Review Article

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Sustainable management of fruit fly infestation in guava for quality fruit production:A review

Raj Kumar[1], Nirmal Singh[1*], Ashwani Kumar[1], Arvind Kumar[1], Prannath Barman[2], S.M. Haldhar[3] and Pratibha Poonia[4]

[1]ICAR-Central Soil Salinity Research Institute, Karnal
[2]ICAR-Research Complex for NEH Region, Tripura
[3]ICAR-National Research Centre for Integrated Pest Management, New Delhi
[4]ICAR-Indian Institute of Wheat and Barley Research, Karnal

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ABSTRACT

The guava is a tropical fruit that originated in Central and South America and has since been grown in many tropical and subtropical areas worldwide. In these regions, guava fruit fly, *Bactrocera correcta*, is a noteworthy pest of guava and other fruits. This particular species of fruit fly lays its eggs in ripening or ripe fruits of guavas, which may culminate in infestations which significantly damage crops. The female guava fruit fly normally releases the eggs within the fruit as part of the life cycle. After hatching, the larvae feed the fruit pulp, which makes it rot and unfit for human eating. In cases of severe infestation, this not only diminishes the fruit's yield and quality but also makes it unmarketable. Controlling the guava fruit fly often involves a combination of cultural, mechanical, biological, and chemical methods. These can include techniques such as fruit bagging, sanitation, trapping, para-pheromone lure, bait spray, biocontrol, bio-pesticide and the application of insecticides. Fruit fly populations can be effectively managed by using fewer chemical pesticides and implementing integrated pest management (IPM) techniques. Maintaining the productivity and quality of guava crops, as well as other susceptible fruits in affected areas requires efforts to control the guava fruit fly.

Introduction

Guava (*Psidium guajava* Linn.) is one of the economically significant fruit crops grown worldwide in tropical and subtropical regions. The guava ripe fruits are a good source of vitamin C, phosphorus, calcium and pectin. The fruit is also used to prepare several processed products such as ready-to-serve (juice), jams, jellies, guava juice wine, and guava pulp wine. Guava leaves have medicinal properties, which may be used in the curing of diarrhoea and also for dyeing and tanning (Kumar *et al.*, 2014; Kumar *et al.*, 2016; Kumar *et al.*, 2017). The area under guava cultivation has increased from 94 thousand ha in 1991-92 to 359 thousand ha in 2022-23, whereas the production increased from 11 lakh tones to 5.59 million metric tons. Guava fruit is severely affected by biotic and abiotic factors such as insects, plant pathogens, vertebrates, invertebrates, temperature, humidity, rainfall and other climatic factors. Approximately 80 species of insect-pests deteriorate the quality of guava fruits and finally affect production and productivity. Nearly 4,000 species of fruit flies (Tephritidae) are distributed in the world, and around 200 species are economically important. Particularly in

Corresponding author's Email: nirmalsingh@hau.ac.in (Dr. Nirmal Singh)

Asian countries, 22 species are listed as financially significant pest species. Collectively, in India, around 243 species of fruit flies have been reported (Agarwal and Sueyoshi, 2005). Three significant species, i.e. *Bactrocera zonata* (peach fruit fly), *Bactrocera dorsalis* (oriental fruit fly) and *Bactrocera correcta* (guava fruit fly), are considered a pest of economic importance in India and are responsible for 30 to 70 per cent losses. The severity of losses depends on fruit fly species, its population, host range, varietal resistance, high reproductive potential, and adaptability to various climates. (Arora *et al.*, 1998, Hussain *et al.*, 2022). Worldwide, tephritid fruit flies are the most critical threat to the horticultural industry (Abbas *et al.*, 2021) and particularly to guava-quality fruit production (Afzal and Javed, 2001; Vargas *et al.*, 2008). Notably, female flies lay their eggs in the flesh of fruits with the help of their needle-like ovipositor. Then eggs emerge as maggots that eat the pulp, resulting in further deterioration of fruits caused by secondary infections caused by bacterial and fungal diseases (White and Elson-Harris, 1992). The puncture site on fruit could be identified by a brownish patch and spread quickly in guava trees, which produce sweet-smelling with an edible rind and creamy white, yellow or pink flesh (Riaz and Sarwar, 2013). Fruit flies are attracted by the pungent/musky odour emitted by ripened fruits, and they remain active throughout the year but become most active in the summer months. Consequently, control measures should be applied before the summer months, and during low activity of fruit flies (winter months), hibernating places must be destroyed to avoid population outbreaks. Controlling fruit flies in guava is crucial as fruit fly lay their eggs in ripe and maturing fruits, and the hatched larvae feed on the fruit pulp, causing damage, reducing the fruit's market value, and making it unsuitable for consumption. This also leads to significant economic losses for guava farmers. Infestation of fruit flies also acts as vectors for various plant diseases. Infested fruits can become breeding grounds for pathogens, which can spread to healthy plants, leading to further crop damage. Thus, controlling fruit flies ensures that guava fruits maintain their quality and are safe for consumption. Consumers expect fruits to be free from pests and diseases, and adequate control measures help meet these expectations. In a nutshell, in this review paper, various methods of controlling fruit flies in guava cultivation for protecting crops, ensuring economic viability for farmers, and maintaining food safety and quality standards have been discussed.

Management techniques to mitigate guava fruit fly incursions

Fruit flies in guava require a combination of chemical, mechanical, biological, and cultural control techniques to manage completely because single control measures like the application of insecticides on guava fruits can't be controlled entirely since infestation is internal. Collectively, IPM is required for the overall control of fruit fly infestation in guava plantations (Vargas *et al.*, 2008), which includes cultural control, early harvest, crop sanitation, soil raking, bagging of fruits, sterile insect technique, trapping, male annihilation technique (MAT), bait annihilation technique (BAT), and chemical approach (Table 1).

Table 1. Management options for controlling guava fruit fly infestation

S. No	Management measure	Practice
1.	Sanitation	Collect, remove, destroy/ bury infested fruits in trenches
2.	Para-pheromone lure/ trap	Methyl eugenol: Mix ethyl alcohol 60 ml + methyl eugenol 39 ml + Spinosad 1 ml Commercial Cue lure: Mix ethyl alcohol 60 ml + Cure lure 39 ml + Spinosad 1 ml
3.	Bait sprays	About 100 g jaggery + 2 ml of Decamethrin 2.8EC in 1 litre water; sprayed on the tree trunks at weekly intervals; Azadiracthin 10,000 ppm @ 1.0 ml/ litre during the fruiting stage.
4.	Botanicals	Neem-based (Azadirachtin) (10-20 ml/ litre), karanj oil (5-10 ml/ litrewater) and tobacco extract (250 g dry leaf / 1000 ml) mixed in 5 litre of water. The methanolic leaf extracts diluted to 5% (v/v) of lantana, karanj, tulsi and datura at 7-day intervals are also very effective.
5.	Cultural methods	(i) Deep soil treatment/ tillage, (ii) Removal of co-host plants, like cucurbits, solanaceous; (iii) Crop rotation; (iv) Clean cultivation, regular weeding, (v) Pruning, (vi) Conservation of natural insect enemies, (vii) Early harvesting, (viii) Placing Traps, (ix) Planting repellent crops, and (x) Soil raking around the tree and drenching with chlorpyriphos @ 4.0 ml/ litre.

6.	Bagging of fruits	Wrapping of individual fruits with transparent polypropylene (20 µ gauge) bag, newspaper bag, and fruit fly net bag at egg stage until ripening.
7.	Exclusion measures	Netting of whole plants up to the trunk gives effective control.
8.	Food lure/ protein hydrolysate	Ripened fruits (pumpkin, banana + insecticide) as bait, protein hydrolysate (Nu-lure®) + livestock/ poultry manure. Nu-lure combined with borax in an aqueous solution containing 9% Nu-lure (vol: vol) with 3% borax (wt: vol) + propylene glycol (10% vol: vol) to prepare the bait solution.
9.	Bio-pesticides/ bio-agents	*Metarhizium anisopliae* (2 x 10^{-8} cfu/g commercial powder @ 2 tsp in 1.0 litre water), the release of parasitoids and weaver ants.
10.	Chemical insecticide	Spray 1250 ml Sumicidin 20 EC (fenvalerate) or Deltamethrin (0.025%) in 500 litres of water per hectare at weekly intervals on ripening fruits commencing from July onwards till the rainy season crop is over.

Sanitation

Crop sanitation should be an essential component of fruit fly control programs in guava orchards. Fruit fly infested over-ripened fruits help in the completion of the reproductive cycle of fruit flies. Therefore, to break down the reproductive cycle, it is advised that fallen and infested fruits should be collected on a regular basis and destroyed by deep-burying into the soil. Field sanitation helps to prevent fruit fly eggs and maggots from developing in infested fruit. Destroying the fruit ensures that maggots do not survive to pupate in the ground to emerge later as adult flies (Singh, 2008). Hasyim *et al.* (2016) reported that due to the adoption of sanitary practices, the percentage of damaged fruits gradually decreased to about 20 percent.

Male annihilation technique (MAT)

MAT is being used widely because it controls the male population of flies, so mating can't take place, and ultimately, the population decreases. A combination of 1% methyl eugenol along with 0.5 % Malathion or 0.1 % carbaryl is found effective against *B. dorsalis* (Balasubramaniam *et al.*, 1972). Methyl eugenol (ME) is a para-pheromone that attracts the male population of fruit flies from a distance of 700-900 meters (Roomi *et al.*, 1993), and it has been applied for the complete eradication of fruit flies in a particular area (Stonehouse *et al.*, 2002; Singh and Sharma, 2011).

BAT (Bait annihilation technique)

The female fruit flies require a protein source for their gonad's development as well as eggs (Hagen and Finney, 1950; Christenson and Foote, 1960). Consequently, a protein hydrolysate has been identified as an efficient attractant for female fruit flies. Previous literature indicates that a bait spray of 1.0 % malathion in 10 % sugar solution can be applied 2-3 times on each tree of guava orchards at 10-day intervals for effective control of fruit fly populations. Alternatively, a bait spraying of a combination of 500 g molasses and 50 g malathion in 50 litres of water at seven days of interval is also an effective method to control fruit flies (Agarwal *et al.*, 1987). Female attractive baits are also very effective against this serious damaging pest for direct control (Mazor *et al.*, 2002). Few compositions of poison bait to control different species of fruit fly are illustrated in Table 2.

Table 2. Baits recommended to attract female fruit flies

Composition of poison bait	Species of fruit fly	References
Coarse flour (middlings) 5 kg+borax five kg+ water (90 litre)	*Bactrocera oleae*	Bouhelier *et al.* (1935)
1% molasses + 0.02% fenvalerate	*B. tau*	Saikia and Dutta (1977)
Jaggery + 0.1% dichlorvos	*B. tau*	Sood and Nath (1998)
Solbait (protein hydrolysate)	*B. cucurbitae*	Fabre *et al.* (2003)
Sugar + ICN enzymatic yeast hydrolysate (3:1)	*B. dorsalis and B. cucurbitae*	Vargas and Prokopy (2006)
Protein hydrolyzate attractants (Agricince, Amaden, BioProx)	*Ceratitis capitate*	Moustafa (2009)

Chemical control

Chemical control should be considered as a last option or as a part of IPM strategies. Under chemical methods, the selection of chemicals is crucial as they must be selective

and environmentally safe, i.e., they must avoid non-target organisms and should have significantly less half-life for degradation. It has been investigated that insecticides are only effective against fruit flies if they are applied alone and neighbours need to make an effort for the same in their orchards. (Manrakhan *et al.*, 2013) Evaluated the efficacy of six different insecticides, viz., abamectin, alpha-cypermethrin, fipronil, imidacloprid, spinosad and Malathion, against fruit flies. They found that a mixture of 2 % 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 (Haider, 2011) evaluated mortality in adult flies (noted at 24 and 48 h after the treatment application and LC_{50} values were estimated) by using insecticides like Talstar 10 EC, Confidor 70WS, Curacron 50 EC, Deltamethrin 2.5 EC, Diptrex 80 WP, Proclaim 1.9 EC, Karate 2.5 EC, Malathion 57 EC, Tracer 240 SC, Steward 360 SC; and results revealed that the field strain exhibited varying ratios of insecticide resistance; being highest against Diptrex (65.32) followed by Curacron (13.20), Confidor (7.12), Talstar (5.97), Karate (5.73), Malathion (5.54) and Deltamethrin (2.35) at 24 hr. For effective control of fruit fly infestation, three sprays of rogor @ 2 ml $litre^{-1}$ water should be applied in the early stage of fruit development 21 days of intervals. Neem oil-based spray and botanicals can also be sprayed towards fruit maturity. Amongst new molecules, spraying 1.25 litre Sumicidin 20 EC (Fenvalerate) in 500 litres of water at weekly interval in the early fruit growth stages is the most effective.

Botanicals

In another experiment, the repellent action of neem oil, tobacco leaf solution, neem seed powder solution and solution made from eucalyptus leaves were compared against guava fruit fly infestation and maximum repellent efficiency was observed by neem oil followed by solution made from eucalyptus leaves, neem seed powder and tobacco leaf (Solangi *et al.*, 2011). A study conducted by Shah *et al.* (2016) reported that maximum (73%) mortality against male fruit flies was found when *Tagetes minuta* extract was used, while in the case of females, maximum mortality was shown by *C. camphora* and *I. rugosus* extract. In an experiment, Leaf extract, stem extract, inflorescence extract, and root extract of basil plant with methyl eugenol as control were applied to reduce the infestation of fruit flies, and it found that inflorescence extract was most effective in measuring the fruit flies (Singh *et al.*, 2020). Previous reports also reflected that water extract from fruits of different botanicals (mango, guava, cucumber and apple) also acted as a fruit fly attractant and helped control the fruit fly population (Mahmoud *et al.*, 2022). Neem Seed Kernel Extract (NSKE) is an efficient ovipositional deterrent for the oriental fruit fly when applied at 0.2 to 4.0 %, thus reducing the number of eggs from 87.5 to 99.2%. A spray of 0.5 to 1.0% neem oil (v/v) has also been found effective in reducing egg-laying by the fruit fly in guava. It is always better to apply repeat sprays after a 10-day interval towards maturity so that the issue of pesticide residues can be minimized (Chandana *et al.*, 2023).

Cultural methods/ environmental management

Cultural management practices are essential components of an IPM strategy, especially for controlling fruit fly infestations in guava orchards. However, a thorough understanding of the different components of the agro-ecosystem in which pests flourish is required. Here are several effective cultural management techniques to control fruit fly populations:

Early harvesting

Frequent harvesting at the fruit colour change stage reduces the availability of ripe fruits for the flies to infestation. It has been proved that the survival of fruit fly larvae in the colour change stage was lower in comparison to the over-ripening stage (Lakra *et al.*, 1991). In separate experiments conducted in Maharashtra and Karnataka, it was observed that early harvesting of guava fruits escaped fruit flies attack (Verghese *et al.*, 2006). Generally, fruit flies are more attracted to fully ripe fruits, so harvesting at an early stage can reduce the chances of infestation. In other words, fruit flies don't prefer green fruits for oviposition, they mostly attack over-ripened guava fruits.

Trap crops

It is an effective method to minimize fruit fly infestation in guava. Since fruit fly is a polyphagous pest and feeds on alternative hosts found in the vicinity of the main crop, the trap crops, for example, cucurbitaceous vegetables (79% infestation), most affected by fruit flies, can be grown in the guava orchards to escape the guava orchards from fruit fly infestations. The infested fruits on trap crops must be collected and destroyed regularly.

Pruning

Regular pruning improves air circulation and sunlight penetration by maintaining an open canopy. It not only helps in reducing the humidity required for the breeding of fruit flies but also makes the orchard less attractive for the flies to inhabit. It is also critical that horticultural operations lead to regulate the crop with the season and increase the yield and quality of fruits. Choudhary *et al.* (2022) reported that fruit

fly infestation was higher in non-pruned orchards than in pruned orchards, and they added that timely pruning is most effective against fruit fly attacks.

Soil raking

Mature larvae enter the soil and go into hibernation stage during the winter season; raking of soil is essential to breaking the reproductive cycle of fruit flies by exposing them to sunlight (Vadivelu, 2014). Ploughing or raking of soil up to 6 cm two times in continuation and once three weeks later reduced the infestation level by around 80 % (Patel *et al.*, 2005; Stonehouse *et al.*, 2005).

Choice of variety

The selection of cultivars is the most effective and economical measure of fruit fly infestation. Available literature suggested that smooth skinned varieties, namely Red Flesh, Allahabad Safeda and local, are highly susceptible to fruit flies (infestation range from 64.2 to 80.4%) (Table 3). In contrast, rough-skinned pear-shaped varieties are the least susceptible (<35.1%). Similarly, fruit fly incidence on different white pulped cultivars revealed higher infestation, i.e. damage ranging from 37.2 to 53.5% (Chandana *et al.*, 2023). Commercial cultivars, viz., Sardar, Allahabad Safeda and Arka Amulya had a high incidence of fruit flies, whereas Arka Kiran, Shillong-1, and Arka Rashmi had relatively less fruit fly damage.

Table 3. Response of different varieties to guava fruit fly infestation

Response	Varieties
Tolerant	Cattleya guava, Shilong-1, KG 1, Thai Pink, Thai White
Moderately tolerant (20-30%)	Chittidar, VNR Bihi, Nridula, MPUAT-1, Barafkhana, Arka Amulya, Punjab Pink, Sweta, Hisar Surkha, Pear Shaped, Behat Coconut
Less susceptible (<10% infestation)	Nasik, Allahabad Surkha, Kamsa-ri, Spear Acid and Superior Sour, Arka Kiran, Arka Rashmi
Least susceptible (<4.8% infestation)	L-46, Lalit, Strawberry guava, Chinese guava
High incidence (>50%)	Sardar, Allahabad Safeda, Arka Amulya, Hisar Safeda, Banarsi Surkha, Pant Prabhat, Safed Jam, Kohir Safeda

(Chandana *et al.*, 2023)

Conservation of natural insect enemies

Conserving natural insect enemies to control fruit flies in a guava orchard is a sustainable and effective method that reduces the reliance on chemical pesticides. The release of *Fopius arisanus* in guava orchards decreased the population of fruit flies. It concluded that the establishment of *F. arisanus* is the most successful example of classical biological control of fruit flies in the Pacific area (Vargas *et al.*, 2007).

Fruit bagging

Covering of developing fruits entirely around one month prior to harvest with paper or cloth bags to stop fruit flies from laying their eggs on fruits. Wrapping fruits with polythene bags is also safer and more economical than wrapping them with cloth or paper bags. Wrapping of individual fruits in a transparent polypropylene (20µ gauge) bag and paper pieces within the polypropylene bag for partial cover from sunlight' is considered the best option for guava fruit fly management. Maximum fruit fly infestation was recorded under un-bagged fruits (96%), while 4 % is covered by polyethene bags, 5.70 % covered by newspaper bags and 7.65 % covered by muslin cloth bags (Abbasi *et al.*, 2014). Further, it was also noticed that covering fruits have no adverse effect on TSS and physical fruit quality, which were similar to unbagged healthy fruits (Sarker *et al.*, 2009). Conclusively, different bagging materials, viz., black polybag, transparent polybag, and brown paper bag, can be applied to protect the guava fruits completely (0 % infestation) from the attack of fruit flies.

Sterile insect technique (SIT)

It is considered an ecologically safe procedure and has been successfully used in broad areas. In this technique, sterile males of fruit flies are released in large numbers for mating with female fruit flies and due to mating with sterile males, female fruit flies either do not lay eggs or lay sterile eggs, so pest population is maintained through this procedure. Sterilization of male fruit flies can be achieved by irradiation, chemo-sterilization, or by genetic manipulation (Kebede *et al.*, 2015).

Biological control

Natural enemies of the fruit flies, such as predators, parasitoids, and pathogens, reduced their population. Biological control has been the most commonly researched control tactic within fruit fly management programs.

Among all the natural enemies, parasitoids are the main natural enemies and have been used against pestiferous fruit fly species. Cai *et al.* (2022) reported that *Fopius arisanus* is the most suitable biological control agent of fruit flies in multi-crop orchards (main crop - guava). Effective searching behaviour and high foraging efficiency are features of *F. arisanus* that lead to higher parasitism rates and explain the success of this parasitoid in the control of tephritids in many crops (Wang and Messing, 2003). Coelho *et al.* (2022) stated that a combination of *Fopius arisanus* (Sonan) and *Diachasmimorpha longicaudata* (Ashmead) provided higher efficacy (76.58%) in controlling *C. capitata* populations, rather than used alone *F. arisanus* (53.76%) and *D. longicaudata* (44.95%). Firake *et al.* (2013) indicated that raking the soil and application of *Metarrhizium anisopliae* @ 5 kg/ha to the soil underneath the tree canopy reduced fruit fly infestation. Sookar *et al.* (2014) also reported that infection by *M. anisopliae* resulted in the reduction of the number of eggs produced by females of fruit fly.

Conclusion

The quality and quantity of guava can only be produced efficiently by reducing fruit fly infestations using sustainable IPM modules. Various control measures have been adopted for the improvement in the productivity and quality of guava produce in different agro-ecological regions. Although fruit fly has a wide host range and the ability to fly long distances, consequently, any control strategy, if applied area-wide, level will be more effective and successful. Efficient IPM modules should be implemented at community level like field sanitation, early harvesting, wrapping of fruits, MAT (Male annihilation technique), BAT (Bait annihilation technique), SIT (Sterile insect technique) and soft insecticides. Preventing the entry of infested material during transportation is also a great source of the spread of the infestation.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

This review article did not generate any supplementary data.

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