainforest to open savannah (De Meyer et al., 2010). Except for Antarctica, the distribution of these insects is global (Kabbashi, 2014). Vegetables are severely harmed by fruit flies as soon as they puncture them to deposit eggs and develop larvae within the fruits (Aluja, 1994). Nearly 400 different fruits and vegetables are attacked by female fruit flies, which lay their eggs inside of them. Some of the most important fruits are apple, guava, mango, citrus, peach, papaya, pumpkin, water melon, cucumber, bitter gourd, passion fruit, and plum. They can move up to two kilometres in search of food, making them exceptional flyers. (Singh et al., 2020). These pests cause direct harm to fruits and vegetables, ensuing in losses of 40–80%, depending on range, location and season (Kibira et al., 2015). Porting countries quarantine restrictions and the presence of these pest species restrict entry to international markets (Lanzavecchia et al., 2014). Strict quarantine regulations have been implemented by the European Union (EU) for the import of fresh goods. At the entry point, if a single larva is found on mango fruit, the entire mango consignment will be rejected and destroyed. Side by side melon fruit fly (*Dacus cucurbitae*) also causes damage the fruits of pumpkin, bitter gourd etc. Subsequently, the EU imposes a restriction on that specific exporting nation. Due to the worldwide nature of this problem and their catastrophic international consequences on the horticultural industry, fruit flies have become the most significant insect pest in the sector. Fruit fly management and control have two quite separate objectives, one is producing a marketable crop and another is accessing fruit fly sensitive markets. A variety of control techniques can be used to keep damage below an economic threshold level and produce a crop free of pests. These can include postharvest treatments, chemical controls, food and parapheromone lures, physical barriers, and the biology and behaviour of fruit flies. Systems techniques can be used as a type of Integrated Pest Management for fruit flies, combining two or more of these tactics. Several management strategies have been followed to control these pests, and biological control has been the most commonly studied control tactic (29%), followed by chemical control (20%), behavioural control, including SIT (18%), and quarantine treatments (17%) (Dias et al., 2018).

Different fruit fly species

Several species of fruit flies are associated with mainly cucurbits and some other vegetable crops in India. Polyphagous nature, wide climatic adaptation, concealed nature of immature stages, high biotic potential and high mobility make the fruit flies one of the major limiting factors in profitable farming of cucurbitaceous vegetables. However, the species composition varies from region to region depending on the variation in the climatic conditions of the regions.

Table 1. Different fruit fly species with their host plant

S.No.	Fruit fly Species	Host plant recorded	References
1.	*Bactrocera cucurbitae*	Cucumber, bitter gourd, spiny gourd, sponge gourd, ridge gourd, bottle gourd, snake gourd, ash gourd, pumpkin, pointed gourd and water melon	Nair et al., 2017
2.	*B. tau*	Cucumber, bitter gourd, spiny gourd, sponge gourd, ridge gourd, bottle gourd, snake gourd, ash gourd, pumpkin, pointed gourdand water melon.	Nair et al., 2017
3.	*B. diversus*	Flowers of pumpkin, ridge gourd, ash gourdand bottle gourd.	Nair et al., 2017
4.	*B. cilifera*	Flowers of spiny gourd.	Nair et al., 2017
5.	*Dacus longicornis*	Snake gourd and pointed gourd.	Nair et al., 2017

6.	*B. scutellaris*	Cucumber, bottle gourd and pumpkin flowers	Prabhakar et al., 2007; Devi et al., 2018; Kapoor, 2002; Sunandita & Gupta, 2007; Gupta & Gupta (2007)
7.	*Bactrocera nigrofemoralis*	Cucumber	Devi et al., 2018; Singh et al., 2020
8.	*Dacus ciliatus*	Bitter gourd, squash melon, pickling cucumber, little gourd, pumpkin, *Citrullus lanatus*, ridge gourd, sponge gourd, cucumber, *Momordica charantia*, *Cucumis callosus*, *Luffa acutangula*, *Citrullus colocynthis*, *Momordica dioica* *Trichosanthes bracteata*	Patel & Patel, 1998, Qureshi et al., 1887; Chaudhary, 2012.
9.	*B.cucurbitae*	Tomato	Narayanan & Batra, 1960; Weems & Heppner, 2001
10.	*B. cucurbitae*	Brinjal	Narayanan & Batra, 1960; Weems & Heppner, 2001
11.	*B. cucurbitae*	Okra	Narayanan & Batra, 1960; Kumagai et al., 1996
12.	*B. cucurbitae*	Chilly	Narayanan & Batra, 1960
13.	*B. cucurbitae*	Cauliflower	Narayanan & Batra, 1960
14.	*B. cucurbitae*	Broccoli	Narayanan & Batra, 1960

The life history of fruit flies

Fruit flies deposit their eggs close to the surface of food that are fermenting or other organic materials that are wet. The little larvae continue to eat close to the surface of the fermenting mass after hatching from an egg. About 500 eggs will be laid by one female. It takes less than two weeks to complete the life cycle from egg to adult. Fruit flies deposit their eggs close to the surface of meals that are fermenting or other organic materials that are wet. The fruit fly's life cycle is completed in around 10–12 days at 25 C, which is quite quick. The stages of life cycle development are as follows: embryo, larva (first, second, and third instar), pupa, and adult.

Nature of damage and yield loss: Regardless of the various fruit fly species, fruit damage as well as vegetable damage and associated symptoms are essentially the same. To deposit their eggs in the soft, delicate fruit pulp, the females pierce the fruit skin with their ovipositor. Watery fluid seeps through the ovipositional puncture and later turns into a brownish deposit on the fruit's epidermis. The maggots enter the fruit pulp after hatching and begin to feast on it. Fruits that are infected become rotten. Via the ovipositional punctures, saprophytic microorganisms can also enter and speed up the fruits to be rotten. However, it has been noted that certain fruit fly species only harm flowers. *B. cilifera* was only found to infest the flowers of the spiny gourd, according to reports, whereas *B.diversus* was found to infest the flowers of pumpkin, ridge gourd, ash gourd, and bottle gourd (Nair et al., 2017). According to Sunandita & Gupta's (2007) research, there is very little *B. scutellaris* infestation in the bottle gourd and pumpkin blooms. But cucurbit blossoms can also be infested by *B. tau* and *B. cucurbitae* (Nair et al., 2017). If management measures are not implemented, losses to cultivated crops could reach 100% (Vayssieres & Carel, 1999). Singh et al., (2000) recorded 31.27% fruit damage in bitter gourd and 28.55% in watermelon. Sisodiya & Jhala (2009) reported more than 50 per cent damage to cucurbits due to *B. cucurbitae*.

Management strategies

Since the vast majority of effective, broad-spectrum, and systemic insecticides are being phased out of the market, managing fruit flies is become more difficult in many places. (Bockmann et al., 2014). Fruit flies lay their eggs inside of ripening fruit, where maggots also develop. The last instar larvae then cross over to pupate in soil that prevents them from accessing insecticides and making them challenging to manage (Heve et al., 2017). Fruit flies are difficult to control with a single method, hence several are needed to achieve sufficient management. Every technique has unique benefits and drawbacks. For example, the male annihilation technique (MAT) works best for only a few species like *Bactocer*a because of a scarcity of suitable lures. Similar requirements apply to the sterile insect method (SIT), which calls for geographical isolation of the discharge sector and bulk breeding of the target pest (Suckling et al., 2016). Consequently, in order to protect our crops against this pest, we must employ a variety of integrated control strategies.

Mechanical control

Generally, fruitfly management techniques involve covering the fruit with protective coverings and utilising traps to catch fruitflies. The former, however, is more expensive than the trap tactics but also more effective. Flies' watts, screens and nets, and environment control plans are examples of protective coverings. Since UV light attracts fruit flies more, insect light raps have been the most common method of trapping them. In addition, fruit wrapping, mass-trapping, and the removal of broken culmination are included in the mechanical management (Dias et al., 2018). Fruit wrapping usually finished one month before harvesting and is done to stop the adult female from laying eggs inside the fruit (Badii et al., 2015). Mass trapping is the use of baits and traps that produce specific volatile compounds to draw insects to the trap and kill those (El-Sayed et al., 2009). The availability of strong and reasonably priced attractants is a prerequisite for mass trapping's efficacy as a manipulative tool (Villalobos et al., 2017). Because of its effectiveness, specificity, and minimal environmental impact, this approach has gained popularity as a means of reducing or eliminating the need for pesticides (Navarro-Llopis et al., 2008). This approach can be used in places where labour is less expensive, although it is labour-intensive (Dias et al., 2018).

Cultural control: There are various cultural practices that can be adopted.

Field sanitation: Buried the infected fruits in deep pits can help slow down the spread of the infestation. In order to stop adult fly reclusion and slow population growth, infested fruits should be buried 0.46 meters deep in the ground (Klungness et al., 2005). The number of fruit flies was considerably decreased by cleaning orchard, which involved gathering and destroying any infested fruits from the trees and the ground. Schmid and Dos-Santos (1998) suggested that elimination of the contaminated fruits by fruit flies should be done as a cultural control measure. According to Makhmoor & Singh (1999), there was a positive correlation between the frequency of watering and hoeing and the pupal mortality of fruit flies.

Bagging of fruit: Fruits (3 to 4 cm long) can be bag-netted on the tree with two layers of paper bags every two to three days to stop adult flies from laying eggs and this may increase return 40 to 58% (Fang, 1989; Jaiswal et al., 1997). Fruit flies can be effectively controlled if cucumber fruits are bagged three days after anthesis and the bags are kept for the following five days, according to Akhtaruzzaman et al., (1999).

Early harvesting: Early harvesting of the fruits is helpful to increase production on a large scale, such as bananas, mango, and oranges. Early harvesting will avoid fruit fly attacks as fruit flies prefer to lay eggs on matured, ripened fruits (Badii et al., 2015; Sidique et al., 2017).

Variety selection: The attack of fruit flies is maximum in late summer or autumn in late maturing varieties, so early maturing varieties can escape attack (Sidique et al., 2017).

Behavioural control: Behavioural control of fruit flies is achieved by the following specific techniques.

Male Annihilation Technique (MAT)

This method involves using para-pheromones to manage fruitflies. Fruit fly populations are suppressed by MAT, resulting in either a complete cessation of mating or a significant reduction in it. Fruitflies are drawn to para-pheromones, which are species-specific and incredibly effective in drawing them in from a distance. Polymeric plugs (in a controlled-release formulation) and liquid form are the two forms in which parapheromones are available. Terpinyl acetate (alpha, alpha, 4-trimethyl-3-cyclohexene-1-methanol); Cuelure (4-(p-hydroxyphenyl-2-butanone acetate); Trimedlure (tert-butyl-4-5-chloro-2-methylcyclohexane-1-carboxylate); and Vertlure (methyl-4-hydroxybenzoate) are among the main types of attractants (Badii et al., 2015). As part of pest control procedures, MAT has been effectively employed to suppress *Bactrocera* pest species. It has also been utilised to eradicate populations in a few isolated locations, on islands, and during outbreaks. Additionally, field research has demonstrated that, at different application densities, MAT (using ME) efficiently suppresses *Bactrocera dorsalis* (Ndlela et al., 2016; Manoukis et al., 2019). Moreover, MAT has a low cost and labour need because it no longer needs to be used frequently (Lloyd et al., 2010).

Pheromone nanogels

Due to their great species specificity, para-pheramones have fewer negative environmental consequences. However, pheromone formulations for field experiments still require improvement because of their unstable character, which includes auto-oxidation, photo-oxidation, isomerisation, volatility, and others (Cork, 2004). (Heuskin et al., 2011). The pheromone (ME), immobilised in a nanogel, has an extended shelf life thanks to nanotechnology and supramolecular self-assembly principles. Pheromone nanogels have been shown to be environmentally benign, to have high residual activity, and to be very effective in open orchards even in unfavourable seasons. Pheromone nanogels exhibit better efficacy in open orchards even during unfavourable seasons, high residual activity, and eco-friendly. Pheromone nanogels have been effectively utilized to control *B. dorsalis*, the fruit fly, and it is anticipated that they will also be able to control other insects in the future (Bhagat et al., 2013).

Sterile Insect Technique (SIT)

The SIT is a vintage tactic from the 1930s. On Curacao Island, it was first effectively applied to suppress screw worm flies in 1953. Later, screw worms were eliminated from the USA and Mexico using this method. The first sterile insect technique was applied in Carnarvon, Western Australia, in 1978 to combat the Mediterranean fruit fly (Medfly). SIT has been successfully used to eradicate a variety of fruit fly species, such as the Queensland fruit fly, *Bactrocera tryoni* Froggatt from Western Australia (Sproule et al., 1992; Andreawartha et al., 1997), the melon fly, *Bactrocera cucurbitae* Coquillett from Japan (Kuba et al., 1996), and *Ceratitis capitata* from Hawaii (Steiner et al., 1970) and California (Cunningham et al., 1980). SIT is an effective and scientifically proven method of controlling pests, such as fruit flies, which are a major problem for the agricultural industry in many tropical nations, including India. SIT has not yet taken effect in India, where quarantine laws pertaining to the Oriental fruit fly, *B. dorsalis*, have restricted mango exports. A few fruits fly-free zones could be established with SIT, increasing commercial production and global trade (Reddy et al., 2016). Effective programs against the Mexican fruit fly *Anastrepha ludens* and recent successful cases of eradicating the Mediterranean fruitfly, *C. capitata*, are two excellent examples of SIT in the Neotropics (Perez-Staples et al., 2021). In general, the SIT entails producing large quantities of sterile insects, irradiating them, and then releasing them into contaminated areas. Recently, artificial intelligence has been utilised to determine when to radiation flies. It was determined that flies might be radiation-treated just one or two days before to their adult emergence. Artificial intelligence was utilised in this situation, where the physiological age of the pupae could be inferred from the colour of its eyes, which varied to indicate adult emergence. Eye colour was used to determine pupal development using image processing and machine learning approaches (González-López et al., 2022).

Host plant resistance and genetic control

Host plant resistance is essential for an Integrated Pest Management approach. It doesn't harm the environment, and farmers don't have to incur any more expenses. There is a good chance that resistance genes from the wild family of cucurbits will be transferred into cultivated genotypes by extensive hybridisation, allowing for the growth of melon fruitfly resistant varieties (Dhillon et al., 2005). Regrettably, cultivating fruit fly-resistant and high-yielding cultivars has not yet proved successful. On the other hand, fruit fly biosystematics and phylogenetics, diversity, host-plant interactions, natural enemies, genomics, insecticide resistance, and semio-and info-chemicals have all been made easier by genetic research (Chakravarthy et al., 2022). RNA interference (RNAi), a technique of gene regulation and an antiviral defence system in cells, has been used to control fruit fly genetics. This has led to the sequence-specific destruction of mRNAs (Huvenne & Smagghe, 2010; Palli, 2012). For example, well-documented research including RNA interference (RNAi) and *B. dorsalis* (Chen et al., 2008), *Bactrocera minax* (Xiong et al., 2016), *Anastrepha suspensa* (Schetelig et al., 2012), and *C. capitata* (Gabrieli et al., 2016) have assessed gene expression and silencing. The majority of research on *B. dorsalis* is known to come from China.

Biological control

Parasitoids: Among fruit fly control programmes, biological control is the strategy that has been studied the most (Garcia et al., 2020). Parasitoids have been employed as biocontrol agents for pestiferous fruit fly species, out of all of them (Vargas et al., 2012; Dias et al., 2018). According to Garcia et al., (2013), the remarkable *Diachasmimorpha longicaudata* has the capacity to adapt and settle in a variety of semiarid or tropical habitats in Brazil, allowing for the management of pestiferous *Anastrepha* species. Additionally, in several Mexican states, augmented location-extensive releases of *D. longicaudata* have been conducted

(Montoya et al., 2007; Montoya et al., 2020). According to Srinivasan (1994), *Opius fletcheri* is the most important parasitoid of *B. cucurbitae*. *D. longicaudata* was employed in Peru to manage *C. capitata* numbers in olive orchards throughout the 1990s. Over the course of two years, more than 50% parasitism was reached with the large-scale recurrent releases of *D. longicaudata* (Garcia et al., 2020). Fruit flies, particularly *C. capitata*, are managed using a variety of parasitoids, including the larval parasitoids *D. fullawayi* (Silvestri), *D. Tryoni* (Cameron), *Tetrastichus giffardianussilvestri*, *P. syttaliaincisi*, *Aceratoneuromyia indica* (Silvestri), *Aganas pisdaci*, *D. longicaudata*, *Fopius vandenboschi*, the egg-larval parasitoid *Fopius arisanus*, the pupal parasitoids *Coptera silvestrii* (Kieffer), *Pachycrepoideus vindemmiae*, and *Dirhinus giffardii* (Clausen, 1978). Apart from parasitoids, entomopathogenic fungi and nematodes have also demonstrated stimulating effects when used to control fruit flies. *Rhagoletis cerasi* (L.) died at a rate of 91% due to entomopathogenic fungus *Beauveria bassiana* (Balsamo), *Metarhizium anisopliae*, and *Isariafumos orosea* (Wize) (Daniel and Wyss, 2009). A useful bioagent for managing *B. cucurbitae* larvae is *Rhizoctonia solani* Kuhn culture filtrate (Sinha, 1997; Sinha and Saxena, 1999). In the field, EPNs have caused an average of 87.1% mortality when applied at 500 infectious juveniles/cm2 of soil, and *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/cfu (Lindegren, 1990). EPNs have also been used in laboratory settings. The stages that are impacted by the natural enemies of fruit flies are summarised in Table 2.

Table 2. Natural enemies of fruit flies and the life stages attacked

S. No.	Natural enemies	Fruit fly species	Life stage attacked	References
1.	*Diachasmimorpha longicaudata*	*Bactrocera dorsalis, Bactrocer azonata, Bactrocera correcta, Bactrocera caryeae*	Larva; pupa	Ashoka & Javaregowda, 2019
2.	*Diachasma alloeum*	*Rhagoletis pomonella, Rhagoletis mendax, Rhagoletis zephyria*	Larva	Forbes et al., 2010
3.	*Spalangiaim punctata, Spalangi aleiopleura*	*Ceratitis capitata*	Pupa	Silva et al., 2020
4.	*Psyttalia humilis*	*Ceratitis capitata*	Larva	Yokoyama et al., 2012
5.	*Copter aevansi*	*Rhagoletis pomonella*	Larva	Muniz et al., 2011
6.	*Trichopria drosophilae*	*Drosophila suzukii*	Pupa	Chen et al., 2018
7.	*Fopius ceratitivorusand Faiditus caudatus*	*Ceratitis capitata*	Egg	Wharton et al., 2000
8.	*Opius bellus*	*Anastrepha fraterculus*	Larva-pupa	Schliserman et al., 2014

Biopesticides

Biopesticides are chemicals that are found naturally in plants and bacteria (Salma and Jogen, 2011). Natural compounds produced from plants, such as azadirachtin from neem, *Azadirachta indica*, have been demonstrated to effectively control approximately 12 fruit flies worldwide (Singh, 2003; Silva et al., 2013). According to Alvarenga et al., (2012), these products have also been employed with parasitoids. The effectiveness of three biopesticides—Spinosad, Abamectin, and *Lecanicillium muscarium*—against the fruit fly assault on bitter gourd (*Momordica charantia* L.) was assessed by Rahman et al., (2019). At varying degrees in relation to the control, all of the biopesticides—both in their solo and combined forms—significantly decreased the fly infestation. Spinosad used alone had a moderately effective effect. The best method for achieving the maximum proportion of healthy fruits and the lowest fruit infestation was to combine Spinosad and *L. muscarium*. Studies on residual control and toxicity (Michaud, 2003), attractiveness and efficacy (Yee et al., 2007), and foraging factors (González-Cobos et al., 2016) have all been used to support the widespread usage of spinosad as baits to control fruitflies. The effects on emergence, mortality, and oviposition were calculated (Yee & Alston, 2006; Yee, 2011). Alam & Khan (2021) conducted an evaluation to assess the effectiveness of several biopesticides in mitigating fruit fly infestation on bottle gourds. They recommended Spinosad (Tracer 45 SC) for cucurbit fruit fly management on a bottle gourd out of all the treatments studied. Recommended as the best biopesticide against fruitflies is spinosad. Allamanda leaf extract, mahoganyoil, and abamectin 1.8 EC were the treatments that performed better than neem oil. In field-caged circumstances, the toxic effects of abamectin have also been suggested as a substitute for diazinon in soil treatment against the *Bactrocera zonata* (El-Gendy et al., 2021). According to these investigations, pupae can be controlled by treating the soil with abamectin.

Chemical control

Fruit flies have been chemically controlled using baits combined with insecticide. DDT was the first synthetic chemical insecticide used to control fruit flies, but it is now banned. Organophosphates eventually replaced DDT. Fenthion (0.025%) plus protein hydrolysate (0.25%) has been foundto reduce the damage to the extent of 8.7% as against 43.3%in the untreated control (Gupta and Verma, 1978). Different insecticides found to be most effective for managing different fruit fly species are mentioned in Table 3.

Table 3. List of different insecticides for the control of different fruit fly species

Sl. No.	Insecticide	Fruit fly species	References
1.	Dipterex+molasses	Muskmelon fruit fly (*Bactrocera cucurbitae*)	Khan & Khattak, 2000
2.	Dipterex	*Bactrocera dorsalis, Bactrocera zonata, Carpomyia incomplete*	Khan et al., 2005
3.	Diflubenzuron	Melon fruit Fly (*Bactrocera cucurbitae*)	Mishra & Singh, 1999
4.	Alpha cypermethrin	Queensland fruit fly (*Bactrocera tryoni*)	Olivia et al., 2017
5.	Spinosad	Mediterranean fruit fly (*Ceratitis capitata*)	Burns et al., 2001
6.	Diazinone	(*Bactrocera zonata*)	Bashir, 2022

Insecticide resistance

Many control methods are being used, including chemical, biological, mechanical, and cultural ones; however, the latter has not been shown to be very effective in managing fruit flies. Chemical control has shown to be the most significant measure. Two methods are used to apply insecticides to fruit flies: baiting and cover spraying. In both situations, resistance to the application technique is likely to arise. Mutations in the pesticide target that reduce their sensitivity to the toxic chemical or a high likelihood of insecticide detoxification are the two main causes of insecticide resistance. Reduced insecticide penetration may result from thickness, a change in the cuticle's chemical makeup, or altered behaviour in which the insect steers clear of insecticide exposure. There may be fewer information on the underlying molecular processes of pesticide resistance in tephritid flies. Around the world, research has been done on pesticide resistance in a variety of tephritid pests. Both the oriental fruit fly, B. dorsalis Hendel, from Hawaii, and the melon fly, *B. cucurbitae*, have evolved resistance to DDT and methoxy chloride. It was also noted that *B. cucurbitae*, the melon fruit fly, had a low degree of lindane resistance (Nigg et al., 2008). The resistance of *Bactocera oleae*, *B. dorsalis* (Hsu et al., 2006; Hsu et al., 2008), and *C. capitata* (Magana et al., 2008) against organophosphates has been established. Malathion resistance in laboratory-selected strains of *A. suspensa* had been reported from Taiwan (Nigg et al., 2008). Malathion resistance in *C. capitata* populations from Spain has also been reported (Magana et al., 2008). There have also been reports of Israeli fruit flies, *Dacus ciliates*, showing resistance to OPs and carbamate (methomyl) (Maklakov et al., 2001). Using a topical software technique, certain other species of fruit flies, *Dacus ciliates*, have also been reported to be resistant to OPs and carbamate (methomyl) in Israel (Maklakov et al., 2001). Apart from being resistant to carbamates, organochlorines, and organophosphates, fruit flies have also demonstrated resistance to synthetic pyrethroids in conjunction with deltamethrin, albeit at relatively low levels of resistance (Haider et al., 2011). Taiwanese *B. dorsalis* has been found to have high levels of resistance to cyfluthrin and fenvalerate (Hsu & Feng, 2002). Research done in Pakistan has revealed that *B. zonata* is resistant to spinosad (a microbe), lambda-cyhalothrin, bifenthrin (pyrethorids), trichofon (organophosphates), and malathion (Nadeem et al., 2014). Gendy (2018) has also reported *C. capitata* resistance to spinosad, fenitrothion, malatox, and malathion. Detoxification of enzymes like carboxy esterases (Oakeshott et al., 2005), S-transferases (GSTs), and P450 mixed feature oxidases (MFOs) has been linked to organophosphate resistance (Feyereisen, 2005), while extended MFOs was previously believed to be associated with pyrethroid resistance in *B. oleae* (Margaritopoulos et al., 2008; Pavlidi et al., 2018) & *B. dorsalis* (Hsu et al., 2004).

Quarantine

The main way that insect pests spread is through the import and export of infected plant material from one region or nation to another that is not infected. Implementing strict quarantine and treating fruits at the import/export ports can stop the melon fly from spreading. Armstrong et al., (1995) reported that a 12-day cold treatment at 1.1 ± 0.6° C eliminated tephritid eggs and larvae from Hawaiian starfruit, *Averrhoa carambola*. The estimated surviving population of avocado fruits infested with *B. cucurbitae* eggs and larvae was reduced by 99.5 to 100% after being heat-treated for 24 hours at 40° C (Yang et al., 1994). Twelve non-European species of Tephritidae and one European species have been found in tropical fruit imports examined in French airports since 1993 (Bayart et al., 1997).

Conclusion

Given the significance of both the pest and the crop, fruit flies can be controlled or suppressed locally at the growers' fields by utilising any combination of the available options, such as fruit bagging, field sanitation, cue-lure traps, protein bait spraying with toxicants, cultivating fruit fly-resistant genotypes, augmentative releases of biological control agents and soft insecticides. Nevertheless, in addition to the alternatives for local area management, it may be possible to improve the results of fruit fly control across a larger region by combining a number of different strategies, such as the male annihilation technique, quarantine, and sterile insect technique. The primary goal of local area management is suppression as opposed to eradication. Quarantine measures can be used to prevent reinvasion once wide area management is used to coordinate and integrate various aspects of an insect eradication operation throughout a whole region, inside a defensible boundary. In order to identify the precise locations of traps, host plant roads, land use regions, and fruit fly populations within a given operational region, a geographical information system (GIS) could also be utilised as an IPM tool. While area-wide sterile insect programs have proven effective, more advanced and potent technologies, including insect transgenesis, should be employed in eradication operations as they can be implemented over larger regions.

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