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Different combinations of pheromone trap, dispenser and chemical treatments for controlling the mango fruit fly, *Bactrocera zonata* Saunders (Diptera: Tephritidae)

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Abstract

Using pheromone traps is one of the standard methods to control the mango fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae). The lower efficiency of traps has made it inevitable to consider more efficient methods of controlling this pest. This study investigated the effect of integrated control treatments. The experiment was a randomized block design with split plots, including four main treatments, four sub-treatments, and five replications to control this pest. Using the pheromone traps alone (two types of traps: McPhail and Delta with two different dispensers: chipboard sheets (neopan chipboard sheets) and glass tubes), the combination of traps and shade-spraying, the combination of traps, and trunk spraying by poisonous bait (a mixture of insecticide and hydrolyzed protein), and finally the combination of traps, shade-spraying, and trunk spraying were compared. The results indicated that applying traps alone was the least effective, and the combination of shade-spraying, trunk spraying, and pheromone traps was the most effective treatment for controlling the pest. Concerning the pheromone traps and dispensers, the McPhail trap was more effective than the delta trap, and the chipboard dispenser was more effective than the glass tubes regarding the number of pest individuals captured and, consequently, the rate of damage reduced. According to the present study's findings, combining different control measures with pheromone traps, replacing delta traps with McPhail ones, and chipboard dispensers with glass tubes would lead to appropriate control of *B. zonata*.

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Introduction

The mango fruit flies, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae) is one of the most important pests of mango, guava, and citrus in southern Iran (Bagheri et al., 2017; Khosravi & Shafaghi, 2013). This pest has been reported in Bangladesh, Indonesia (limited distribution), Laos, Myanmar, Nepal, Oman, Pakistan, Saudi Arabia, Sri Lanka, Thailand, UAE, Vietnam, Egypt, Mauritania, and Iran (Zingore et al., 2020; Qin et al., 2021). *B. zonata* is the predominant species of fruit flies in most mango-producing countries (Irshad & Jilani, 2003; Khosravi et al., 2018). More than 50 wild and agricultural plant species are hosts of *B. zonata*

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(Ghanim, 2009). The infested fruits rot quickly and become inedible due to the growth of saprophytic fungi (Abdullah et al., 2002), and begin to fall off which can cause up to 70% damage to the crop quality (Shinwari et al., 2015). Female flies lay their eggs in the skin of ripe fruits; after hatching, the larva digs tunnels and penetrates into the fruit tissue. In an infested fruit, different larval instars are usually observed which show oviposition times and generation overlapping (Shehata et al., 2008).

A variety of control methods such as chemical, biological, and mechanical methods as well as pheromone traps are used to reduce the damage of the mango fruit fly (Murtaza et al., 2021). The insecticides used against this pest belong to organophosphates, carbamates, pyrethroids and new chemical groups (Khan et al., 2015). Diazinon from the group of organophosphates is usually used to control the various stages of the fruit fly (El-Gendy et al., 2021; Bilal et al., 2021). Chemical control not only leads to increase of the pest resistance (Nadeem et al., 2014), but also the insecticides could not penetrate into the fruit to kill the larvae (Hossain et al., 2017). Due to the high level of damage of this pest, use of chemical and non-chemical methods against this pest is inevitable (Bagheri et al., 2017), whereas some eco-friendly methods such as insect sterilization (Enkerlin & Quinlan, 2002; McInnis et al., 2007), cultural methods (Schellhorn et al., 2000), have suitable performance to control *B. zonata*. Over the past decade, the attractants such as methyl eugenol and hydrolyzed protein have been widely used for mass capturing of fruit flies (Epsky et al., 1999; Vargas et al., 2008; El-Gendy, 2012; Ghanim, 2013; Navarro-Llopis & Vacas, 2014; Manrakhan & Addison, 2014; Rizk et al., 2014; Amin, 2015; Khan et al., 2015; Ahmad & Begum, 2017; Bagheri et al., 2017; El-Metwally & Ragab, 2020; Abbas et al., 2021). Methyl eugenol is a plant compound derived from the essential oils of 200 plant species and 32 families (Abbas et al., 2021). Using methyl eugenol leads to fewer offspring of the pest because of sex ratio disturbing (Mirani, 2007), as well as protecting the environment (Sing et al., 2020; Abbas et al., 2021; Hasnain et al., 2022). Whereas numerous studies have shown the effectiveness of different traps against fruit flies (Mc Phail, 1939; Mohamed, 2002; Khosravi et al., 2018), methyl eugenol has been used in traps for mass trapping of fruit flies in various crops including mango (McQuate et al., 2005). This study aimed to evaluate the efficacy of different attractant traps with different dispensers as well as some pesticides in reducing damage and population density of the mango fruit fly.

Material and Methods

Statistical plan and treatments

This study was carried out in two adjacent and relatively uniform orchards in Minab (27° 07' 51.74" N; 57° 05' 13.78" E), Hormozgan Province, southern Iran during the spring and summer of 2020, as a randomized block design with split plots include four main treatments, four sub-treatments and five replications. There were 20 mango trees in each main plot (in total 400 trees). The treatments included pheromone trap (OT) as control and three other integrated treatments including pheromone trap along with the trunk spraying by poisonous bait of hydrolyzed protein for controlling adults, pheromone traps along with the shade spraying by diazinon to control pupae in the soil, pheromone traps, shade spraying along with the trunk spraying by poisonous bait of hydrolyzed protein and diazinon insecticide (Fig. 1).

Fig. 1. Trunk spray by the poison bait of hydrolyzed protein and diazinon in the shade of tree (A) Shade spray by diazinon to kill pupa (B).

Every main treatment had secondary treatment in the form of split plots (sub-treatments) to compare the type of trap and dispenser. The two types of pheromone traps (Delta and McPhail) and pheromone dispensers (glass tubes and chipboard sheets) were used in the sub-treatments. The treatments were labeled as Delta trap with glass tube dispenser (DT), Delta trap with chipboard sheet dispenser (DN), McPhail trap with glass tube dispenser (MT), and McPhail traps with chipboard sheet dispenser (MN). Sticky paper was used in Delta traps and 2% non-aromatic dishwashing liquid was used in McPhail traps. Small half-filled glass tubes (5 cm in length and 0.6 cm in diameter) of methyl eugenol were used as glass tube dispensers, which had perforated plastic lids to evaporate pheromones. Small pieces of chipboard (4 × 2 × 2 cm) covered with methyl eugenol were hung inside the trap using thin wires as chipboard dispensers (Fig. 2 and Fig. 3). Every trap hung away from direct sunlight inside the tree canopy, was monitored weekly and the pheromone, sticky paper and liquid inside the trap were replaced if it was necessary.

According to the research plan, the main and sub-treatments were randomly distributed in plots and blocks. After implementing the plan, samplings were weekly carried out to evaluate two important indicators including the percentage of damaged fruits during harvest, and the number of attracted insects to the pheromone traps as an indicator of trap efficiency. All harvested fruits from each tree (healthy and infested) were counted and the percentage of infested fruits was determined. The number of captured insects in each trap was counted to evaluate the efficacy of the traps.

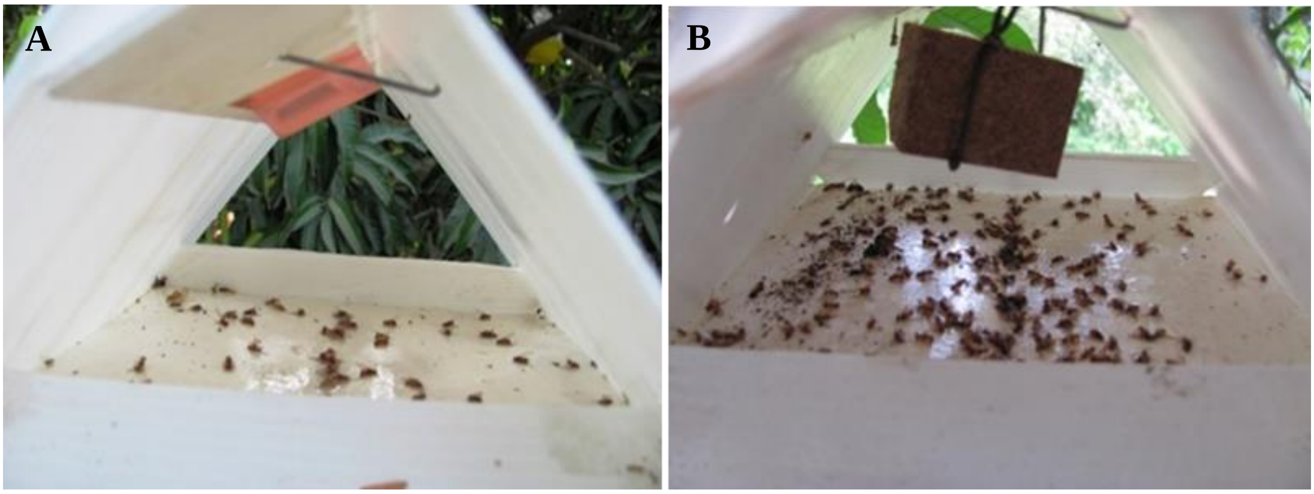

Fig. 2. Delta trap with glass tube dispenser (A) Delta trap with chipboard dispenser (B).

Fig. 3. McPhail trap with chipboard dispenser (A) McPhail trap with glass tube dispenser (B).

Data analyses

The data of the current study were analyzed by statistical software R version 4.1.2 (Crawley, 2007) in two different perspectives. The first view was the effectiveness of management treatments, type of traps and type of pheromone dispensers on reduction of pest damage, in which the percentage of damage was considered as an indicator for comparing treatments with each other. The second view was the effect of the trap type and dispenser type on the pest population, in which the number of captured insects in the trap was used as an indicator for treatment comparing. A pairwise comparison test in the R package was used to classify the treatments in terms of their effects (Crawley, 2007).

Results

Evaluating of damage percentage

The results of the analysis of variance (Table 1) showed that the different treatments significantly affected the percentage of pest damage. Furthermore, the effect of blocks was significant while the interaction between blocks and treatments was not significant. The results showed the highest damage in the control treatment, while the treatment of combined pheromone trap and shade spraying (pupal control in the soil) had no significant difference with the control treatment (Fig. 4). The damage of the fruit fly in the two above-mentioned treatments was significantly higher than the other treatments including trap and trunk spraying, or trap, trunk, and shade spraying. The least damage was observed in the combined treatment of the pheromone traps, trunk, and shade spraying (Fig. 4). On the other hand, each factor of the treatment had a significant effect in reducing pest damage and some of them had interactions with each other.

Table 1. Analysis of variance of the mango fruit fly damage (%) on crop in different treatments after harvesting.

Source of variation	df	Sum of squares	Mean of squares	F value	P value
Treatment	3	374.31	124.77**	15.48	0.01<
Block	4	183.36	45.84**	5.99	0.01<
Treatment ×Block	12	153.86	12.83	1.59	0.092
error	380	3061.94	8.058	------	

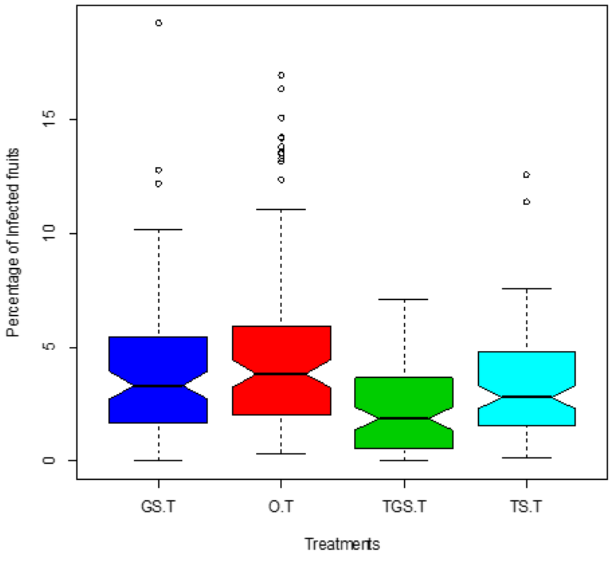

Fig. 4. The percentage of infested fruits in different combined treatments (OT= trap alone; TS.T= combination of trap and trunk spray; GS.T= combination of shade spray and trap; TGS.T= combination of all factors).

Figure 5 shows the difference between the two types of dispensers as well as the more important role of the pheromone dispenser than the trap type. The effect of all three factors including spray, trap, and type of dispenser was significant on the percentage of pest damage. The least pest damage belonged to the treatment of the McPhail trap that had a significant difference compared with the treatment of the Delta trap.

The interaction curve of traps and management treatments showed that the percentage of damage in treatments of McPhail traps was lower than in treatments of delta traps, it also showed that combination of McPhail trap, shade and trunk spraying with 1% of damage had the best efficiency in pest damage control (Fig. 6). All treatments with chipboard sheet dispensers with 1% damage were more effective than that of the glass tube dispenser.

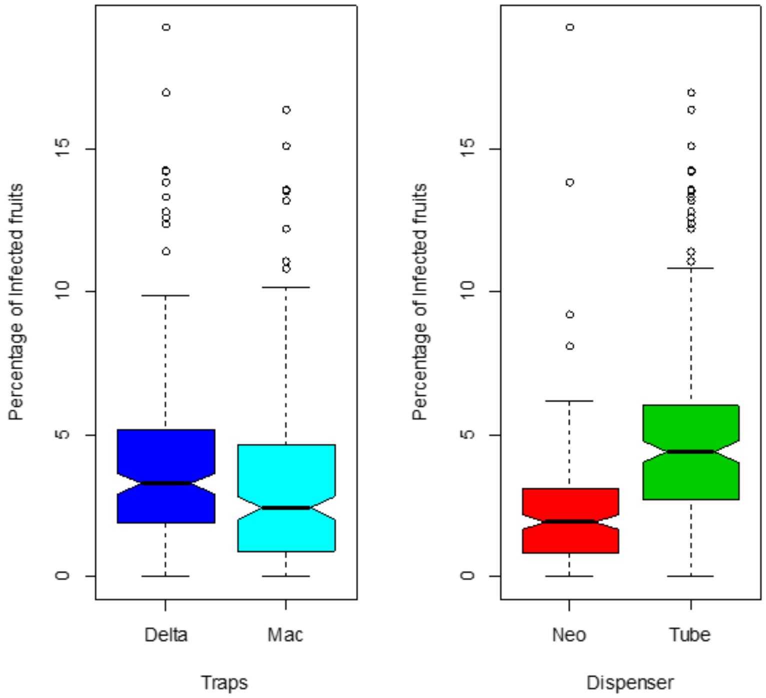

Fig. 5. The percentage of infested fruits in different treatments based on the type of trap and pheromone dispenser.

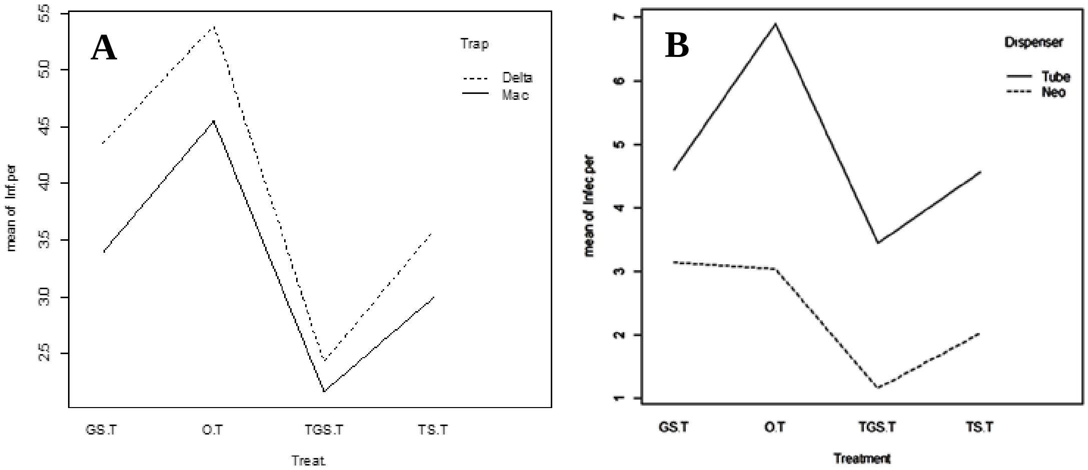

Fig. 6. The interaction between trap and combined treatments on the damage percentage of mango fruit flies (A) pheromone dispenser and combined treatments on the damage percentage of mango fruit flies (B).

Pest population analyses

The relationship between pest population and traps indicated that the type of trap and pheromone dispenser were effective on the insect attraction. However the combined treatments had no significant role in insect attraction to the traps, and the influence of the block was not significant (Table 2). The results showed that all treatments affected the population fluctuations of the captured insects by traps in the same way and had no significant difference with each other (Fig. 7). According to the results, the highest rate of insect captured in the trap treatment alone was due to the McPhail trap that was almost three times more than that of delta trap (Fig. 7). Although the traps with glass tube dispenser had lower rate of insect capturing compared to traps with chipboard one (10% in comparison), there was no difference between McPhail and Delta traps with glass tube dispenser, whereas the McPhail trap with chipboard dispenser had the highest rate of insect attraction (Fig. 8).

Table 2. Analysis of variance of the captured flies in traps and its relationship with the type of pheromone trap, pheromone dispenser and different combined treatments (*** denotes the result is statistically significant at 0.1% level).

Source of variation	df	Sum of squares	Mean of squares	F value	P value
Replication	4	183	46	0.001	0.965
Spraying	3	121447	40482	0.729	0.56
Error a	12	666531	55544	-----	-----
Trap	1	4036684	4036684	103.908	<0.001***
Spraying × trap	3	50866	16962	0.437	0.73
Error b	16	621575	38848	-------	-----
Dispenser	1	11736448	11736448	531.824	<0.001***
Spraying × dispenser	3	91126	30375	1.376	0.25
Trap × dispenser	1	4070508	4070508	184.450	<0.001***
Trap × dispenser × Spraying	3	47884	15962	0.723	0.54
Error	352	7768045	22068	-------	------

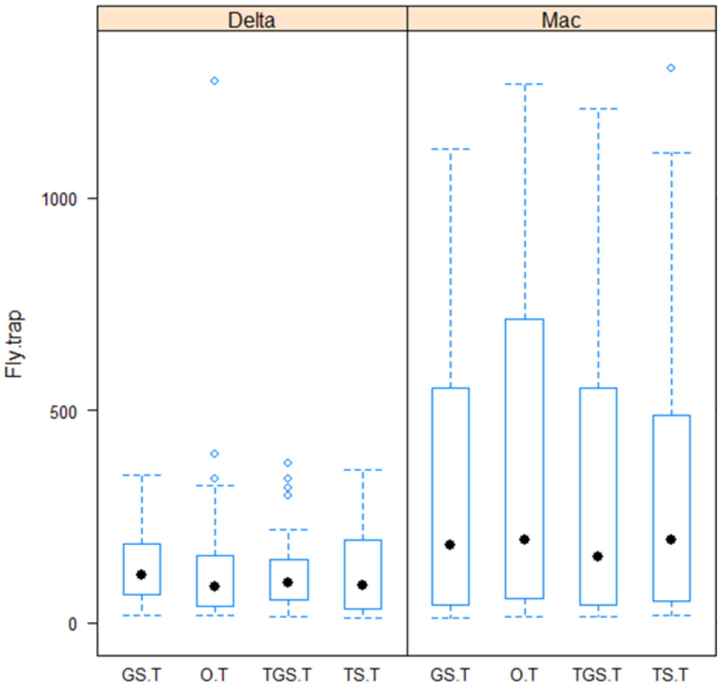

Fig. 7. Fruit fly capturing in different treatments based on type of trap (McPhail and Delta).

The graph of fluctuation in the population of insects caught with traps in different integrated pest management treatments by two types of dispensers (Fig. 9) also showed that the influence of treatment on the number of insects captured in traps is negligible. This graph shows the efficient influence of pheromone dispensers on insect capturing. The highest rate of insect capturing in these treatments is related to the trap treatment alone with chipboard dispenser. As this graph indicates, the difference between the rates of insect capturing in treatments that have the same pheromone dispenser is small, and this is evidenced by the limited and insignificant effect of the treatments on the rate of insects capturing traps.

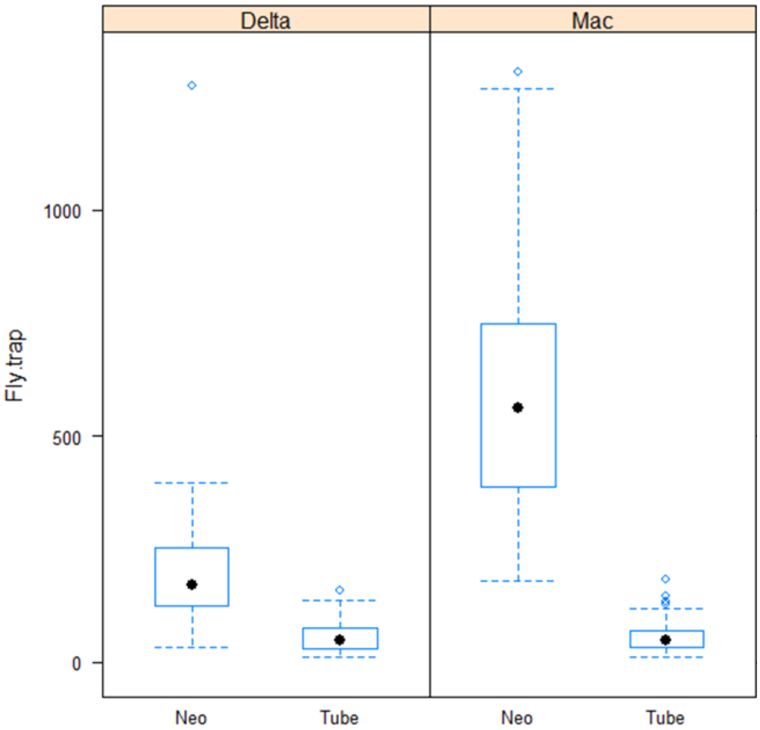

Fig. 8. Fruit fly capturing in different traps based on the type of pheromone dispenser.

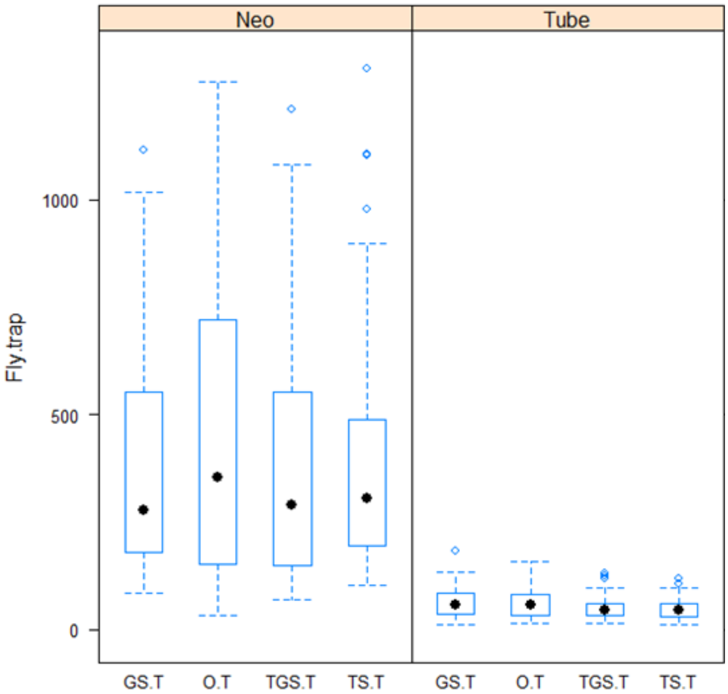

Fig. 9. Fruit fly capturing in different treatments based on type of pheromone dispenser.

Discussion

Based on our findings, the pheromone traps alone could not control the damage of mango fruit fly. In cases where the trap alone was used to control the pest, a significant percentage of the fruit was damaged at harvest time. Combining pupal control treatments in soil (shade spraying) and attracting adult insects by trunk spraying (hydrolyzed proteins and insecticides) significantly reduced the pest damage and enhanced the efficiency of traps. A comparison of three control treatments showed that combined treatments had significant effect on reducing pest damage. These results are consistent with the experiments carried out by Abbas et al. (2021), which considered the combined methods for the best control of the pest. According to the results, the damage of mango fruit fly varied from about 2% to 5% in different treatments. The highest pest damage was in the trap treatments alone while the lowest was in the combined treatment of pupal and adult insect control with pheromone traps. In addition, three factors of trap, type of dispenser, and spraying had a significant effect on reducing the pest damage. Alzubaidy (2000) indicated that a combination of two types of delta-shaped Jackson traps, 99% methyl eugenol and 1% insecticide, and combination of McPhail traps with a glass tank were suitable methods for control *B. zonata*. In addition, other combined control methods such as trap baiting methods, using diazinon insecticide in the soil or on the trunk, and removing the infested fruits were as effective control methods in California for several years. Singh et al., (2020), Khosravi et al. (2018) and Vargas et al. (2008) also proved that the simultaneous use of traps, pesticides and attractants such as methyl eugenol and protein hydrolyzed play an important role in controlling *Bactrocera* population. In this study, controlling adult insects by trunk spraying (mixture of insecticide and protein hydrolyzed) was more effective than shade spraying alone to control pupae as well as had less harmful environmental effects. Plowing and flame throwing operations are the other eco-friendly methods to control the pupal population of this pest in the soil (Askari & Pezhman, 1988). Based on the results, the McPhail trap with the chipboard dispenser was the best trap for maximum insect attraction which is consistent with the results of the research carried out by Burrack et al. (2008). In other studies, it has been reported that bait traps with chipboard dispensers had higher efficiency in mango fruit fly attraction than other traps (Bagheri et al., 2017; Khosravi et al., 2018). Applying attractants and logical use of insecticides to control the mango fruit fly can support the natural populations of enemies. Several natural enemies including pathogenic nematodes such as *Heteroribatidid* sp. and *Steinernema* sp., predators, and parasitoids such as *Aganaspis daci* (Hym.: Figitidae) attach this pest and they can be used for the management of this important pest (Usman et al., 2001). In conclusion, trunk spraying by using poisonous bait of hydrolyzed protein and insecticide, trapping to attract adult insects by McPhail traps with chipboard dispensers can be recommended for controlling the population of the mango fruit fly.

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Conflict of interest

The authors declare that there are no conflicts of interest present.

CRediT author statement

M. Sadeghi: Field and laboratory works. **M. Askari Seyahooei**: Supervision, methodology and data analysis. **M. Fallahzadeh**: Supervision. **A. Bagheri**: writing, reviewing & editing. **A. Ameri Seyahooei, M. Khademipour** and **S.S. Modarresi-Najafabadi**: Writing & editing.

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