*Available online at* www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.139

**ISSN: 2582 – 7146**

Current Research in Agriculture and Farming

*Curr. Rese. Agri. Far.* (2021) *2*(3), 8-16

Peer-Reviewed, Refereed, Open Access Journal

*Review Article*

# Management of *Bactrocera zonata* (Diptera: Tephritidae) through Application of Different Tactics: A Review

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Received: 12.03.2021 | Revised: 19.04.2021 | Accepted: 3.05.2021

**ABSTRACT**

*Bactrocera zonata is the most destructive pest in tropical and subtropical regions. In this region, it is the most devasting fly, due to its high reproductive potential, mobility, host range, and adaptability to climate. Those countries which are considered as fruit-producing countries lose their international markets due to the quarantine regulations which are imposed to avoid the invasion of a fruit fly. For the management of B. zonata, the use of chemical insecticides against fruit fly is in practice for several decades which originate from environmental imbalance, diseases in humans and animals and develop resistance. Different methods are alternatives to chemical control, grouped into cultural, physical, behavioral, genetic, and biological control. In this review, we summarize all the control measures which can be used singly or in the integrated form with other measures to control the B. zonata.*

***Keywords:*** *Fruit fly, Bactrocera zonata, Chemical control, Pheromones, Bait Application Technique.*

## INTRODUCTION

The peach fruit fly, *B. zonata* is a serious pest of fruits and vegetables in South-East Asia. It causes damage to horticultural crop losses 25-100% in mango, peach, guava, apricot, and figs. Chemical insecticides against *B. zonata* are effective and in practice for several decades and have several drawbacks (Pourseyed et al., 2010). Different methods have potential and best alternatives to the chemical control such as sanitation, plant resistance, harvesting time (Ekesi et al., 2010), fruit bagging (Sharma & Sanikommu, 2018), bait application technique, male annihilation technique (El-Gendy, 2013; & Nisar et al., 2020), Sterile insect Technique (Uddin et al., 2018), parasitoids, predators, entomopathogens, and botanicals (Hosni et al., 2012; Anbesse et al., 2013; & Rashad et al., 2015).

**Cite this article:** Bilal, H., Raza, H., Qayyum, M. A., Ijaz, M., Bashir, M. I., Baig, M. A., & Hassan, M. (2021). Management of *Bactrocera zonata* (Diptera: Tephritidae) through application of different tactics; a review, *Curr. Rese. Agri. Far. 2*(3), 8-16. doi: http://dx.doi.org/10.18782/2582-7146.139

**Chemical Control**

Chemical control is the most common method used and several pesticide formulations have shown effectiveness for various fruit fly species (N'depo et al., 2015). Despite the disadvantages of pesticide applications for the environment, this method is still used alone or in combination with other control agents against numerous fruit flies species. In Pakistan, endrin, dialordin, dipterex (trichlorfon), dimecron, diazinon, and malathion were used as a cover spray-on mango orchards against *B. zonata*. Different chemicals target various developmental stages of the fruit flies. Malathion targets the adults while diazinon, target the popping larvae and emerging adults. Mosleh et al. (2011) reported that at 24 hours after treatment, diazinon was the most toxic compound to *B. zonata*, followed by Malathion, Lufenuron, and Methoxy fenozide, males had LC50 values of 0.20, 0.48, 8.97, and 9.73 ppm, while females had LC50 values of 0.26, 0.91, 11.26, and 14.12 ppm.

Diazinon has been used extensively in soil drench applications to control immature fruit fly stages, mature larvae, pre-pupae, and pupae (El-Gendy et al., 2021). Direct application of chemicals has led to a number of detrimental effects like accumulation of pesticide residues in the environment (Mahmood et al., 2016), mortality of non-target species that can be beneficial to the ecosystem, development of resistance (Nadeem et al., 2012), also exposing the consumers and producers into health risks (Nicolopoulou-Stamati et al., 2016). The results suggest that *B. zonata* has developed resistance to trichlorfon, malathion, bifenthrin, λ-cyhalothrin, and spinosad (Nadeem et al., 2012). These insecticides have successfully contributed to the suppression of *B. zonata* populations when combined with traps and attractants (Hanafy & El-Sayed, 2013)

**Physical control**

Pre-harvest fruit bagging and post-harvest quarantine treatments are two physical methods of fruit fly control. Fruit bagging is an effective method for keeping the environment and the fruit physically apart. It is mainly based on the wrapping or bagging of individual fruits to prevent female oviposition. In addition to disease and insect pests, fruit bagging reduces mechanical damage, fruit cracking, sunburn, bird damage, and agrochemical residues (Sharma & Sanikommu, 2018). This is done before the fruits reach the stage of maturity at which they are susceptible to infestation (Sarwar, 2015). There have also been reports of fruit bagging for contribution in reducing *B. zonata* infestation by fruit flies (Sarker et al., 2009). Uddin et al. (2016) suggest that the use of double-layer brown colored bags would be an eco-friendly management measure against the infestation of fruit flies. However, mango farmers must bag their mango after 40-55 days of fruit set.

**Cultural control**

These techniques include the selection of a tolerant variety, early harvesting prior to fruit maturity, ensuring field sanitation by collecting and destroying infested, dropped, damaged, and overripe fruit, and raking and plowing to expose the pupae to sunlight and predators (Dias et al., 2018). Multiple research and reports have shown that cultural approaches minimize the rate of adult emergence of various species of fruit flies (Klungness et al., 2005; & Ekesi et al., 2010). In mangoes, there is a strong variability of fruit fly resistance consistent with efficiency and consistency. The fruit peel is responsible for oviposition resistance. Infestation of fruit flies may also be prevented by harvesting crops before the stage of maturity where the fruit or vegetable is not vulnerable to fruit fly attack and can minimize fruit damage or decrease fruit damage. Proper field sanitation is important to minimize *B. zonata* populations, infested fruits should be harvested from a field, buried at least 50 cm below the soil surface, or put in plastic bags and left out in the sun for about 10 days for most of them to die for infestation-free fruit (Ekesi et al., 2010).

**Behavioral Control**

Behavioral Control of fruit fly management included two main tactics that are Sterile Insect Technique (SIT) and Attract and kill technique. Which is further divided into the Male annihilation technique (MAT) and the Bait application technique (BAT).

**Bait Application Technique (BAT)**

Management of *B. zonata* mainly depends upon the use of food baits mixed with an agent used for killing. Bait spray is currently successfully used in some fruit fly control programs (Barclay et al., 2014; & Shelly et al., 2014). Many studies have demonstrated that baiting is an effective to control either used alone or in combination with other control agents against many fruit flies species (Stonehouse et al., 2007). Both male and female fruit flies are attracted to these lures. Al-Eryan, (2008) find out that a formulation containing beef extract, borax, molasses, and malathion can be used to track and manage the peach fruit fly, *B. zonata*. Mostly, commercially these attractants provide sugar and protein sources to adults. Several natural compounds (corn, milk, and soy), synthetic lures (ammonium and trimethylamine), bacteria (Enterobacteriaceae) have been evaluated as food-bait attractants and have become commercially available to detect and control *B. zonata* adults (Sookar et al., 2006; & Epsky et al., 2014). In attraction adults of B. zonata, Ammonium Acetate was the strongest possible attractant in synthetic food-odor lures (El-Gendy, 2013). The bait Application Technique has minimum effect on natural enemies and pollinators. This method is less time-consuming and less laborious.

**Male Annihilation Technique**

In this method, pheromones are used in controlling fruit flies. This strategy use to attract and kill technique and consists of pheromones which attract the male adults onto a killing agent (insecticide). MAT aims to reduce the population of the males of the *B. zonata* hence reducing the chances of mating and the most effective in controlling *B. zonata* (Hussain et al., 2010). Fruit fly pheromones are extremely species-specific and effective at attracting fruit flies from long distances. Many types of attractants have been reported to attract fruit flies (Tan et al., 2014). Methyl eugenol and Cuelure are widely used as attractants for males of *B. zonata* (Nisar et al., 2020). Khan et al. (2015) findings show that methyl eugenol attracts male peach fruit flies, and that using a methyl pheromone trap, we can easily reduce the population of adult peach fruit flies. This tactic is useful if it is used with an "area-wide" suppression strategy (Al-Eryan et al., 2018). This approach is used as spot treatments, with several dispensers acting as carriers of methyl eugenol and toxicant (such as neutral cord, cotton cord, felt block, and plant fiber blocks). Insecticides used in MAT are mostly organophosphorus compounds including Malathion, Dichlorvos, and Naled (Ghanim et al., 2010). From a distance of 1km, 2g of poison Linate and 2cc of lure will attract the peach fruit fly, B. zonata, and kill it easily for up to 15 days (Khan et al., 2015).

**Sterile Insect Technique (SIT):**

The sterile insect technique (SIT) has been used to control other tephritid pests, and it could be used to control *B. Zonata* as well (Ndzana Abanda et al., 2016). This method involves artificially sterilizing male fruit fly populations and then releasing massive groups of sterile males into infested areas, where they mate with wild females. This is done to interrupt the normal reproductive cycle of insects and leads to the leads the females to produce infertile eggs or not lay eggs, it is species-specific. Fruit flies are exposed to X-rays, gamma rays, and electron beams (Draz et al., 2016).

The effects of Gamma rays on *B. zonata* include adult emergence, sex ratio, male and female sterility and deformed pupae (Draz et al., 2008), pupal size, flight ability, female fecundity, and mating competitiveness of *B. zonata* sterile males (Mahmoud & Barta, 2011). Uddin et al. (2018) stated that there is possibility *B. zonata* management/or eradication at Gamma rays radiation dose 3.5 Kr in SIT.

Sterile males can also use as a vector to transmit the diseases to the adults. In a sterile insect release program, sterile *B. zonata* males may be used as *B. bassiana* vectors to supplement pest suppression (Sookar et al., 2014a). When compared to wild males, the fruit fly mass-rearing process and radiation sterilization of the males in SIT can sometimes result in a reduction in the consistency of the released sterile males. So far, there are limited scientific data available for the suppression of *B. zonata* population using sterile insect technique.

**Botanicals**

Botanical insecticides are typically pest-specific and relatively safe for non-target species, such as humans. They are also biodegradable and environment friendly. Moreover, unlike traditional insecticides, which are limited to a single active ingredient, plant-derived insecticides are made up of a variety of chemical compounds that work together to affect both physiological and behavioral processes. As a result, the likelihood of pests developing resistance to such substances is reduced. The acetone extract of turmeric outperformed the petroleum ether, acetone, and ethanol extracts as a growth inhibitor and repellent against *B. zonata* (Siddiqi et al., 2006). Naheed et al. (2004) demonstrated that *Curcuma longa, Acorus calamus,* and *A. indica,* all have repellent and growth-inhibiting properties against *B. zonata*. Three plant species, *Peganum harmala, Saussurea lappa,* and *Valeriana jatamansi* were evaluated after being isolated in petroleum ether (a mixture of C5-7 alkanes).

The most successful oviposition deterrent for *B. zonata* was *P. harmala* (Yasmin, 2004). The most promising repellents against Peach fruit fly were petroleum ether extract of C. longa, ethanol, and acetone extract of *P. harmala*. *P. harmala* acetone extract, *V. jatamansi* ethanol extract, and S. lappa petroleum ether extract were also found to be effective oviposition deterrents. The overall egg-laying was suppressed by *C. colocynthis* (Rehman et al., 2009). The egg repellency effect of neem on eggs deposited in orange fruits after being sprayed with previous concentrations was high, reaching 5.0% eggs/puncture/fruit, compared to 65.8% for the control. Furthermore, at 600 ppm, the percent of eggs hatching decreased to 76.2 %, compared to 89.0 % in the control group (Farag Mahmoud & Shoeib, 2008).

**Biological Control**

Biological control is an economical method and poses less threat than pesticides to humans and the environment (Rizvi et al., 2009). There are various strategies, including inoculation, inundation, classical and conservation biological control for introducing biocontrol agents within insect control programs. Natural enemies, parasitoids, predators, and pathogens are commonly used in biological control (Dias et al., 2018), which act by feeding on the pest, parasitizing the pest, and causing diseases.

**Natural insect enemies**

The release of exotic parasitoids and predators from the pest's native area is perhaps one of the control strategies that can minimize pest populations to manageable levels in classical biological control programs (Adly, 2016). *Psyttalia sp, Tetrastichus giffardianus, and Aganaspis sp*. emerged as parasitoids from *B. zonata* puparia (Mahmoud et al., 2019). Potential parasitoids of *B. zonata* A. daci (Hosni et al., 2012) and pupal parasitoid, Dirhinus giffardii (El-Husseini et al., 2008). Exotic parasitoid species, A. daci against *B. zonata* applied in the field and the first recovery was about a month post releasing date, as the percentage of parasitism attained 9.7% (El-Heneidy et al., n.d.). Predation took place on adult fruit flies and ants disturbed them during oviposition which was the major cause of reduction in fruit fly damage. Most predators of fruit flies belong to families Coccinellidae, Staphylinidae, Formicidae, Dermaptera, Pentatomidae, Coreidae, Carabidae, and Chrysopidae. Including insects there are predatory mites, *Typhlodromips swirskii, Amblyseius largoensis, Cydnosus negevi, Proprioseiopsis kadii,* and *Neoseiulus barkeri* were assessed when fed on eggs of *B. zonata*.

**Entomopathogens**

Insect pathogens are natural microorganisms found in many environments. These organisms can induce disease in the life stage of their insect host. Pathogens such as nematodes, bacteria, and fungi have been shown to be potential biological control agents against *B. zonata*.

**Entomopathogenic nematodes** kill their hosts by introducing bacteria into the host body causing death (Rizvi et al., 2009). *Heterorhabditis* and *Steinernema* species have been reported to cause mortality in some tephritid species. (Mahmoud et al., 2016) stated that different stages of *B. zonata* may be infected by EPNs. Through the interface region with the soil surface, nematodes may enter larvae within dropping guava fruits. During the emergence of pest adults from pupae, they infect newly developed pupae in the soil as well as the pest adults. The new isolate, *Heterorhabditis marelatus*, showed high potency in handling *B. zonata* adults emerging from their pupae, killing large number of the adults within 48 hours of emergence (Saleh et al., 2018). EPNs have been used in biological control for decades, but they still need to be improved before they can be used more widely in agriculture. Selective breeding and the isolation of additional species and populations may lead to improvements (Anbesse et al., 2013).

Entomopathogenic fungi are parasites that can cause oviposition deterrence, reduce the fertility and fecundity of the adult and disable and kill the insect pest (Sookar et al., 2014b). The mode of action of EPF is started by the attachment of the spores and the conidia on the cuticle layer of the host, in favorable conditions spores germination will start, grow and become a colony in insect cuticle (Valero-Jiménez et al., 2016). In EPF (Ascomycota: Hypocreales) *Baeuveria bassiana* and *Metarhizium anisopliae* are some of the well-considered fungi due to their special character and actions (Meyling & Eilenberg, 2007). They have several effects on the insect which include molting disruption, repellency, and interference with development, oviposition deterrence, and high mortality. These features have made entomopathogenic fungi one of the more attractive biological control agents. According to the method followed by (Gul et al., 2015), *I. furmosorosea and M. anisopilae* pathogenicity was 30-40% and *B. bassiana* was more than 20%. Adult emergence was highly affected by the *I. fumosorosra*. Treated pupae exhibit satisfactory symptoms like shrinks, darkness, deformation, and incomplete emergence of the adults. *B. bassiana* adult death rate is higher in soil application instead in *M. anisopilae*.

When the concentrations of the two studied fungi were increased at the same time of exposure, the mortality rates of *B. zonata* pupae increased significantly. Adult mortality was influenced by soil treatments, with *B. bassiana* treatments having a higher mortality rate than *M. anisopliae* and control treatments. Emerged adults from both fungi-treated pupae had mycosis on their outer surfaces, and some emerged adults had malformation and refused to emerge (Rashad et al., 2015).

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