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REVIEW ON MORPHOMETRICS AND MANAGEMENT OF *BACTROCERA ZONATA* (DIPTERA: TEPHRITIDAE), AN ECONOMIC PEST IN PAKISTAN

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Abstract

Bactrocera zonata (Saunders), Diptera: Tephritidae, is a voracious pest. Many host plants are attacked by *B. zonata* which causes a loss of $200 million per year in Pakistan. The hosts of *B. zonata* are guava, mango, peach, apricot, citrus, and fig. Climate change affects the metabolic processes of insects as an increase in temperature delays the process of insect development, and affects their survival rate, and longevity. Temperature affects the growth stages and development of *B. zonata* from larval emergence to adulthood. The behavioral responses shown by insects are governed by volatile compounds released by insects and host plants. Factors affecting host plant selection involve host finding and host acceptance. Host finding and host acceptance are controlled by vision, mechanoreception, olfaction, and contact chemoreception. Exogenous and endogenous factors influence the activity of insects. The intensity of light and temperature can limit the locomotory, flight, and foraging behaviors of fruit flies. *B. zonata* is a destructive pest and difficult to control due to its ecological, and morphological behaviour. Management of fruit flies is difficult. Several control tactics, including wrapping, covering, and spraying artificial pesticides are being used. For immediate control, farmers use insecticides such as diptrex, triazophos, and imidacloprid. The excessive use of pesticides has led to many issues which made scientists believe in biological control measures. The best practice to control any pest is IPM, which can replace other practices as well, as agrochemicals Entomopathogens, predators, parasitoids, and bait traps of botanicals are used worldwide for biological control.

Keywords: Behavior, Climate Change, Fruit Fly, IPM, Mechanoreceptions, Predators

Introduction:

B. zonata is native to tropical Asia and widely distributed in Indonesia, Nepal, Oman, India, Bhutan, and Pakistan (Delrio and Cocco, 2012). *B. zonata* is a polyphagous and quarantine pest with a wide host range, causing a loss of $200 million in fruit exports per year (Delrio and Cocco, 2012). Fruit flies are distributed along the coastal, subcoastal, semi-desert, and northern plains of Pakistan. In 2017, the species was reported in the Sargodha district from April to May, with the highest populations recorded in February and October. In climate change scenarios, pests can shift their host range according to environmental conditions (Arif *et al*., 2017). The distribution of *Bactrocera* spp. in Pakistan is presented in Table 1.

It was also observed in some arid regions and Punjab's levellands. Because it is a rare pest, the hilly regions of Peshawar and Islamabad were also alerted (Marwat *et al*., 2013). Although *B. zonata* is active all year round, March, May, July, and August were the months with the highest seasonal abundance. The pest breeds in the spring, overwinters as a pupa, and hibernates during the winter (Kapoor, 1986). Fruit flies are found all throughout the world, disrupting international trade and incurring enormous financial losses to fruits and vegetables.

Host Plants:

B. zonata is a polyphagous pest with the ability to fly 25 miles or more in search of a host plant. There are approximately 40 species of fruit that are attacked by *B. zonata*. The hosts of *B. zonata* are guava, mango, peach, apricot, citrus, and fig.

Biology and ecology:

Bactrocera zonata (Saunders) Tephritidae: Diptera have four growth stages: eggs, larvae, pupae, and adults. The first stage of *B. zonata* development is an egg laid by a female under the skin of the fruit. The eggs are creamy white, elongated, and elliptical in shape, approximately 1.0 to 1.2 mm long, with a distinct micropyle. Eggs hatch into larvae within 3–30 days at 35−15℃ (Binyameen *et al*., 2021). The entire life cycle is completed within 15 days at 35 ℃ and 60 days at 15 ℃ (Adly, 2016).

The larvae consisted of a rolled spiral head, three thoracic segments, and eight abdominal segments (Balmès and Mouttet, 2017). Mouth hooks, anterior spiracles, and posterior spiracles are special characteristics of *B. zonata* that change during larval development (Murtaza *et al*., 2021). *B. zonata* undergoes three larval instars. The respiratory system of *B. zonata* consists of two pairs of spiracular openings at the prothorax and posterior side of the abdomen. The first larval instar is 0.07 to 0.09 in length and white in color. The posterior end of larvae is broad and round, whereas the anterior end is tapered (Balmès and Mouttet, 2017). Yellowish-brown mouth hooks are present on the head. The body is semi-transparent, and the skeleton is visible near the head region (Fadul, 2021).

Table 1: Distribution of *Bactrocera* spp. in Pakistan

Province	Species	Reference
Punjab	*B. dorsalis, B. zonata,* and *B. cucurbitae*	(Ahmad *et al*., 2019)
	B. dorsalis, B. zonta, B. cucurbitae, and *B. correcta*	(Noman *et al*., 2021)
	B. zonata	(Khan and Naveed, 2017)
Sindh	*B. dorsalis,* and *B. zonata*	(Zain-Ul-Aabdin Abro *et al*., 2020)
Balochistan	*B. zonata*	(Khan *et al*., 2016)
	B. zonata, B. tau, B. invadens, B. cucurbitae, and *B. dorsalis*	(Maula *et al*., 2022)
	B. cucurbitae	(Qureshi *et al*., 2017)
Khyber Pakhtunkhwa	*B. dorsalis, B. correcta, B. cucurbitae, B. signata, B. scutellaris, B. tau, B. nigrofemoralis, B. zonata,* and *B. zahadi*	(Kausar *et al*., 2022)

B. zonata lays white to creamy yellowish eggs under the fruit peel. One female lays a maximum of 93 eggs per day, and approximately 564 eggs are laid by the females throughout their lifetime (Awad, 2012The adult emerges from the pupae and sexually matures within 2-3 weeks at 35-15℃. Females can live for 82-112 days.

Environmental factors influencing the growth and development of *B. zonata*. An optimum temperature of 25℃ to 35℃ and humidity of 40-60% is necessary for *B. zonata* survival (Khan and Naveed, 2017). The largest population of *B. zonata* was seen in June, July, and August, while the following months saw a fall in population (Khan and Naveed, 2017; Murtaza *et al.*, 2021). Growers in Pakistan face problems with fruit and vegetable infestations. Management of *B. zonata* can be effectively implemented with proper knowledge of its life cycle.

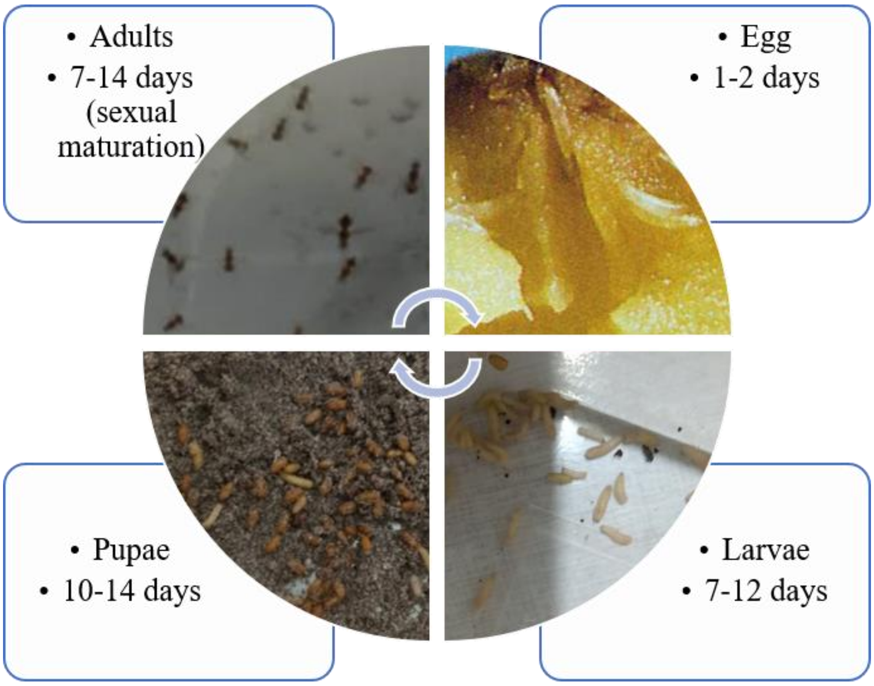

Figure 1: Life cycle of *Bactrocera zonata*

Bactrocera zonata attacks peaches, guava, mangoes, papaya, and citrus. It can fly for approximately 15 miles in search of a host plant. *Bactrocera zonata* competes with other species of Tephritidae fruit flies due to its short developmental phase, high reproductive rate, and survival. Compared to its competitors, *B. zonata* can endure lower relative humidity and can survive buried in soil for a longer period than its pupae. Adult fruit flies feed on nectar, rotting fruits, and plant sap for development and reproduction. The feeding behavior of *B. zonata* was temperature-dependent, and the most efficient feeding behavior was observed at night. Under field conditions, the fruit fly completed development at 10°C. The ideal temperature for the development of feeding, egg-laying, and pupation was observed to be 25 to 29°C. The fruit flies remained active from early March to mid-November. After 10 to 16 days of adult emergence, oviposition occurs in the fruit skin with a 38.1 mm diameter.

Oviposition behavior of *B. zonata*:

B. zonata shows two types of oviposition characteristics: pre-alighting and post-alighting behavior. These behaviors have a crucial role in population growth. It was revealed that the maximum number of pupae and adults were formed in guava (Murtaza *et al*., 2021). Analysis of volatile chemicals present in the fruit showed that some aromatic and aliphatic esters are the major factors for egg-laying *B. zonata*. Guava volatiles play an important role in the attraction and oviposition of *B.*

zonata (Binyameen *et al*., 2021). Another experiment was conducted to determine *B. zonata's* oviposition preference for guava, banana, chikoo, ber, apple, and citrus. In this case, guava is preferred (Rauf *et al*., 2013). Species-specific competition between the Tephritid species, *Anastrepha fraterculus,* and *Ceratitis capitata*, was used to evaluate the species interaction. They rejected the fruits, which were previously infested by conspecific and heterospecific individuals. The results suggest that the infestation of Tephritid species may vary due to the recognition of hetero-specifics. Cross-recognition is a beneficial trait in nature due to which inter-specific competition is reduced and results in the coexistence of species (Liendo *et al*., 2020).

Adnan *et al*. (2020) experimented on sexual compatibility, and mating performance was studied under semi-field conditions. It has been reported that the average mating time was observed at 5-6 hours for *B. zonata*. Ndzana Abanda *et al*. (2016) evaluated the sexual competitiveness of males in SIT programs. Attraction to methyl eugenol is an age-dependent factor that accelerates the sexual maturity of *B. zonata.* showed some behavioral effects when exposing its antennae to some volatile compounds. Pyrazines, ethyl esters, and spiroacetals were identified using SSGA. These volatile chemicals are released by fruit flies and increase in quantity, specifically with age (Levi-Zada *et al*., 2020).

Fruit flies also show an attraction to mango extract, as they have some electro-physiological responses to mangoes (Aluja, 2020). Approximately 14 species of host plants are preferred by fruit flies. The most preferred hosts for fruit flies are mangoes and bananas. Fruit flies also exhibit color preferences and behavioral responses. Trap color preference in the field was evaluated, and the results showed that trap color affected the preference of fruit flies. Yellow traps are the most preferred for fruit flies. Some behavioral reactions are affected by trap colors, such as host finding, flower visitation, egg deposition, and proboscis extension. This study shows that there are some photoreceptor sensitivity characteristics in flies. Fruit flies can imagine colors and differentiate between them (Lunau, 2014).

The mating and courtship behaviors of phytophagous insects depend on the host plant. Females simply visit the host plant for oviposition and feeding purposes, while males search for host plants for females. Oviposition punctures of *B. zonata* result in the invasion of saprophytic microbes, which results in the rotting of the fleshy tissues of the fruit. After the emergence of larvae, they start feeding on flesh, which results in fruit decay. Infested fruits fall to the ground, which facilitates the pupation of *B. zonata.* On the other hand, it also causes economic loss by reducing mango exports (Myers *et al*., 2016).

Environmental factors affecting *B. zonata*:

Temperature and humidity, for example, have an important impact on the population growth of fruit flies. July and June were the months of greatest population growth for *B. zonata* (Noman *et al*., 2021). Using maximum and minimum temperatures, rainfall, and humidity, evaluated the growth and development of *B. zonata* (Khan *et al*., 2021). The maximum population of *B. zonata* was observed at peak temperature when the mango fruits were ripped. Rainfall and humidity were negatively correlated with the development of *B. zonata*. (Chiu *et al*., 2019) studied the temperature influence on transgenic and natural *B. dorsalis* development. The population was exposed to 30℃, 32.5℃, and 35℃, The growth and development of both fly strains were negatively affected. High temperatures affected life history traits (Ndlela *et al*., 2021)

Temperature affects the growth stages and development of *B. zonata* from larval emergence to adulthood. The geographic pattern of fruit fly occurrence and their behavior were studied under laboratory conditions by managing at different temperatures. From 15 to 30°C, the development process decreased as the required temperature increased. There was a significant difference in temperature between the four incubation periods. Egg development time was significantly reduced as temperature decreased from 15 to 25°C, not between 25 and 30°C. Similar to the temperature range of 15 to 30°C, the development process of larvae and pupae decreases as temperature increases. The larval and pupal lower thresholds for the development were 13 and 10. 9°C.The population rate was highest in *B. zonata* at 87 ± .48 at 25°C, which is considered the optimal temperature for growth. Based on these results, fruit fly population dynamics can be predicted, which will help make management tools.

Spatio-temporal variations of *B. zonata* were studied in the context of temperature fluctuations. According to risk indices, 59.69% of the area is highly suitable for *B. zonata* in India (Choudhary *et al*., 2021). The population growth model predicts that the optimum temperature for survival of the *B. zonata* population is in the range of 25 to 30 Results reported that the intrinsic rate and finite rate were maximum at 30℃ while at low temperatures they were in the range of 15 The population was unable to lay eggs. Hence, temperature shows prime importance in population growth (Choudhary *et al*., 2020).

As population growth is highly temperature-dependent, diets given to immature *B. zonata* also play an important role. Ben-Yosef *et al.* (2021) investigated the nutritional importance of larval diets by manipulating the diet by adding yeast at 2 to 10 percent and evaluating the heat and cold tolerance by population. A yeast-deficient diet resulted in significant adult weight loss. Yeast-rich diets showed a significant tolerance level for heat stress. There was no significant difference in adult survival based on larval diet composition. Acute cold stress (3−3°C for 2 hours) did not have a significant effect on adult survival. Nutritional heat-tolerance mechanisms regarding diets were discussed.

In the climate change scenario, temperature extremes play a major role in increasing pest populations. Ullah *et al*. (2022) reported that temperature extremes at low and high levels significantly increase larval development, pre-adult durations, APOP, TPOP, and mean longevity of *B. zonata*. The findings of the experiment showed that the stress of temperature increased larval development, reproduction rate, and life span of *B. zonata.* Life history traits that remain under the influence of temperature might be changed and become a key strategy for pest management.

Interspecific Competition

He *et al*. (2023) witnessed the phenomenon of interbreed competition in insects, notably among closely akin species, which is frequently concomitant with an encroachment process. Tephritid incursions in regional populations brought about alterations in interspecific populace contests, culminating in the eradication of local colonies. (Courtney and Kibota, 2017). The comprehension of such rivalry in Tephritidae could be conceptually elucidated by the inherent mechanisms and validate the hierarchical structure and biological assessment markers that are employed for forecasting the capacity and achievement of invasive Tephritid fruit flies (Charlery De La Masseliere *et al*., 2017).

The egg-laying inclination of both *B. correcta* and *B. dorsalis* towards various hosts displayed significant selectivity; hosts with a favorable aroma were highly favored for the growth and maturation of their offspring. Relying on a sole parameter (survival rate, pupal weight, or development period) was insufficient to assess the host adaptation of tephritids; it was discovered that there was a convergence between both species and differentiation in ecological habitats. the larval stage, there was a notable occurrence of elevated population density and intense competition. Nevertheless, *B. correcta* larvae exhibited greater resilience in such crowded conditions compared to *B. dorsalis*, elucidating their competitive prowess. The mating behavior of both species displayed dissimilarities, revealing a negative influence on each other in an uneven manner. Three species, *B. correcta*, *B. dorsalis*, and *Ceratitis capitata*, were also investigated concerning their interactions, which revealed that there is no interbreeding among them. However, oviposition competition was evident in guava at the optimal temperature, and the two *Bactrocera* species had a significant inhibitory effect on *C. capitata* (He *et al*., 2023).

In the majority of Dacines, there is a form of "scrambles" competition among larvae, leading to a certain level of pressure, causing the resulting pupae and adults to reduce in size as larval density per fruit rises. Diminutive females exhibit lower fecundity, possess a reduced number of ovarioles, and face a higher likelihood of survival challenges, especially considering Australia's suboptimal weather conditions (Inskeep, 2019). Despite multiple sympatric dacines breeding in the same fruit, there is scarce evidence of interspecific conflicts among them (Castro-Vargas *et al*., 2023). Senior larvae inflict significant damage on younger larvae within the same fruit through an unidentified mechanism; competition for resources occurs among larvae of the identical age group (Kay, 2023).

While *B. dorsalis* was limited, *B. zonata* made up to 98% of all males collected in India using GK hooks baited with methyl eugenol, according to studies (Baker *et al*., 2019). *Anastrepha striata* adults attacked and pushed away *C. capitata* adults from guava fruits, based on findings reported by Paranhos *et al*. (2021). While *A. obliqua* and *C. capitata* were found present in 94% of mango-infested fruits (Petitinga *et al*., 2021) and 6% of them, respectively.

In 60.4% of relationships, *A. obliqua* in Central America scared *C. capitata* off mangoes by attacking. The occurrence of competitive conduct was not present in 35.8% of the occurrences. *A. obliqua* appeared to be evicted from the fruits by *C. capitata* in the remaining 3.8% of observations Ghanim, 2009, *A. obliqua* prefers mango fruits as a landing spot, but *C. capitata* prefers oranges. According to interspecific competition study, *A. obliqua* is a stronger opponent than *C. capitata*. *A. obliqua's* reaction to the presence of *C. capitata* is to first circle the smaller fly before charging directly at it and driving it off the fruit, the difference in size could have a role. The fact that *A. obliqua* is three times bigger than *C. capitata* may be the cause of this competitive superiority. Similarly, the abundance of fruit flies is normally influenced by fruit. In intraspecific competition, among *B. zonata* and *C. capitata* populations, *B. zonata* was *the* predominant population due to its dominance and environmental potential (Ghanim, 2009).

Duyck *et al*. (2022) examined interspecific competition mechanisms among polyphagous fruit flies (Diptera: Tephritidae) species. In both larval and adult interfering rivalry, these species displayed an unbalanced and hierarchical interaction among themselves. During the three consecutive seasons, *B. zonata* replaced *C. capitata* at a higher rate on eight distinct host plants, including mandarin, navel, mango, Valencia oranges, balady, apricot, guava, and peach. (Abd-Elgawad, 2021). The most dominant population from March to May in different orchards was *B. zonata* as compared to the Mediterranean fly (Boulahia-Kheder, 2021b). The presence of *Bactrocera invadens* (Drew) in 350 people was associated with issues with *Ceratitis cosyra* and other closely related fruit fly species (Ali *et al*., 2014). Interspecific competition appears to be the cause of this behavior, which could account for the observation of *B. invaders* while *C. cosyra* dominated emergence from the hatched fruits of alternate host plants by as much as 87%.

For oviposition, females spend some time on host selection. The better the host, the greater the oviposition, larval development, and survival. The chemical cues released by host plants determine the tephritidae host selection range. Polyphagous insect species respond more strongly to visual messages and plant-released volatile compounds (Aluja, 2020). The feeding, fecundity, and growth habits of insects may be directly affected by plant metabolites and nitrogen content (Jaworski and Hilszczański, 2013).

The fruit fly *B. tryoni* showed preferences for oviposition in citrus fruits. Compared to the lemon and other cultivars, the grapefruit was discovered to be the most favored fruit for oviposition (Muthuthantri and Clarke, 2012). Similar findings were also demonstrated by Prakash and Kaur (2022), which determined the ovipositional preferences of *B. zonata* in various fruits such as apples, guavas, citrus, and berries.

Behavioral reactions of *B. zonata* adults in response to some olfactory stimulants:

The behavioral responses shown by insects are governed by volatile compounds released by both insects and host plants. The insect response toward attractant pheromones is elicited by the various semiochemicals of the host plant (Quilici *et al*., 2014). In many of the findings, it was suggested that peach fruit flies prefer to lay eggs in a suitable host. Their ovipositional preferences are influenced by many factors, such as the topography of the area, climatic conditions, and fruit odors, sizes, and colors (Lux *et al*., 2017). In another finding, it was reported that fruit color, size, odor, skin type, and foliage influence host insect selection preferences (Salman *et al*., 2022).

Methyl eugenol is the most effective allure for male flies of *Bactrocera* spp. and *Ceratitis* species, excluding those belonging to the subgenus *B. zeugodacus*. Some flies of the Dacine subgenus showed a response to methyl eugenol and cure lure. The effective range of methyl eugenol at very low concentrations is u to 1 km (Manrakhan 2016; Manrakhan *et al*. 2017; Manoukis *et al*. 2017 Yesmin 2019). Allelochemicals are generated through ingestion for specific functions like defense and sexual communication (de Souza *et al*., 2022).

This unique phenomenon takes place in the interaction of insects with plant materials, including phenylpropanoids and Tephritid fruit flies. For defensive purposes, the insects assimilate the plant chemicals directly or convert them into derivatives through feeding on plant tissues. Methyl eugenol proved to be effective when combined with various insecticides (like malathion, dichlorvos, or toxic baits) to detect and monitor male *B. zonata* flies in orchards (Navarro-Llopis and Vacas, 2014). (Drew (1987) and Hosseini *et al*. (2017) proposed that the fruiting host plant functions as a pheromone attracting males and a food attractant for females. Primarily, *dacine spp* react more strongly to olfactory stimuli than to visual ones.

As a result, trapping using male lures (Trimedlure and methyl eugenol) is essential for quarantine surveys and fruit fly specimen identification. Ghanim (2009) highlighted that *B. zonata* exhibited a response to methyl eugenol and combinations of Dorslaure, as well as mixtures of Trimedlure and Capilure in the field. The baited traps with malathion and methyl eugenol were used to investigate seasonal fluctuations of *B. zonata* and *B. dorsalis* Bagheri *et al*. (2017). In Pakistan, *B.*

zonata can be monitored using baited traps with methyl eugenol, male lure, and insecticides. Traps containing cotton wicks treated with methyl eugenol were effective for 9 weeks duration. (Draz, 2016).

Methyl eugenol along with plant-derived attractants is used for the management of *B. zonata* (Amin, 2017). In Pakistan, an extract from *Ocimum sanctum* leaves was found to be a powerful attraction that could attract *B. zonata* from orchards up to 0.8 kilometers away. Ghanim (2009) documented that a trap containing a glass petri dish with five drops of methyl eugenol successfully trapped a total of 49.36 male fruit flies in a sapote orchard. The trapped species included *B. dorsalis, B. correcta* and *B. zonata.* Males of *Ceratitis, Dacus*, and *Bactrocera* can be collected using synthetic bait traps also known as para pheromones.

Male adults of *B. zonata* were caught using protein hydrolyzate as bait and the attractant methyl eugenol mixed with 50% EC Malation (Agarwal *et al*., 1999; Khosravi *et al*., 2018). *B. zonata*, methyl eugenol-baited traps loaded with three pesticides (Diptrex, Laser, and Methomyl) were placed in guava plantations in Pakistan at several elevations (1, 1.5, and 2 m). Diptrex emerged as the most effective insecticide, with the traps placed at a height of one meter proving to be the most successful. Mixture of yeast brewery waste which was prepared by local protein bait was used in comparison of imported bait through McPhail traps which were significantly effective in management of *B. zonata.* Gupta and Bhatia (2000) and Stanley *et al*. (2015) conducted population monitoring of *B. zonata* and *B. dorsalis* using bottle traps placed in guava and mango orchards. The highest capture of 98.6 and 517.0 males per trap for mixed populations was observed in mango and guava orchards. Ragab and Youssef (2021) assessed three attractants: an old local attractant (prepared one year ago), a 2% solution of di-ammonium phosphate, and a fresh local attractant (comprising molasses, brewer's yeast, and water) at a concentration of 15%, for attracting *B. zonata* using McPhail traps in fig orchards located in the north-western coastal region. The capture-to-detection (CTD) ratio of *B. zonata* varied between 0.04 and 0.69, 0.02 and 1.49, and 0.02 and 0.07 flies when fresh local attractant, diammonium phosphate, and old local attractant were employed, respectively.

Anjum *et al*. (2000) evaluated the effectiveness of diffused methyl eugenol in controlling *B. zonata* and *B. dorsalis* in mango orchards. The 2 to 6 traps were hanged pheromone traps per hectare and concluded that four pheromone traps were effective control for these pests. The male annihilation method of managing *B. zonata* in orchards was tested using soaked-wood blocks as a substitute for the plastic traps now in use (Afzal *et al*. 2000). Each block was the best option for on-farm fly control in every situation, killing nearly twice as many flies and lasting nearly twice as long as a plastic trap. According to Amin (2013), the most effective method for delivering methyl eugenol was the cotton wick dispenser. Methyl eugenol was the most successful attractant among those tested, attracting the greatest number of *B. zonata*.

Hasnain *et al*. (2023) evaluated a number of substances for their capacity to draw *B. zonata* to guava orchards. Ammonium acetate, di-ammonium phosphate, ammonium sulfate, ammonium hydroxide, and ammonium chloride were the compounds that produced the following daily trapping rates: 30.52, 28.74, 25.58, 17.15, and 17.56 adults, respectively. Compared to males, females showed a stronger affinity to ammonium compounds. *B. zonata* was less attracted to buminal and egy-lure (food attractants) than to ammonium compounds.

Sidahmed *et al*. (2014) utilized wet wooden blocks loaded with methyl eugenol to create a device for *Bactrocera* spp. According to Afzal and Javed (2001), oblong plywood shapes might be the best shape and material for lethal blocks in male annihilation that target *Bactrocera* spp. fruit flies. Using McPhail traps on gradually mature fruits, Amin (2013) evaluated the effectiveness of three distinct concentrations of di-ammonium phosphate (1%, 2%, and 3%), in attracting *B. zonata* during a one-year period. There were three concentrations for which the weekly mean of captured flies was ranked: 1% (59.82 flies/trap), 2% (62.38 flies/trap), and 3% (73.82 flies/trap). The concentration of 3% turned out to be by far the most appealing.

Buminal 5% (16.27 flies/trap), eugenol (3.39 flies/trap), di-ammonium phosphate 3% (40.11 flies/trap), and buminal 10% (13.25 flies/trap) were the other attractants that produced the weekly mean of captured flies, in decreasing order. All captured flies attracted by methyl eugenol and eugenol were male, whereas the remaining attractants captured both males and females. Arya *et al*. (2022) Cue-lure and methyl eugenol were tested for their efficiency against fruit flies *B. cucurbitae* and *B. zonata* infesting *Momordica charantia*. During the twenty-third standard week, the largest population peak was 395.6 and 297.3 per trap with cue-lure and methyl eugenol, respectively, whereas during the twentieth standard week, the top population was 423.3 and 396.3, respectively. Population dynamics and maximum temperature had a substantial positive association.

Using stiner-type traps at a consistent location, the population of *Bactrocera* fruit flies was monitored with two types of lure (cue-lure and methyl eugenol). *B. zonata* showed attraction to methyl eugenol from April to July. Moreover, Hee and Tan (2006) and Mandanayake *et al*. (2023) Hemolymph has a role in transporting the attractant-derived pheromonal components from the crop to the rectal gland organ, where the chemicals are released towards twilight, as demonstrated by the discovery of these pheromonal elements in the hemolymph of male *B. dorsalis* fed methyl eugenol. In order to draw adult *B. zonata* to citrus orchards, Saafan (2005) and Darwish (2014) evaluated a number of attractants, including bactrogel 1.3%, di-ammonium phosphate 2% and 3%, and buminal 5% and 10%. For buminal 5%, buminal 10%, di-ammonium phosphate 3%, and bactrogel 1.3%, the mean catch per trap per day (CTD) in the first season (2002/2003) was 0.14, 0.08, 0.05, and 0.06 flies, respectively. Females were more attracted to all tested chemicals than males. The traps (buminal 2.5%, buminal 5%, buminal 10%, di-ammonium phosphate 2%, and di-ammonium phosphate 3%) were effective in management of male and female *B. zonata* adults (Saafan, 2005b).

Elnagar *et al*. (2010) assessed three categories of attractants: sexual, olfactory, and food. Methyl eugenol lure demonstrated the highest trapping efficacy for *B. zonata*, specifically as a male attractant. Furthermore, food attractant lures showed the highest proportion of *B. zonata* females compared to olfactory traps. evaluated eight dispenser types (saturated with a blend of methyl eugenol and the toxicant DDVP).

Host preference:

Factors affecting host plant selection involve host finding and host acceptance (Courtney and Kibota, 2017). Host finding and host acceptance are controlled by vision, mechanoreception, olfaction, and contact chemoreception (Bestea *et al*., 2021). The biochemical and physical characteristics of fruits are linked to fruit ripening (Tangpao *et al*., 2022). He *et al*. (2023) reported that the volatile chemicals of mango and guava play an important role in fruit fly host preferences. The volatiles present in mangoes, which are associated with the ripening of fruit, are also involved in attracting fruit flies. Physical damage to fruit may facilitate the puncturing of fruit flies (Grechi *et al*., 2021)

Infestation by fruit flies depends on the maturity stage of the fruit and the abundance of fruit flies (Drummond *et al*., 2019). Less than 4% fruit infestation was recorded in greenish, mature greenish, and early yellowish fruit stages. Maximum fruit invasion was recorded in ripe and overripe fruit stages, approximately 14–16% (Grechi *et al*., 2021). The peel texture of the fruit also facilitates the infestation of fruit flies. A comparative study of host preference revealed that the quality and quantity of the host affect the development of progeny. A maximum number of progeny was recorded in mangoes (Sarwar *et al*., 2013). Kumar *et al*. (2021) found significant variations in the growth, development, and net reproductive rate of fruit flies on four mango cultivars. The physical and biochemical characteristics of fruit play a role in the variation in growth and development of fruit flies.

Knowledge about host selection by fruit flies is crucial, as it helps the flies locate and assess hosts for oviposition. The flies use their sensory cues for food selection. *B. zonata* females lay eggs in delicate and tender portions of fruits by piercing through the ovipositor, and then larvae develop in the fruit. The peach fruit flies normally visit various fruits and then decide which host fruit is most preferable for oviposition (Joachim-Bravo *et al*., 2001). The female *B. zonata* locates the host distance and the source of food from a distance by using sensory receptors and odor receptors, respectively. After the host fruit selection on a morphological basis, the fruit flies land and take a taste bite to check the suitability of food for their progeny's development. The host fruit's rejection and acceptance are determined by the host fruit's appearance, size, shape, and fragrance (Murtaza *et al*., 2021)

Host utilization is not only dependent on the host fruit's nutritional content; it also depends on other factors. The hard fruit skin of unripe fruit is a limiting factor for fruit flies (Balagawi *et al*., 2005). The biological parameters of insects, such as larvae size, number of eggs, adult life, and ovipositional period length, are influenced by host fruit quality and type (de Oliveira *et al*., 2012). Fruit flies are attracted to fruits because of their lipid and protein content, which is required for egg deposition, locomotion, metabolism, flight, and sexual maturity. The water content is obtained through the environment, rain, or vapors (Koswanudin *et al*., 2018). The nervous system of insects is influenced by chemical cues that ultimately affect host selection. Fruit host susceptibility may alter its chemosensory responses. The banana and bitter gourd proved to be preferred hosts for *B zonata* and *B. cucurbitae* (Saeed *et al*., 2022)

Host fruit selection preferences depend on the landing states of fruit flies. In pre-and post-landing states, females reach the host fruit and then decide to oviposit there. When the fly encounters the host fruit, it first evaluates its suitability. The acceptance and rejection of the egg-laying site depend on the chemical and sensory responses of the host plant. The physical characteristics of the same plant change from species to species. The nutritional content, defense strategies, and physical states of host plants determine female flies' oviposition preferences (Balmès and Mouttet, 2017). In host preference, a suitable host's presence is crucial. About 40% of insects are host-specific. In the genus *Bactrocera,* various fruit flies are specific to hosts, while others are not. For oviposition, fruit flies select the vegetables by considering their progeny's performance (Salgado and Saastamoinen, 2019)

Daily Rhythms of *B. zonata*:

The activity of insects is influenced by exogenous and endogenous factors. The locomotory, flight and foraging behaviors of fruit flies are limited by the intensity of light and temperature (Gadenne *et al.*, 2016). Bayoumy and Metwally (2017) evaluated the flight activity of *B. zonata* and Mediterranean fruit flies in guava orchards on an hourly basis. The male peach fruit flies took off before the females, but Mediterranean females and males took off at the same time. An increase in temperature above 30℃ affects the flight of male rather than female flies. Temperature and male flight activities of fruit flies are inversely related, while a positive relationship between female flight activities and temperature was found. On the other hand, humidity is also negatively linked with male activity. A peach fruit fly male is attracted to sexual and olfactory attractants more than a Mediterranean fruit fly. Male catches were highest between 7:00 and 10:00 a.m., while female captures were highest between 11:00 and 5:00 p.m., reported that males fly actively in the morning while females fly actively in the evening in search of food and oviposition. This suggests that *B. zonata* and Mediterranean fruit flies are diurnal as well. Spray treatments for both species should thus be delivered between 7:00 a.m. and 10:00 a.m. for males and 11:00 a.m. and 5:00 p.m. for females.

Levi-Zada *et al.* (2020) have established behavioral impacts, or *B. zonata* antennae sensitivity, to pesticides. Through Solid microextraction and Gas chromatography, Mass Spectrometry analyses were performed to uncover volatiles unique to each sex of *B. zonata* that are released in a daily periodicity. The volatiles identified through chemical synthesis and GC-MS were pyrazines and ethyl esters. It was revealed that each volatile increase or decrease in number was specific to sex. Another technique that reveals the variation in the sensitivity of male and female antennas to certain volatiles is Electroantennographic (EAG) dose response.

Bertolini *et al.* (2018) used Oxitec's self-limiting olive fly technology (OX3097D-Bol) to study the olive fly circadian clock based on evolutionary, genetic, anatomical, and behavioral responses which revealed that the circadian clock of olive fruit fly and *Drosophila melanogaster* are same. Changes in physiological conditions affect the expression of chemosensory receptors in *Bactrocera dorsalis*, which adapt to different states such as feeding, mating, and time of day. The study suggests that these receptors play a significant role in physiological processes related to insect reproduction and survival Jin *et al*. (2017).

Management of *B. zonata*:

B. zonata is a destructive pest and difficult to control due to its ecological, and morphological behaviour. Management of fruit flies is difficult. Several control tactics are used, including wrapping, covering, and spraying artificial pesticides (Stejskal *et al*., 2021). For immediate control, farmers use insecticides such as diptrex, triazophos, and imidacloprid (Dias *et al.*, 2018). The excessive use of pesticides has led to many issues that scientists believe in biological control measures. Paranhos *et al.*, (2019) reported that the excessive use of artificial termiticides resulted in resistance within four decades. The best practice to control any pest is IPM, which can replace other practices as well as agrochemicals (Deguine *et al.*, 2021). Entomopathogens, predators, parasitoids, and bait traps of botanicals are used worldwide for biological control.

Physical control:

Sharma and Sanikommu, (2017) reported that bagging fruits and post-harvest quarantine treatments are the physical control methods. Fruit bagging keeps the fruit free from fruit fly attacks and physical injury. This is undertaken just before the fruits reach the maturity stage when they are vulnerable to infection (Sarwar *et al.*, 2013). According to Amin *et al.* (2008), double-layer brown-colored bags are eco-friendly tools for managing fruit flies. The practice of fruit bagging should be adopted 40-55 days before the fruit setting.

Cultural control:

Cultural control practices include the implementation of tolerant variety, field sanitation practices, and eradication of infested fruits from the ground (Dias *et al.*, 2018). Manoukis *et al.* (2019) reported that cultural practices help to minimize *B. zonata*. *B. zonata* infests the mango peel and the larvae feed on the mango pulp due to which the mango quality is destroyed. Infested fruits must be buried 50 cm below the soil surface to minimize the infestation of *B. zonata*. Larvae of *B. zonata* can be destroyed by placing the infested fruits under the sun for 10 days (Manoukis *et al.*, 2019).

Biological control:

In comparison to pesticides, biological management is more affordable and less harmful to both people and the environment (Paranhos *et al*., 2019). There are several methods of introducing biocontrol agents into pest control programs, including vaccination, inundation, traditional biological control, and conservation biological control. According to Dias *et al.* (2018) parasitoids, predators, natural enemies, and pathogens are frequently used in biological management, because they attack pests by eating them, parasitizing them, and spreading illnesses.

Natural insect enemies:

One method for reducing pest populations to tolerable proportions in conventional biological control programs is the deployment of exotic parasitoids and predators from the insect's native location (Adly, 2016). Parasitoids include *Psyttalia* sp., *Tetrastichus giffardianus*, and *Aganaspis* sp. Reported parasites include *Dirhinus giffardii*, a pupal parasitoid of *B. zonata* (Mahmoud *et al.*, 2019). The initial revival occurred approximately a month after the release date of the exotic parasitoid species. *Aganaspis daci* against *B. zonata*, as the incidence of parasitism reached 9.7%.

Ants interrupted them during oviposition and preyed upon mature *Drosophila melanogaster*, which was the main reason for the decline in fruit fly devastation (Mariano *et al.*, 2019). The families Staphylinidae, Carabidae, Dermaptera, Chrysopidae, Formicidae, Coreidae, Coccinellidae, and Pentatomidae contain most fruit fly predators (Paranhos *et al.*, 2019). Predatory mites, which also include insects, were evaluated when eaten on the eggs of *B. zonata*, including *Amblyseius largoensis, Neoseiulus barkeri, Cydnosus negev, Typhlodromips swirskii*, and *Proprioseiopsis kadii* (Momen *et al.*, 2016)

Entomopathogens:

Natural microbes called insect pathogens can be found in a variety of situations. At different stages of the insect host life cycle, these pathogens can cause sickness. It has been demonstrated that pathogens like nematodes, bacteria, and fungi are viable biological control methods for *B. zonata* (Shaurub, 2023)

Entomopathogenic nematodes cause their victims to die by introducing germs into the body (Aryal *et al*., 2022). Some tephritid organisms have been observed to be severely affected by *Heterorhabditis* and *Steinernema* species. According to (Mahmood *et al.*, 2016), EPNs can infect *B. zonata* at various developmental stages. Nematodes can access dropping guava fruit larvae through the area where the soil surface and interface region meet.

They infect both pest adults and newly produced pupae in the soil as pest adults emerge from their pupae. The newly discovered specimen, *Heterorhabditis marelatus*, demonstrated remarkable effectiveness against adults emerging from the pupal case of *B. zonata*, killing a significant portion of adults within 45 days after birth (Saleh *et al*., 2019). Entomopathogenic nematodes have been used as biocontrol agents for many years. This may be improved by the isolation and selective breeding of more populations and species (Perry *et al*., 2012). Parasites known as entomopathogenic fungi can prevent oviposition, decrease ovulation and reproduction of adult insect pests, and kill or paralyze them (Wei *et al*., 2023).

According to (Valero-Jiménez *et al*., 2016), the mode of action of EPF is initiated by the attachment of the spores and conidia to the host's cuticle layer, where they begin to germinate, grow, and eventually form a colony. *Metarhizium anisopliae* and *Baeuveria bassiana* are well-known EPF fungi (Ascomycota: Hypocreales) because of their distinctive traits and behaviors. They have several negative consequences on insects, such as impairment of molting, abrasion resistance, impairment of maturation, inhibition of oviposition, and significant mortality. Entomopathogenic fungi are among the most appealing biological control agents owing to these characteristics.

Biopesticides:

Biopesticides are eco-friendly and species-specific. Synthetic insecticides contain some chemicals which are harmful to non-target organisms. Biopesticides are not resistant to pests. Ugwu *et al*, (2021) experimented with the efficacy of three ethanol extracts of *Aframomum melegueta*, *Piper guineense*, *and Zingiber officinale* with a comparison of commercial botanical pesticides of AzaSol (6% azadirachtin) for the control of *B. dorsalis*. Pupation of *B. dorsalis* was targeted to evaluate the efficacy of ethanol extracts in the soil of tree canopies. *P. guineense* and *A. melegueta* showed maximum control in comparison to AzaSol.

Chemical Control:

The most popular technique of control is chemical, and various pesticide formulations have shown success against different species of fruit flies (Vargas *et al*., 2015; Dias *et al*., 2018; Boulahia-Kheder, 2021; Maktura *et al*., 2021;). This strategy is still employed alone or in conjunction with other control agents to combat a variety of fruit fly species, despite the negative environmental effects of pesticide application. Dipterex, Malathion, Endrin, Dialordin, Diazinon, and Dimecron were used in Pakistan as a cover spray on mango orchards to prevent *B. zonata* growth.

Various pesticides target distinct fruit fly growth stages (Maula *et al.*, 2022). While diazinon attacks emerging adults and popping larvae, malathion targets the adults. The lethal concentration of diazinon in males was 9.73 ppm while in females it was 14.12 ppm. According to (El-Gendy *et al.*, 2021) diazinon was the most hazardous substance to *B. zonata* at 24 hours following treatment, followed by methoxy fenozide, and lufenuron, malathion. To suppress the population of fruit flies, diazinon has been widely applied as a soil drench. The practical implementation of chemicals has had many negative effects, including excessive insecticide residue in the environment. (Mahmood *et al.*, 2016).

Li *et al*. (2021) evaluated the sub-lethal concentration of insecticides on the growth and development of *B. dorsalis.* Six insecticides were assessed against the progeny of *B. dorsalis* by using age stage, and two sex life tables. Insecticides negatively affect growth and development. The maximum reduction was observed in chlorpyrifos.

Conflicts of interest

There is no conflict of interest related to this article.

Author's contribution

All authors have contributed equally

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