

Food baited traps in fruit fly management: Present status and future prospects

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Fruit flies (Diptera: Tephritidae) pose a serious threat to horticultural crops. Globally, fruit flies are responsible for reducing the export value of fruits and vegetables up to 30 to 100 percent. The fruit fly females are responsible for economic damage by laying about 300-400 eggs at a time on the rind of the fruits. Upon their emergence, the maggots feed on the fruits, causing them to rot and decay. Managing fruit flies is a challenging task as they have high reproductive capacity and greater adaptability. Locally, fruit flies are trapped using fish meal as lure but because of its putrefying properties, it also attracts other dipteran flies and occasionally helpful insects like parasitoids, which poses a limitation. While, farmers rely on pesticides to manage this notorious pest. Male Annihilation Technique (MAT), which exploits the olfactory senses to mass trap the fruit flies are very much successful where the males alone are trapped using para pheromones *viz.*, methyl eugenol, cue-lure *etc.* But in recent years, a wide range of food materials; fruit pulp, vegetable pulp, protein hydrolysate, *etc.* have been utilized as baits to catch fruit flies, both male and female. The review discusses the several types of food baits that are used to attract fruit flies and how to use them to trap both sexes more successfully.

Keywords: Behavioural management of fruit flies, Food additives, Fruit pulps, Vegetable extracts, Protein baits, Dispersants

Introduction

Fruit flies (Diptera: Tephritidae) can be categorized as a major pest of many fruit and vegetable crops. There are more than 4500 species from 500 genera worldwide under the family Tephritidae out of which 1400 develop inside fleshy fruits up to maturity¹. In the Indian subcontinent, about 325 species of fruit flies have been reported, of which 205 are from India alone². Under Tephritidae, one of the most economically important subfamilies is Dacinae and the genus of great significance in this subfamily is *Bactrocera* which includes species like *Bactrocera dorsalis* (Hendel) previously known as *Dacus dorsalis* and *Bactrocera zonata* (Saunders). *Bactrocera cucurbitae* is another economically important species of the sub-genus *Zeugodacus*³ infesting cucurbits. Several fruits and vegetables are considered to be severely affected by the Peach Fruit Fly (PFF), *B. zonata* (Saunders), and the Melon Fruit Fly (MFF), *B. cucurbitae* (Coquillett)⁴. They reduce the export value of agricultural produce in many countries due to the severe trade quarantines, apart from causing direct losses to fruit and vegetable

crops⁵. The extent of crop loss varies between 30 percent and 100 percent depending on the environmental conditions, crop susceptibility, host and season of attack⁶. The damage loss caused by *Bactrocera* spp. can reach up to 100 percent⁷. The fruit flies attack mango by laying eggs inside the fruit at the marble stage. In 1-2 days, the eggs hatch and the larvae feed on the flesh of the fruit. As a result, the fruit becomes soft and rotten leading to fruit damage and dropping⁷. Monitoring is considered as one of the preliminary activities to control the fruit fly infestation as a part of the Integrated Pest Management (IPM) strategy. Surveillance and monitoring can be carried out by keeping the pest population on check with parameters like fly period, fly activity, fly intensity *etc.*, by using traps containing attractants⁸. Traps can be of varied forms, like lure traps, bait traps and so on with different components inside it. The Male Annihilation Technique (MAT) using methyl eugenol lure, cue-lure and the Sterile Insect Technique (SIT) have also found profound interest among scientists. Food baits with different structured components like fruit pulps, protein mixes, graded alcohols, molasses, yeasts, sugar and various other attractants have been formulated and commercialized in large scales. The bait traps are ecofriendly, cost effective and species

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specific, which proves to be economical and useful to farmers. This review aims to cover the control techniques of fruit flies using different food baited traps, throwing light on what the future prospects this management practice holds.

Losses due to infestation

Fruit flies cause heavy losses to horticultural crops, making them unfit for marketability which leads to a huge economic loss (Fig. 1). Fruit flies are reported to cause a yield loss of 2.5-59.0 percent³. The tephritid flies cause direct damage to many important export crops up to an extent of 40-80 percent loss, depending on the locality, variety and season of the crop⁹. In cucurbits, crop loss varies from 30 to 100 percent, and in peak season of guava, infestation goes up to 80 percent^{6,10}. In Africa, the native fruit flies caused direct loss up to 40 percent, while the species *B. dorsalis* caused a damage up to 50 percent¹¹. Fifty percent of the national mango production in Mali was lost due to fruit fly infestation¹². In Papua New Guinea, *B. cucurbitae* damages 95 percent in bitter gourd and 90 percent in snake gourd¹³. The species *Bactrocera correcta* caused 60-80 percent damage in guava plantations at Pakistan and *Carpomyia vesuviana* (The Ber fruit fly) causes about 90–100 percent damage in indian ber (*Ziziphus jujube*) in India and Iran¹⁴. The genus *Bactrocera* causes yield loss of about 40-80 percent in mango¹⁵ and 60-80 percent in guava¹⁶. Fruit fly incidence causes indirect losses, such as export rejections due to quarantine laws and cost of facilities for fruit treatment and eradication¹⁷. Of the total fruits set in cucurbits, more

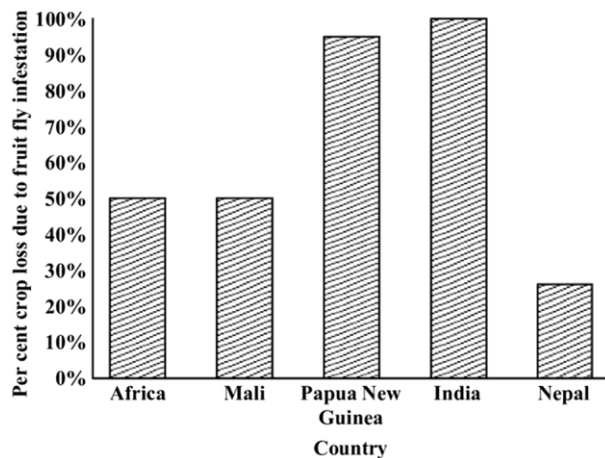


Fig. 1 — Percent crop loss due to fruit flies in different countries. The x-axis represents the loss percentage due to the fruit fly infestation. India considerably shows greater loss of crop (about 95-100 percent).

than 26 percent were dropped or damaged shortly after setting and 14.04 percent were destroyed during the harvesting stage which left only 38.8 percent marketable fruit, in Nepal¹⁸. The enormous havoc created by the fruit flies require severe management practices to be followed by the farmers.

Trapping system for the management of fruit flies

Male Annihilation Technique (MAT) using para-pheromones

The Male Annihilation Technique (MAT) is often used to eradicate pestiferous tephritid fruit flies, such as *Bactrocera dorsalis* (Hendel). MAT involves the application of male-specific attractants combined with an insecticide in spots or stations across an area to reduce the male population to such a low level that suppression or eradication is achieved¹⁹. The attractants that have been widely used across the world are the methyl eugenol (ME) (4-allyl-1,2-dimethoxybenzene-carboxylate) cue-lure (CL) (4-(p-acetoxyphenyl)-2-butanone) and trimedlure (TML) (tert-butyl 4 (and 5)-chloro-2-methylcyclo-hexane-1-carboxylate)²⁰, while ME and CUE are specific to species belonging to the genus *Bactrocera*²¹, TML has been found effective against the species under the genus *Ceratitidis*²¹.

Many management studies have been made on different species of fruit flies with one or multiple hosts using these para-pheromones, such as studies of pre- and post-harvest IPM for the mango fruit fly, *B. dorsalis*²², damage assessment and management of cucurbit fruit flies in spring-summer squash¹⁸, response of *Bactrocera* spp. stating the importance of mass trapping and managing fruit fly infestations²³. The studies suggested that traps incorporated with methyl eugenol were effective up to an extent of 70-75 percent²², in different shapes of traps, the efficiency has been reported to be within the range of 15 to 20 percent²³.

Species composition and population dynamics studies have been carried out using methyl eugenol and cue-lure as the key components which has yielded many fruitful results. Different species of fruit flies attacking mango and guava viz., *B. dorsalis*, *B. zonata*, *B. correcta* and *B. diversa*^{24,25} have been trapped in the methyl eugenol (ME) installed traps and cue-lure traps²⁶. Population dynamics have also been figured out based on weather relations and weather parameters with the use of methyl eugenol²⁷. Efficacy studies of methyl eugenol have been carried out to check the attractancy and response of fruit flies

to the para-pheromones²⁸, methyl eugenol, cue-lure, bac-lure²⁹ in guava and vegetable fields³⁰. Efficacy studies and mass trapping works have also been carried out significantly to suppress the Mediterranean fruit fly (*Ceratitidis capitata*) in Turkey with the use of female targeted attractant lure bio-lure and the male targeted sex attractant lure Trimedlure²¹.

Sterile Insect Technique (SIT)

Another behavioural control method that has been reported against fruit fly management is the Sterile Insect Technique (SIT). It consists of mass production, sterilization, and release of insects in an affected area where sterile males mate with wild females leading to no reproduction. The aim behind this technique is to disturb the regular reproduction cycle of the insects. It is a genetic pest control method that is environmentally friendly and exclusively for the target species, and it has no adverse impact on non-target organisms³¹.

Food baited traps used for the management of fruit flies

Protein sources used as food baits to attract fruit flies Protein in different compositions and formulations have been used successfully to trap different fruit fly populations in fruit and vegetable crops (Table 1). Protein is required by insects for their nutritional development, which is why these protein-based baits are an efficient attractant. Soyabean hydrolysate yielded a good result in attracting fruit flies at about 95 percent as a rich source of protein^{32,33}. Food baits composed of Protinex with

jaggery, yeast and ammonium acetate were found to be significantly superior than other baits in trapping fruit fly population in guava orchard with a population of 8.33-8.93 in two different locations, in India³⁴. Many different types of protein baits *viz.*, soya protein, yeast, casein and Protinex have been used to study the role of protein baits in attraction of fruit flies, out of which Protinex have proved to be highly efficient³² and showed about 44.45 percent reduction in fruit fly incidence in cucurbits³⁵ and about 3.51 to 16.84 fruit flies/trap/week were reported in mango and guava orchards³⁶. Protein hydrolysate has proved to be the most efficient in attracting *B. tau* (6.1 adults/30 min) and *B. cucurbitae* (6.3 adults/30 min)³⁷. Highest attractancy of *B. tau* to hydrolysed protein of which 46.00 percent were male and 46.50 percent were female has been recorded³⁸.

Fruit sources used as food baits to attract fruit flies

Fruit pulps have been reported to be the most effective base bait for attracting fruit flies in several studies^{39,46} (Table 2). The odour from the fruits stimulates the olfactory senses of the fruit flies and engage them to be attracted towards the traps. Olfaction in insects is very strong and serves as a great tool in the pest management system. Insects can smell odours from distances and can communicate with each other to locate the source of the odour. This olfactory sense has been efficiently used in the management of fruit flies by formulating food baits with different components and attractants.

Fruit pulps of banana used as base bait component has been proved successful by many researchers³³ and

Table 1 — Protein sources used as food baits to attract fruit flies

Protein sources	Target Species	Host crop
Soybean hydrolysate	<i>B. cucurbitae</i>	Snake gourd ³³
Yeast	<i>B. cucurbitae</i>	Cucurbits ³⁹
Enzymatic yeast hydrolysate	<i>B. cucurbitae</i> and <i>B. dorsalis</i>	Guava ⁴⁰
Soyabean, yeast, casein, Protinex	<i>B. correcta</i> , <i>B. dorsalis</i> , <i>B. cucurbitae</i>	Guava, Mango ³⁶
Yeast	<i>Z. cucurbitae</i>	Bitter gourd ⁴¹
Yeast	<i>Bactrocera</i> spp.	Cucurbits ⁴²
Protein hydrolysate, yeast hydrolysate	<i>B. cucurbitae</i> and <i>B. tau</i>	Bitter gourd and cucumber ³⁷
Torula yeast and borax	<i>Z. cucurbitae</i>	Cucurbits ⁴³
Soyabean, yeast, Protinex	<i>Bactrocera</i> spp.	Guava ³⁴
Yeast, Protinex	<i>Z. cucurbitae</i>	Snake gourd and Ridge gourd ⁴⁴
Hydrolysed protein, Yeast	<i>B. tau</i>	Cucurbits ³⁸
Protein hydrolysate	<i>B. zonata</i>	Mango ¹⁴
Yeast	<i>B. cucurbitae</i> and <i>B. dorsalis</i>	Mango ⁴⁵
Protinex and Soyabean	<i>Z. cucurbitae</i>	Bitter gourd and Snake gourd ³²
Soyabean, yeast, casein, Protinex	<i>Z. cucurbitae</i>	Bitter gourd ³⁵
Yeast	<i>C. ditissima</i>	Citrus ⁴⁶

Table 2 — Fruit sources used as food baits to attract fruit flies

Fruit sources	Target Species	Host crop
Banana, grapes	<i>B. cucurbitae</i>	Snake gourd ³³
Banana	<i>B. cucurbitae</i>	Cucurbits ³⁹
Mango pulp, guava pulp	<i>B. correcta</i> , <i>B. dorsalis</i> , <i>B. cucurbitae</i>	Guava, Mango ³⁶
Rotten banana	<i>Z. cucurbitae</i>	Bitter gourd ⁴¹
Banana	<i>B. cucurbitae</i>	Cucumber ⁵⁰
Banana	<i>Bactrocera</i> spp.	Cucurbits ⁴²
Banana	<i>B. cucurbitae</i>	Spring – summer squash ¹⁸
Guava juice	<i>Z. cucurbitae</i>	Guava ⁴⁸
Banana pulp 3	<i>B. cucurbitae</i>	Snake gourd and Ridge gourd ⁴⁹
Fruit pulps of banana, grape, guava, mango, papaya, ackfruit and pineapple	<i>Bactrocera</i> spp.	Cucurbits ⁴⁷
Guava pulp, banana pulp, papaya pulp	<i>Bactrocera</i> spp.	Guava ³⁴
Guava, Cane sugar, Muskmelon	<i>Z. cucurbitae</i>	Snake gourd and Ridge gourd ⁴⁴
Banana Pulp	<i>B. tau</i>	Cucurbits ³⁸
Guava pulp, papaya powder	<i>B. zonata</i>	Mango ¹⁴
Banana	<i>B. cucurbitae</i> and <i>B. dorsalis</i>	Mango ⁴⁵
Banana	<i>Z. cucurbitae</i>	Bitter gourd and Snake gourd ³²
Banana slurry	All the species of fruit fly	Bitter gourd ⁵¹
Banana, guava, pineapple	<i>Z. cucurbitae</i>	Bitter gourd ³⁵
Sugarcane spirit	<i>C. ditissima</i>	Citrus ⁴⁶

Table 3 — Vegetable sources used as food baits to attract fruit flies

Vegetable sources	Target Species	Host crop
Bitter gourd, Cucumber	<i>B. tau</i>	Bitter gourd and cucumber ³⁷
Cucumber juice	<i>B. tau</i>	Cucurbits ³⁸
Tomato	<i>Z. cucurbitae</i>	Bitter gourd and Snake gourd ³²
Tomato, and bitter gourd juice	<i>Z. cucurbitae</i>	Bitter gourd ³⁵

showed a consistent superiority in fruit fly catches³⁵. Fruit fly numbers varied from 2.47 flies/trap/day⁴⁷, 4.7 & 6.9 flies/day³⁹ to 14.1 flies/trap/day³³ in banana base baits. The attraction of *B. tau* in banana pulp baits was recorded to be 28.50 percent³⁸. Guava pulps have also proved to be efficient in attracting different fruit fly species. Guava pulp with ammonium acetate recorded an attraction of 5.59 total fruit flies/trap/week³⁶, while guava along with muskmelon pulps have attracted large number of *Z. cucurbitae* females in snake gourd (70.00 percent) and ridge gourd (67.18 percent) crops⁴⁴. Mango pulp combined with 5 percent ammonium acetate attracted 4.63 *B. dorsalis* flies/trap/week, 4.25 *B. cucurbitae* flies/trap/week and about 8.88 total fruit flies/trap/week in Mango plantations³⁶.

Volatile sources from fruit pulps attractive to fruit flies A study was made on the isolation and identification of host cues from mango, that attract gravid oriented fruit fly⁵². They recorded seven electro-physiologically active compounds from Alphonso variety and fifteen from Chausa variety of

mango viz., Heptane, Myrcene, (Z)-Ocimene, (E)-Ocimene, Allo-ocimene, (Z)-Myroxide, (RS)- γ -Octalactone in the former and 3-Hydroxy-2-butanone, 3-Methyl-1-butanol, Ethyl butanoate, Ethyl methacrylate, Ethyl crotonate, Ethyl tiglate, (RS)-1-Octen-3-ol, Ethyl hexanoate, (S)-3-Carene, p-Cymene, Ethyl sorbate, α -Terpinolene, Phenylethyl alcohol, Ethyl octanoate, Benzothiazole, in the latter.

The complete volatile profile of food bait containing guava and muskmelon along with bait additives was investigated⁵³. Ethyl hexanoate, 3-phenyl-1-propanol, acetate, 1-tetradecene, ethyl cinnamate, cetene, n-hexadecane, and tert-hexa-decanethiol were identified as volatile substances from the food bait combination. Through GC-EAD experiments, it was found that among the seven volatile compounds, ethyl-hexanoate and n-hexadecane showed maximum response and were found to be responsible for the attraction of female fruit fly in the food bait combination in gourds eco system.

Vegetable sources used as food baits to attract fruit flies

Vegetable sources (Table 3; Fig. 2) like bitter gourd and cucumber have been tried as base baits

against *B. tau* which has yielded a fruitful result in attracting about 3.7 adults/30 mins and 2.6 adults/30 mins, respectively³⁷. Cucumber juice has also been

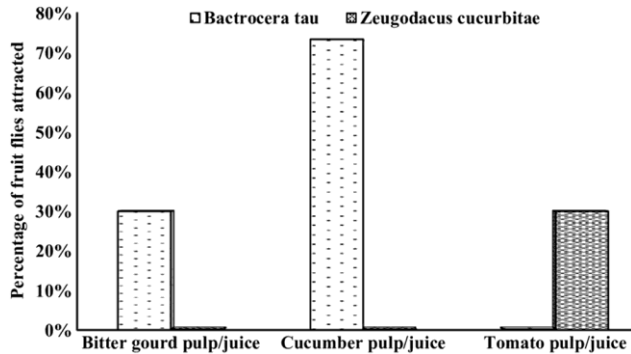


Fig. 2 — Comparative analysis of attraction of *B. tau* and *Z. cucurbitae* to vegetable sources. *B. tau* tends to get more attracted towards the vegetable sources as compared to *Z. cucurbitae*.

FOOD BAIT SOURCES ATTRACTING DIFFERENT FRUIT FLIES

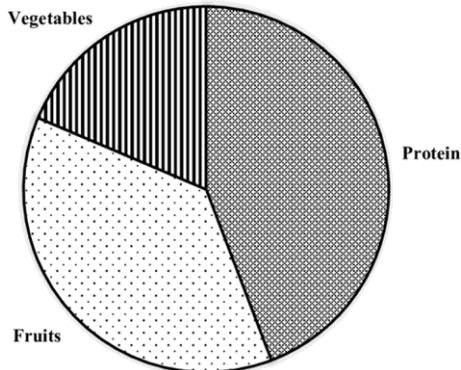


Fig. 3 — Comparative analysis of different food bait sources attracting different fruit flies. Food baits containing protein have been used in more numbers and found to be successful as compared to the other components.

used to trap *B. tau*, in which a record of 29.33 percent males and 44.0 percent females has been reported³⁸. Tomato is reported to be effective in attracting female and male fruit flies, *Zeugodacus cucurbitae*³². Tomato juice has successfully attracted *Z. cucurbitae* in bitter gourds with a record of 3.35 fruit flies/trap/week with 2.09 being females and 1.26 males³⁵.

Comparative analysis of different food bait sources attracting different fruit flies

The different sources that have been used as food baits *viz.*, protein sources, fruit sources and vegetable sources so far have reported to be successful in controlling the fruit fly populations. Among these, the food baits with protein sources have significantly proven to be effective to stimulate the olfactory senses of the fruit flies (Fig. 3).

Food Additives used in food baits to attract fruit flies

Food additives like food graded alcohol, yeast, vinegar, jaggery and molasses have been found to increase the effectiveness of food baits in many studies (Table 4). Jaggery acts as a source of sugar and has been found efficient in increasing the efficacy and attraction of the food baits¹⁴. Additives *viz.*, vinegar has also been tested in enhancing the fermentation and effectiveness of the food baits by many workers^{46,51}.

Comparative analysis of different additives used in food baits

Different sources have reported that the efficiency of the food baits increase when incorporated with different additives (Fig. 4). Of the sources cited in this review, many miscellaneous products like beef extract, fermented rice, chicken manure extract *etc.*

Table 4 — Food additives used in food baits to attract fruit flies

Food additives	Target Species	Host crop
Fishmeal, beef extract, bread, dog biscuit, FGA, palm oil, vinegar	<i>B. cucurbitae</i>	Snake gourd ³³
Jaggery	<i>B. cucurbitae</i>	Cucurbits ³⁹
Sugar, fish meal	<i>B. correcta</i> , <i>B. dorsalis</i> , <i>B. cucurbitae</i>	Guava, Mango ³⁶
Citric acid	<i>Z. cucurbitae</i>	Bitter gourd ⁴¹
Jaggery	<i>B. cucurbitae</i>	Cucumber ⁵⁰
Fermented rice	<i>B. cucurbitae</i>	Spring – summer squash ¹⁸
Citric acid	<i>Bactrocera</i> spp.	Cucurbits ⁴²
Sugar	<i>B. cucurbitae</i> and <i>B. tau</i>	Bitter gourd and cucumber ³⁷
Chicken manure extract	<i>Z. cucurbitae</i>	Guava ³⁴
FGA	<i>B. cucurbitae</i>	Snake gourd and Ridge gourd ⁴⁹
Jaggery	<i>Bactrocera</i> spp.	Guava ³⁴
Jaggery	<i>B. zonata</i>	Mango ¹⁴
Fishmeal	<i>B. cucurbitae</i> and <i>B. dorsalis</i>	Mango ⁴⁵
Vinegar, fish meal	All the species of fruit fly	Bitter gourd ⁵¹
Palm wine, sugarcane spirit, apple cider vinegar, sugar	<i>C. ditissima</i>	Citrus ⁴⁶

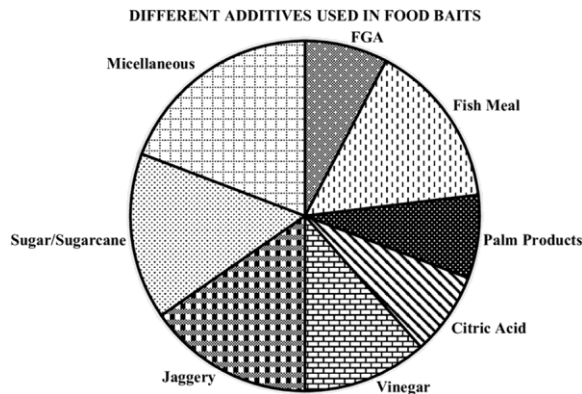


Fig. 4 — Comparative analysis of different additives used in food baits to attract fruit flies.

have been used in enhancing the action potential of the fruit flies. Sugar, fish meal and insecticidal compounds have been reported in about 14 percent of sources and have found to be effective, followed by jaggery at 11 percent, vinegar and palm products at 9 percent and food graded alcohol (FGA) and citric acid at 6 percent⁴².

Dispersants used for increasing longevity of food baits to attract fruit flies

Polyethylene glycol

Polyethylene glycol was incorporated at the rate of 1 percent as an additive in grape juice, reconstituted grape concentrates, powdered grape mixes, and torula yeast extracts and their efficiency in attracting the Mexican fruit fly *Anastrepha ludens* was compared. Grape juice with polyethylene glycol (PEG) had the highest capture rate, and juice with or without polyethylene glycol was significantly better than concentrate or powder products⁵⁴.

Grape juice bait with a protein-based bait (ammonium acetate + putrescine lures, or torula yeast) was compared, that has been previously reported to be attractive to *Zaprionus indianus*⁵⁵. Additionally, the effects of four different preservatives (polypropylene glycol, polyethylene glycol, proxel, and sodium tetraborate) and their effect on bait age was also examined. The findings demonstrated that, grape juice baits with no preservative added made on the day of deployment (0 day) or aged in the laboratory for 3-4 days captured the maximum numbers of *Z. indianus*, while solutions aged in the laboratory for 6-9 days captured fewer.

Glycerol

The bioactivity of optimized formulations containing 20 wt percent glycerol (D1), 20 wt percent

propylene glycol (D2) and without added alcohol (negative control) were tested against larvae, pupae and adult of *Aedes aegypti*. It was found that propylene glycol produced smaller droplets at lower concentrations but poor long-term stability at higher concentrations, whereas glycerol had an appreciable effect on initial droplet size and stability with increasing concentration⁵⁶.

Polyethylene glycol and glycerol

In a corresponding study it was found that both sexes of *A. grandis* Boheman responded to a synthetic pheromone mixture grand lure in field condition⁵⁷. They found that a wick type formulation containing glycerol, polyethylene glycol, water and methanol was over 80 percent competitive as an attractant for 7 days. The effectiveness of synthetic pheromone attractants was prolonged by adding polyethylene glycol 1000 (20.4 percent), glycerol (32.3 percent), water (12.8 percent) and a commercial gel formulation was prepared and tested in traps against *A. grandis* which had an extended trap life of more than one week⁵⁸.

Oils

Combination of base baits such as grapes, banana and sodium hydrolysate with controlled releasers were tested for enhancing the longevity of the bait. Among the tested controlled releasers, palm oil was found to have more longevity (5 days) in the field when compared to other additives. Combination of grapes, alcohol and palm oil showed greater efficacy (37 percent) among the other combinations tested in the field³³.

Thickeners used in enhancing the consistency of food baits

Sodium alginate

A biodegradable, broad castable alginate hydrogel for the delivery of an aqueous low-dose thiamethoxam sucrose bait was developed and assessed in replicated field trials in commercial citrus groves⁵⁹, in order to produce a baiting product for control of *L. humile* suitable for large-scale application. According to the findings, alginate hydrogels can effectively control *L. humile* while using 99.99 percent less pesticide to be applied to orchards than commercial barrier spray treatments.

Aloe vera gel

The performance of twelve types of lure traps with added *Aloe vera* gel to all combinations in order to increase the longevity against desiccation for

managing fruit fly was investigated⁶⁰. Results showed that, with a catch rate of 475.00 fruit flies/trap, the Green Victory Methyl eugenol (ME) fruit fly trap demonstrated the best performance in eliminating the adult fruit fly population during the cropping period. However, a low-cost mineral bottle trap (ME + wooden block + Spinosad) was shown to be the most effective trap, capturing 440.00 fruit flies per trap.

Gelatin

The effectiveness of two commercial fruit fly attractants: raspberry essence for *B. tau* and *B. cucurbitae* in vegetables and methyl eugenol for *B. dorsalis* and *B. zonata* in peach orchards were investigated⁶¹. The semi-solid form of the bait was made by dissolving 30 mg of gelatin in 50 mL of water and adding it to liquid solutions of methyl eugenol and raspberry essence. The results showed that the semi-solid phase of methyl eugenol had the highest number of fruit flies per trap of *B. dorsalis* (9.08) and *B. zonata* (11.19) while the liquid phase had the lowest number of *B. dorsalis* (5.06) and *B. zonata* (7.30). Similar to this, *B. tau* (12.9) and *B. cucurbitae* were much more prevalent in the semi-solid phase of raspberry essence (8.08). Compared to the liquid forms, the semi-solid forms of attractants captured a greater number of fruit flies over a longer period of time.

Corn starch

The potential of phagostimulants added to bioinsecticides that enhance the pathogen's consumption were examined⁶². 18 micro-encapsulant matrices were created using three biopolymers: gelatin, pectin, and corn starch along with five additional phagostimulants: maize spike, fresh maize cobs, alfalfa, sorghum leaves, and cabbage. The findings indicated that beet armyworm larvae preferred cabbage powder or maize spike over raw cabbage and matrices of gelatin and pectin biopolymers.

Preservatives used in inhibiting the growth of micro-organisms in food baits

Bait stations were placed in plots for 6 days that contained sugar water and a protein marker, which collected ants along transects that extended away from the bait stations in an effort to evaluate how far ants transfer liquid bait in vineyards⁶³. To receive either nontoxic or poisonous bait, two plots within each of the seven blocks were randomly assigned to

one of two treatments. The central bait station in nontoxic plots contained a 25 percent sugar and 0.2 percent citric acid as preservative solution in distilled water. Dispensers in toxic plots held a mixture of 25 percent sucrose, 0.2 percent citric acid, and 0.5 percent boric acid. The findings suggested that insecticide bait stations should be placed at intervals of 36 m or fewer to control ants as Argentine ants often forage at distances of less than 36 m in Californian vineyards.

The effects of four different preservatives (sodium benzoate, potassium sorbate, sodium nitrite, and ethyl p-hydroxybenzoate) were evaluated on the beer waste-based protein bait, a product widely used to control populations of *B. dorsalis* (Diptera: Tephritidae)⁶⁴. The findings demonstrated that the four preservatives were each capable of significantly inhibiting a range of bacteria at different dose levels. At the highest dose, 1:1 (v: v), sodium benzoate significantly inhibits *Staphylococcus spp.*, potassium sorbate inhibits *Lactobacillus spp.*, sodium nitrite inhibits *Escherichia spp.*, and ethyl p-hydroxybenzoate significantly inhibits *Staphylococcus spp.* and *Xanthomonas spp.*

Behavioural response of fruit flies to volatile compounds

Wind tunnel bioassay

The efficacy of Bio Anastrepha®, a hydrolysed protein, and Bionis YE MF®, a yeast extract, were evaluated in the field and in laboratory bioassay using wind tunnel, and the key volatile compounds emitted by the combinations were identified⁶⁵. Hydrolyzed protein and yeast extract were attractive to *A. obliqua* in the wind tunnel, but only pure yeast extract and yeast extract with sugar were attractive in the field.

In both wind tunnel and semi-field cage bioassays, it was found that feeding Zingerone (ZN), a phenylbutanoid, to *Z. tau* males increased male courtship and the attractiveness of sexual signals, resulting in increased female attraction and subsequent mating success⁶⁶.

Olfactometer bioassay

The behavioural response of *Z. cucurbitae* to the cucumber kairomone lure composed of nine synthesised compounds were tested⁶⁷. To ascertain the impact of the fruit fly attraction response on the removal of one or more compounds from the blend of nine compounds, olfactometer bioassay was carried

out. According to the findings, removing (E)-2-Octenal and acetic acid from the mixes did not cause much alterations in the attraction response. These findings led to the removal of the aforesaid chemicals, leading to the development of a final synthetic mix for evaluation trials.

The olfactory behaviour of mature male and female melon flies in response to body volatiles from cue lure fed and unfed mature male melon flies, protein fed immature male and female, and protein unfed mature male and female melon flies was examined⁶⁸. The results of the olfactometer assay showed that male and female melon flies were both attracted to the cue lure fed male flies body volatile and the cue lure unfed male flies body volatile, respectively.

In order to compare the catches of wild males to those made using tomato-based traps and cue-lure traps in the field, an olfactometer experiment was undertaken⁶⁹ to assess the lifespan (weeks 1-15) reaction of *B. tryoni* males to the odour of tomato, a recognised host of this fly. The results revealed that male *B. tryoni* started sensing tomatoes when they reached sexual maturity (2 to 3 weeks old), and they continued to do so until the age of 15 weeks.

Electro physiological response of fruit fly to food baits

The attraction response of *Z. cucurbitae* to the volatiles that emanated from cucumber and tomato plants were quantified⁷⁰. Analysis was carried out in coupled gas chromatography electroantennographic detection. Volatiles collected from both the host plants were injected into the GC column which was simultaneously split into two portions of effluents; one part of effluent moved into flame ionisation detector which detected the eluted compounds while the other part of the effluent moved through the antennal preparation and elicited attraction response in the antenna fixed over the electrodes. Simultaneously greater concentration of o-cymene, medium concentration of p-cymene and minimum concentration of α -cedrene reported significant attraction in both the sexes of the melon fruit fly.

The attraction response of tephritid fruit flies to the volatile collected from five different commercially available protein-based bait were evaluated⁷¹. These volatiles were evaluated for their attraction response in GC-EAD. Results shown that ethyl hexanoate and 3-methylbutyl acetate elicited response in most species of the tephritid fruit flies. Based on the

antennal activity of varied tephritid species, 13 different compounds were selected and a synthetic blend was developed.

Electrophysiological and behavioral responses of Queensland fruit fly females to fruit odors were studied and EAD-active compounds were identified for each fruit, with 14 from cherry guava, six from banana, 13 from orange and 15 from feijoa. Seven of the compounds identified were common to two fruits (ethyl octanoate, hexyl hexanoate, isoamyl isobutyrate, β -myrcene, (Z)-3-hexenyl butyrate, (Z)-3-hexenyl hexanoate, 2-heptanone), with all others identified from a single fruit type only. Thus, 41 different compounds were identified from the fruit, amongst which twenty-six were confirmed with synthetic compounds⁷².

Limitations of food baits and the ways to overcome them

Generally, high temperatures cause food-based bait material to dry out, which decreases fly attraction. To address this problem, extending the bait's shelf life by incorporating different edible oils will help to prolong the bait's shelf life and enhance its attractiveness in the future³³.

Future prospects of food baits

Current food baits are mostly male biased, and baits that attract more of females, would be more effective in bringing down the population. The baits can be developed with compounds which mimic host fruit odors to increase the attraction. Food bait formulations can be designed with highly attractive volatile organic compounds (VOCs) and additives such as oils, dispersants, polyethylene glycol, etc. The design of traps need modification incorporating both olfactory and tactile cues. Since, olfactory cues play an important role in bringing the flies to the traps, transparent or plastic material could be more helpful rather than bold and dark-coloured materials which may repel the flies. Extensive field trials under different environmental conditions and cropping systems are required before commercialisation and subsequent use by farmers.

Conclusion

In this review, different management practices to manage the fruit fly infestation in horticultural crops, including chemical and behavioural control measures have been discussed. Food baits of different

compositions are being used, targeting different fruit fly species in a variety of hosts, among which food baits with protein sources have proved to be significantly effective. The use of para-pheromones like methyl eugenol though effective, is male biased, leaving the female population in the field. Baits which capture both sexes effectively, can be incorporated into the IPM package and have the potential to reduce the use of insecticides. Keeping in view the safety and regulatory concerns, food baits are to be developed using safer and cheaper compounds, which are eco-friendly and cost effective. Food baits show great promise for an ecologically sound and sustainable strategy against fruit flies in horticultural ecosystem.

Conflict of interest

The authors declare no conflict of interest.

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