



Research Article

Management of Fruit Flies *Bactrocera zonata* (Diptera: Tephritidae) Infesting Mangoes (*Mangifera indica*)

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Abstract | Fruit flies (Diptera: Tephritidae) are considered highly destructive insect pests damaging numerous fruits and vegetables across the globe, causing significant economic losses. In the present investigations, a series of experiments were conducted comprising of food and sex lure, and neem oil to devise an IPM model for the management of fruit fly *B. zonata* in mango orchards. The data were recorded on the percent infestation in dropped and harvested fruits. The neem oil at 5% and 3% concentrations was found effective for controlling fruit flies. Pheromone traps lured with Methyl Eugenol in combination with intermittent food bait comprising of protein hydrolysate resulted in 86.48 and 94.18% reduction in fruit fly population in dropped and harvested fruits in first picking 87.5 and 89.2% in second picking, respectively. The IPM model comprised of 1) installation of sex lure traps (4/acres), 2) Crop Hygiene (CH) [removal of weed flora from fruit fly resting and sheltering places], 3) hoeing (twice) under the mango trees; 4) twice application of intermittent food bait during the fruiting season. It was evident from the obtained results that tested IPM practices reduced infestation of fruit flies 0.4% in dropped and 0.8% in harvested fruits respectively compared to that of farmer's practices (conventional approach) where 7 and 10.5% infestation of fruit flies was recorded in dropped and harvested fruits. In conclusion, the IPM protocol comprising of the combination of bait application, MAT, orchard sanitation and the cover spray of plant derivatives was most effective in reducing fruit flies in mango orchards.

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Introduction

Fruit flies (Diptera: Tephritidae) are highly destructive insect pests affecting numerous fruits and vegetables across the globe, causing significant

economic losses (Marchioro, 2016; Midgarden *et al.*, 2016). With over 4000 described species, these insects are highly polyphagous and are known to inflict severe losses to more than 300 host plants (Susanto *et al.*, 2017). The fruit flies cause both quantitative

and qualitative damages in tropical and subtropical regions worldwide. The extent of damage varies according to infesting species and the host plant, typically intensifying as fruits ripen (Kakar *et al.*, 2014). Production losses caused by fruit flies range from 10% to 70%, reaching up to 100% in orchards lacking protective measures (Manurung *et al.*, 2012). In Pakistan, mango orchards suffered production losses of 74.66% due to fruit flies (Khan *et al.*, 2005). Fruit flies infest mangoes at the pre-ripened stages and lay tiny rice-grain shaped white eggs just beneath the skin of the fruit by finding a softer area to facilitate the emerging larvae for food (Amin, 2017). The newly emerged larvae feed inside the fruit and make it undesirable for human consumption. As the larvae grow, the fruit ripens prematurely and ultimately falls on the ground, probably due to some accelerated physiological activities (Boinahadji *et al.*, 2019). Where full-fed larvae bore out of the fruit and pop to find a suitable place on the soil to pupate. During pupation, it completes all the body parts, and after three to five days passing as pupae, it emerges as a little golden fly with attractive wings, ready to infest new fruits after mating. The adult fruit fly has a life of up to three months and lays up to 1000 eggs (Irshad and Jilani, 2003; Mohd *et al.*, 2011). This high fecundity rate and overlapping generations during the fruiting period make it a devastating pest of almost all fruits and vegetables. The occurrence of fruit flies is one of the major points of concern for importing countries, with good fruit fly eradication programs, and usually, they refuse or are reluctant to accept commodities from the area with fruit fly prevalence. In the past, some countries denied the import of Pakistani mangoes and citrus stating similar reasons and/or pesticide residues over the MPL (maximum permissible limit) in the fruits, mainly used for fruit fly management.

In various parts of the world, huge losses in mango production have been reported due to fruit flies *Bactrocera dorsalis* (Hendel) and *B. zonata* (Saunders) and *B. correcta* (Bezzi) (Verghese *et al.*, 2006; Zida *et al.*, 2020). They cause direct losses by causing drastic reductions in yields and indirect losses are caused by affecting the exports (Zida *et al.*, 2023). The peach fruit fly *B. zonata* is reported as a native dominant species in South Asia, and rapidly spreading to other regions of the world. The pest is known to infest over 50 host plants (Sarwar *et al.*, 2013). In Pakistan, the *B. zonata* populations are higher during the months of July and August, attacking mainly early and mid-va-

rieties (Mohyuddin and Mahmood, 1993).

Control of fruit flies is somewhat challenging because eggs and larvae are protected inside the fruits and pupae in the soil. Therefore, the relatively exposed adult stage is the usual target of pest control action. To manage the adult fruit flies, mainly in Pakistan, synthetic pesticides are used. Male Annihilation Techniques (MAT) are also popular among some progressive farmers. However, the chemical used in these traps (Methyl Eugenol) attracts only males with no effect on females. Protein hydrolysate, a food attractant, is a prerequisite for females to lay mature eggs. It is mixed with toxicant and applied intermittently on foliage to attract and kill the females. All these control tactics have been evaluated by many authors Marwat and Abdullah (1992), Abdullah and Latif (2000), Abdullah and Latif (2001), Abdullah *et al.* (2002) and Irshad and Jilani (2003) from different agro-ecological zones, but none of the aforementioned tactics could perform up to the mark of satisfaction of consumers or farmers when practiced independently or poses great environment or health concerns, ultimately affected the export in the international market.

Neem is a dicotyledonous plant, widely distributed in the Indo-Pak subcontinent, known for its pesticidal activity for a long time. Its insecticidal (Zebitz, 1987), ovicidal (Gajmer *et al.*, 2002), anti-feedant (Nakaniishi, 1975), anti-molting (Singh, 2003), and ovicidal deterrent (Gajmer *et al.*, 2002) activity has been well reported across the world. Different extracts of neem seed kernel have been proven very effective against fruit flies (*B. zonata*) in lab conditions (Jilani, 2004). Singh (2003) tested fecundity fertility and post-embryonic development of fruit flies *B. cucurbitae* and *B. zonata* under lab conditions and got good results, neem and other botanical insecticides have never been tested against fruit flies in field conditions. Preparation and application of raw neem-based insecticide is easy and practicable under the socio-economic conditions of Pakistan. However, refined azadirachtin and ready to use neem-based insecticides are also available for use. Considering the feeding and oviposition habits of adult flies, the studies in hand were designed to test the efficacy of neem oil and to integrate eco-friendly control measures by utilizing bio-pesticides of neem origin. The hypothesis is to give a farmers friendly solution to the fruit fly issue that is compatible with regulations and buyers' preference for "organic food". The experiments were conducted on a farmer's field

with full participation of mango growers.

Materials and Methods

Experiment-1: Studies on sex and food lures and neem oil

Experiments were conducted at village Panyalia ([32° 14' 35" N, 70° 52' 55" E] Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan) in well-established mango orchard of Chunsa variety was selected for the trial. The experiment was conducted in randomized block designed with three replications and comprised of 6 treatments including the untreated check, i.e. 1) installation of male sex lure traps, 2) food bait application of protein hydrolysate, 3) application of neem extracts, 4) sex lure traps coupled with food bait application, 5) sex lure traps coupled with neem extracts and 6) untreated check. Male traps were installed at 4/acres and replenished every month. Bait of protein hydrolysate + fipronil @1ml/l of water and neem extracts (0.5% aqueous solution) were administered twice during the fruiting period at the interval of ten days. First application was made when 2-5% fruits on the sun facing side showed softness.

Neem oil @ 0.5% aqueous solution (to get a homogeneous solution, neem oil was added to a detergent solution) was administered as cover spray using knapsack sprayer. There was at least one buffer row of trees on each side of treatment/ replication; however, a larger buffer was left for MAT.

Data were recorded on the % infestation in dropped and harvested fruits. Dropped fruit from each treatment/replication were gathered and three samples of at least 20 fruits were examined carefully for fruit fly infestation, or exit hole of larvae and recorded. Three samples of fifty fruits from the harvested lot of each treatment/ replication were observed very carefully for fruit fly infestation. The infestation in both dropped and harvested fruits were expressed in percentage and data were analyzed using Statistix 8.1 computer software. The means of the treatments were separated using Least Significant Difference (LSD) test at $P < 0.05$.

Experiment-2: Lures and biochemical control

The experiment had 3 treatments including the untreated check. The tested treatments were 1) Male Annihilation Technique (MAT coupled with Bait (protein hydrolysate) Application Technique (BAT), 2) neem oil 3% and 3) untreated check. The experiment was conducted following the protocol mentioned in

the first experiment. The data on % infestation on dropped and harvested fruits were recorded using the aforementioned procedure and analyzed accordingly.

Experiment-3: Lures and reduced neem oil application

The experiment had treatments viz. MAT combined with BAT; neem oil at 5 %, Neem oil at 3% and an untreated check. All treatments were applied as mentioned above and experimental protocol was maintained accordingly in the first experiment. The infestation data on dropped and harvested fruits were recorded accordingly and data were analyzed as mentioned in the first experiment.

Experiment-4: Testing of IPM model

Based on the findings of the series of experiments mentioned above, an IPM model was developed and implemented on 60 acres (800 trees) of mango plantation. The orchard had predominated commercial variety *Chounsa* (a mid-season and moderately susceptible mango variety to fruit fly). The orchard was divided into two parts by a pathway (the natural dividend line). The comparatively larger portion was used for IPM and the rest was left to farmers' own will in terms of pest management. All the trees were treated with fungicides in the month of February. 1) Male annihilation traps were installed soon after the fruit setting stage (second week of May) at the rate of 4 traps/acre and serviced with lure every other month in IPM orchard. 2) weed flora were removed 3 times during the experiment, to eliminate the adult flies resting, sheltering, and feeding sources. 3) soil under the canopy of trees, was hoe twice to destroy the pupae. 4) food bait of protein hydrolysate was administered just before the fruit ripening (21st of June) and repeated after ten days. For data recording, dropped fruits were collected from a composite heap, 11 samples of 15 fruits (n=15) each were examined for fruit fly infestation in both IPM and untreated orchard. While 11 samples of 100 fruit (n=100) each were examined from the harvested lots. Fruits with larvae exit holes were recorded as infested fruit however, deformed or doubtful fruits were cut open and infestation was confirmed by the presence of larvae or sorted as sound fruit.

Statistical analysis

The data generated in all the experiment were analyzed using F statistics (Collins and Seeny, 1999), using Statistix 8.1 software.

Results and Discussion

Experiment-1: Studies on sex and food lures and neem oil

Infestation in dropped fruit was 27.03% in untreated check and showed a significant difference (Table 1) with other treatments. The least infestation was observed in treatment where lure traps were combined with food bait application (2.80%) and lure traps coupled with neem oil application (5.37%). Food bait application alone was statistically as effective as lure traps + neem oil. Male sex attractant and neem application were least effective among the treatment tested, in terms of fruit fly infestation in dropped fruits.

Table 1: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (first picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT	11.97b	3.77 b
BAT	7.17 c	3.63 b
Neem oil	11.23 b	3.06 bc
MAT+BAT	2.80 d	0.30 d
MAT+ Neem oil	5.36 c	0.90 cd
Check	17.03 a	6.87 a
LSD _{0.05}	2.47	2.41

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

NS - Non Significant

The maximum fruit fly infestation in harvested fruits was 6.87% in untreated check (Table 1). The least infestation was observed in male sex lure traps combined with either food bait or neem extract (0.30 and 0.90% respectively). Non-significant difference was observed among treatments, sex lure traps, food bait and neem oil application. Neem oil application was statistical at par with treatment where sex lures traps and neem application was combined.

Fruit fly infestation in harvested fruit at second harvest in presented in Table 2. Data depict slightly higher infestation level during second harvest in untreated check (8.60%). Least infestation was observed in sex lure + food bait treatment (0.53%) and lure traps coupled with neem oil treatment (0.83) being statistical at par with solo treatments of neem oil and bait application. Treatment where only male sex lure traps were used, with 3.91% infestation, was as effective as bait

application or neem oil application.

Data presented in Table 2 regarding dropped fruits showed significantly least infestation in MAT+BAT treatment followed by MAT + neem oil and food bait application alone. Neem oil application had maximum fruit fly infestation among the tested treatments being non-significant from untreated check.

Table 2: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (second picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT	14.43 ab	3.91 b
BAT	8.50 bc	3.53 bc
Neem oil	13.43 ab	2.93 bc
MAT+BAT	4.07 c	0.53 c
MAT+ Neem oil	6.63 bc	0.83 c
Check	20.83 a	8.60 a
LSD _{0.05}	8.71	3.046

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Mean infestation in dropped and harvested fruits was least in combined treatment of MAT and BAT, followed by MAT and neem oil. Solo treatments of MAT and BAT in harvested fruits proved at par to each other. However, BAT had non-significant difference with that of neem oil + MAT in dropped fruit.

Highest reduction in fruit fly infestation was observed in combine treatments of lure traps and bait application in harvested fruits (94.18%) and in dropped fruits (86.48%) followed by sex lure traps + neem oil application, where reduction in infestation was 88.79 and 76.38 % in harvested and dropped fruits respectively (Figure 1). The solo treatments of lure traps, bait and neem oil application had 50.43, 53.66 and 61.64 % reduction in infestation in harvested fruits respectively. The reduction in fruit fly infestation in same treatments was 48.03, 69.16 and 51.44% respectively.

Experiment-2: Lures and biochemical control

The infestation level of untreated tree was 51.3% in dropped fruits and 5.5% in harvested fruits (Table 4), which shows the natural fruit fly infestation level during the experimental period. Similarly, both treatments (MAT + BAT and neem oil) had infestation level ranging from 1.0 and 1.5% in harvested fruit,

respectively. While it was 8 and 14.5% in dropped fruits, respectively.

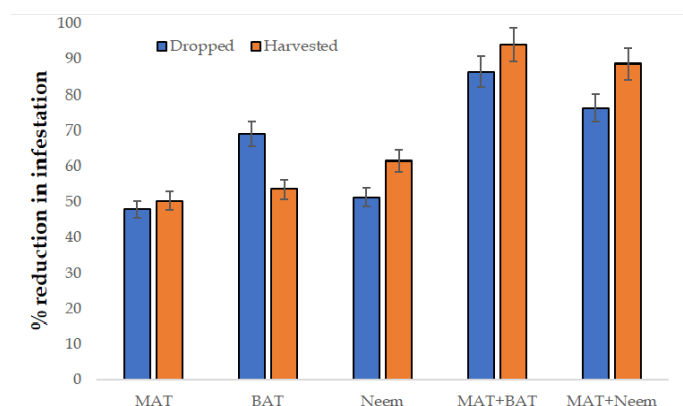


Figure 1: Percent reduction of fruit fly infestation over control in dropped fruits as affected by different treatments.

Table 3: Mean percent fruit infestation as affected by different treatments in dropped and harvest fruits.

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT	13.20 b	3.83 b
BAT	7.83 c	3.58 b
Neem Oil	12.33 b	2.97 bc
MAT+BAT	3.43 d	0.49 d
MAT+ Neem Oil	6.00 cd	0.86 cd
Check	25.40 a	7.73 a
LSD _{0.05}	3.29	2.12

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Table 4: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (first picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	9.20 b	0.93 b
Neem Oil	13.48 b	1.50 b
Check	48.75 a	5.13 a
LSD _{0.05}	18.62	2.72

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Neem oil and MAT + BAT significantly reduced the infestation level of fruit flies in dropped fruits as compared to control (14.8 and 8.0%). However, there was no statistical difference in both treatments.

Fruit fly infestation level in harvested fruits ranges from 5.5 - 1.0%. Neem oil and MAT + BAT had significantly lesser infestation level in the harvested fruits than untreated control. MAT + BAT with 1.0% of fruit fly infestation proved significantly better, followed by neem oil with 1.5% infestation level.

Percent fruit fly infestation reduction was more or less similar with a less than 2% difference in dropped and harvested fruits in MAT + BAT and neem application (Figure 2). Neem oil treatments proved to be more or less as effective as MAT + BAT in percent reduction. However, percent fruit fly reduction over control by 80.02 to 81.25% gives a confidence of the effectiveness of neem oil activity against this pest, which has never been tested against fruit fly in mango.

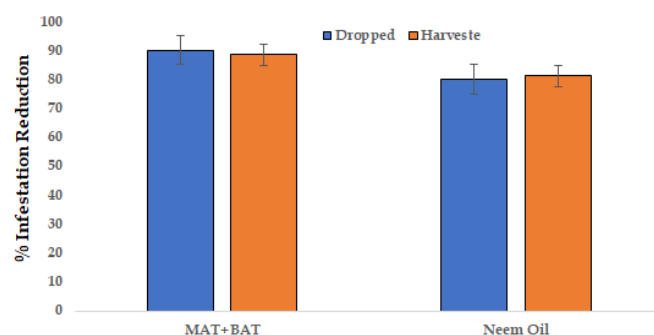


Figure 2: Percent reduction of fruit fly infestation over control in dropped fruits as affected by different treatments

Table 5: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (second picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	10.30 b	1.25 b
Neem Oil	16.18 b	1.65 b
Check	48.75 a	5.88 a
LSD _{0.05}	21.49	2.69

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Experiment-3: Lures and reduced neem oil application

In the third experiment, the overall fruit fly infestation level was higher than the second experiment, with more or less similar trend in the dropped fruits. However, both concentrations of neem oil, with 23.4 infestations for 3% and 22.4 infestation for 5% concentrations, proved statistically at par with that of

MAT + BAT (18.9%) and found significantly better in controlling the infestation level in dropped fruits over control (Table 7). The infestation level in harvested fruits also showed similar trend with 0.44% infestation in MAT + BAT treatment, followed by 0.66% fruit fly infestation in neem oil 5% and 1.32% infestation in neem oil 3% concentration treatments. All these treatments were statistically at par with each other but proved significantly better than the untreated control, where the infestation level was as high as 9.97%.

Table 6: Mean infestation as affected by different treatments in dropped and harvest fruits.

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	9.75 b	1.09 b
Neem Oil	14.83 b	1.59 b
Check	51.00 a	5.50 a
LSD _{0.05}	20.00	2.66

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Table 7: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (first picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	17.15 b	0.49 b
Neem Oil @5%	22.93 b	0.66 b
Neem Oil @3%	23.82 b	1.30 b
Check	66.97 a	9.40 a
LSD _{0.05}	8.011	3.739

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

The highest fruit fly infestation reduction over control (81.82%) was observed in MAT + BAT treatment, followed by neem oil 5% (72.73%) and neem oil 3% which gave only 54.50% in harvested fruits (Figure 3). MAT + BAT and neem oil 5% showed more infestation reduction in harvested fruits than in dropped fruits this trend was other way round in neem oil 3% treatment, where dropped fruits showed more reduction in fruit fly infestation than harvested fruits. In dropped fruits, MAT + BAT treatment had 70.78% reduction in infestation and 72.73% in neem oil at 5% concentration. Treatment neem oil at 3% had 63.83% reduction in fruit fly infestation over control in harvested fruits.

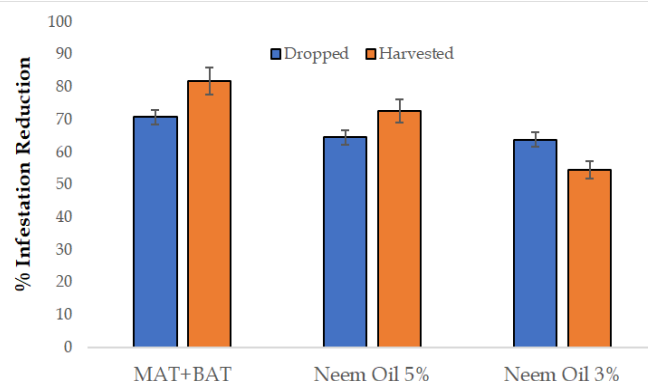


Figure 3: Percent reduction of fruit fly infestation over control in harvested and dropped fruits as affected by different treatments.

Table 8: Percent fruit infestation as affected by different treatments in dropped and harvest fruits (second picking).

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	20.65 b	0.43 b
Neem Oil @5%	21.80 b	0.72 b
Neem Oil @3%	22.98 b	1.36 b
Check	66.22 a	10.56 a
LSD _{0.05}	10.43	5.73

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Experiment-4: Testing of IPM model

The results showed a significant decrease in fruit fly infestation with IPM model application in both dropped and harvested fruits (Figure 4). The fruit fly infestation dropped to less than one percent (0.8%) in harvested fruits of IPM plots whereas; it was 10.5% at farmers' practices. In dropped fruits it was 0.4% in the treated plots comparing to that of 7.0% in untreated check plantation. Similarly, percent reduction of fruit fly infestation over control showed a 94.3% in dropped fruits and 92.4% in harvested fruits.

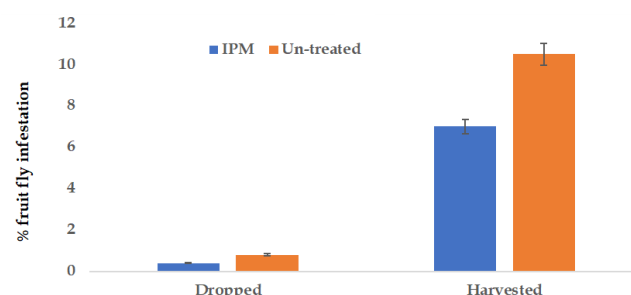


Figure 4: Percent reduction of fruit fly infestation over control in harvested and dropped fruits as affected by different treatments.

Fruit flies are considered as a major constraint for the production of mangoes in many countries of the world. They cause significant economic losses in tropical and subtropical regions around the globe. Integrated pest management strategies are recommended for the effective and sustainable management of fruit flies. In current investigations, maximum infestation of fruit flies was noted in dropped fruits as the farmers do not pay any attention to over-ripen fruits as these fruits carry meager market value due to having minimum shelf life. These over ripen fruits are vulnerable to mechanical damage and oviposition of fruit flies (Castrejon-Gomex *et al.*, 2004). As dropped fruits carry low grade and are vulnerable to mechanical injury, growers do not care about their collection and disposal so they become breeding sites for fruit flies which ultimately results in a higher infestation of harvested fruits Bakri (1991) documented that fermented fruits were found more attractive to fruit flies as compared to mature orange fruit. Therefore, disposal of dropped fruits should be practiced in order to eliminate the breeding sites for fruit flies. One of the studies revealed that neem oil treatments of fruits have significantly lower infestation than untreated fruits. This lower infestation clearly showed an oviposition deterrent effect of neem oil as reported by many researchers for different pest species worldwide (Nadia *et al.*, 1995; Tianyun and Mulla, 1999).

Table 9: Mean infestation as affected by different treatments in dropped and harvest fruits.

Treatments	Mean % infestation	
	Dropped fruit	Harvested fruit
MAT+BAT	18.9 b	0.44 b
Neem Oil @5%	22.4 b	0.66 b
Neem Oil @3%	23.4 b	1.32 b
Check	67.09 a	9.97 a
LSD _{0.05}	7.78	4.65

Means followed by different letters are significant from each other at 5% level of probability using LSD test.

Low infestation in the harvested fruits (1-1.5%) of treated trees could be further reduced to zero level by installation of traps round the year. (Stonehouse *et al.*, 2002) and adoption of other cultural practices like the destruction of fruit fly pupae by ploughing, orchard sanitation, picking up of dropped fruit (Vergheese *et al.*, 2004) border application of synthetic pesticides or bait (Prokopy *et al.*, 2004; Vergheese *et al.*, 2004).

The combination of lures (sex and food) has not been reported for fruit fly management in mangos. Even a single lure, either as food or sex, has been proven an effective and environmentally safe alternative to synthetic pesticides (Prokopy *et al.*, 2004; Barry *et al.*, 2005; McQuate *et al.*, 2005; Pelz *et al.*, 2005; Yee and Chapman, 2005). However, Wang *et al.* (2005) showed their reservation for conservation of fruit fly parasitoids in bait application and Revis *et al.* (2004) reported aging deterioration of bait activity. The lower infestation of fruit flies in combined treatments of MAT and BAT compared to single treatment of sex lure or food bait was because only one sex was collected in a single treatment and killed while in combined treatment both sexes were eradicated resulting in lower infestation.

More than 80% reduction in fruit infestation was achieved by the application of neem extracts. The effectiveness of neem extract has not been reported against mango fruit flies before this study. Neem has many active compounds including azadirachtine act on insects by different means, thus proved affective against fruit flies as well. The neem derivatives have been reported to carry repellent activity against adult insects. The findings of Anonymous (2004) and Jilani *et al.* (2004) also support our results regarding the activity of neem oil. Barry *et al.* (2005) also demonstrated an equal fruit infestation of fruit flies in blueberries with the application of azadirachtine, Spinosad bait and synthetic insecticides, confirming that the fruit infestation method of evaluation was a better option (Pelz *et al.*, 2005; Yee and Chapman, 2005).

In the third experiment, though neem oil @ 3% concentration treatment had a numerically higher infestation level (1.32%) but it was statistically at par with MAT + BAT. The mean percent infestation of fruit flies in the dropped fruits was on the higher side in all treatments. Farmers usually don't care about dropped fruits as fruit fly infested fruits drop and have no market value, while it is very important to monitor and eliminate the dropped fruits to avoid future population buildup and outbreak of new generations. It could be generalized that neem oil, even at 3% concentration, proved a good alternative in suppressing the pest and ecologically safe bio-pesticide and should be promoted for controlling fruit flies in mango orchards. Since neem oil has many active compounds, which act on insect behavior like suppress feeding, deter oviposition, delay molting, and reduce fecundity.

All treatments reduced the infestation of fruit flies ranging from 86 to 95% in harvested fruits and 65 to 71% in dropped fruits over control, which was quite in conformity with the previous studies (Roger *et al.*, 2002; Vargas *et al.*, 2003; Prokopy *et al.*, 2004; Pelz *et al.*, 2005; Yee and Chapman, 2005). So it is concluded that neem oil has great potential for the control of fruit flies and can be used as a substitute for synthetic pesticides. The combination of bait application, MAT, orchard sanitation and cover spray of plant derivatives could provide a reliable and sustainable management tool for fruit flies in mangos. This environmentally friendly biopesticide also fits in the WTO regulations and is safe for the environment and workers' health.

Conclusions and Recommendations

The fruit fly is the most dangerous insect pests of mangoes. The research based IPM model for the management of *B. zonata* in mangoes, comprised of year-round male annihilation technique (MAT), intermittent application of food bait (protein hydrolysate), application of neem oil on weed flora of the orchard and hoeing under the tree canopy resulted in < 1% (0.8%) infestation in harvested fruits comparing with 10.5% in farmers' orchard and is recommended for the effective management of fruit flies in mango orchards.

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Novelty Statement

The integration of plant-based pesticides, such as neem oil, along with sex lures and food attractants for the management of the fruit fly *Bactrocera zonata* has never been tested before in the agro-climatic conditions of Dera Ismail Khan, Pakistan which were found highly effective for the environmental friendly management of fruit flies.

Author's Contribution

Khalid Abdullah: Principal author who conducted research and wrote the manuscript.

Muhammad Mamoon-ur-Rashid: Conducted the research and wrote the manuscript

Muhammad Safdar Baloch: Contributed in writing the manuscript.

Iqtidar Hussain, Zuhair Hasnain and Muhammad Naeem: Contributed in statistical analysis and making corrections in the final draft.

Conflict of interest

The authors declare no conflict of interest.

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