ISSN: 2996-962X

Research Article

Archives of Biology & Life Sciences

Gut Microbiota and Its Ecological Interactions In Bactrocera Zonata and Its Impact on Food Security & Agricultural Pest Management: A Comprehensive Review

Muhammad Umar javed[1*], Abrar Hussain[1], Shahzad Saleem[1], Tayyaba Asghar[1], Sammer Shahzadi[1] and Aqsa Bibi[2]

[1] *Faculty of Health Science, Department of Bioscience, COMSATS University Islamabad, Pakistan*

[2] *Centre for Advanced Studies in Pure and Applied Mathematics, Bahauddin Zakariya University, Multan, Pakistan*

[*] Corresponding Author
Muhammad Umar javed, Faculty of Health Science, Department of Bioscience, COMSATS University Islamabad, Pakistan.

Submitted: 2025, Jan 09; **Accepted:** 2025, Feb 07; **Published:** 2025, Feb 10

Citation: Javed, M. U., Hussain, A., Saleem, S., Asghar, T., Shahzadi, S., et al. (2025). Gut Microbiota And Its Ecological Interactions In Bactrocera Zonata And Its Impact On Food Security & Agricultural Pest Management: A Comprehensive Review. *Archives Biol Life Sci, 2*(1), 01-22.

Abstract

Bactrocera zonata or peach fruit fly, is a quarantined pest and is a major threat to horticultural crops especially in Pakistan and South Asian region. Influence of gut microbiota in determining the biological and behavioral features of B. zonata concerning digestion, immunity, mating, and foraging. Bacterial species which are Enterobacter, Lactobacillus, and Acetobacter are involved in the various aspects of nutritional acquisition, immunology, and fertility through producing volatile metabolites that impacts on sexual activity. It also plays a part in the ecological adaptations of gut microbiota; they put forward new approaches to integrated pest management (IPM). This Integrated pest management deals with microbiome change, pheromones disruption and the use of microbiome boosted baits, which supports the environmental objectives of agriculture. Digital surveillance and monitoring systems can be used to enhance the real-time adoption. IPM strategies such as microbiota manipulation and pheromone intervention present ecological innovative pest control solutions to chemical insecticides. These methods involve using protein based chemicals, microorganisms and mechanical attractants such as methyl eugenol and protein hydrolysate lures. Modern technologies provide higher accuracy and efficacy of these methods: digital video surveillance, and the use of automated equipment in monitoring contribute to suppression of B. zonata. This review predisposes indications of microbiome-targeted approaches towards changing the 'paradigm of pest control' in the context of IPM, reducing pesticide reliance, perusing conservation of beneficial insects and indeed nurturing sustainable agriculture. This biological control aims for field testing, gut microbiota manipulation, and targeted microbial management for location dependent pest management solutions for optimization of pest control and to tackle current and emerging issues in agriculture.

Keywords: Gut Microbiota, Microbial Symbiosis, Bactrocera Zonata, Traps Methyl Eugenol & Protein Hydrolysate Baits, Male Annihilation Technique (MAT), KEGG-Toll and IMD Pathways

1. Introduction

Agriculture represents 32% of Pakistan's Gross Domestic Product, while it employs over 50 percent of the labor force and about 70% of its population indirectly [1]. Fruit production falls within this sector, with an annual 8.71 million tons from 843,900 hectares of cultivated land in Pakistan [2]. However, these fruits are rendered commercially when attacked by pests and insects, such as *Bactrocera zonata* fruit flies. This pest is typically found in tropical and subtropical regions, has an increased host range, generally several host crops in one area or local region, and causes massive and significant losses to horticultural crops. Recent studies have reported the roles of gut microbiota in mediating insect physiological functions and behavior. As far as *Bactrocera zonata* is concerned, the midgut of this specific type of fly contains *Enterobacter*, *Lactobacillus*, and *Acetobacter* gut-associated bacteria that are essential for digestion process, feeding ability, immune system, mating, and foraging behavior.

Some of these bacteria also help in reproductive success by developing volatile compounds, which influence the attractiveness of the mating between them due to the volatile compounds synthesized by these bacteria (Liu *et al*. 2022) Although some forms of bacteria, *Lactococcus lactis* and *Providencia*, can chemically alter mating signals, pheromone mating attraction, which is also an integrating pest management strategy through microbiome association. *Drosophila* also depends on gut bacteria to help speed up immune priming, making it more resistant to pathogen attack [3]. By modification, *Bactrocera zonata* immune defenses can manipulate the gut microbiome and make the organism more vulnerable to biological control methods [4]. *B. zonata* is causing around 90% yield losses in certain regions of Pakistan causing hardship to the local farming as well as economic losses to the country [5].

However, it is possible to manage these insects using chemical insecticides rather than conventional methods for pest control because of safety concerns regarding environmental protection and human health [6]. The focus is on the use of friendly pest management control strategies, such as Integrated Pest Management with biological pest control, and the use of ecologically friendly practices for the control of these challenges. Contribution of gut symbiotic microbiota to insect behavior. Pest control is one of the most interesting areas for further investigation. Research has found that the mid-section of a fruit fly's gut contains bacterial communities that disrupt nutrition, reproduction, mating, foraging, and attraction [7]. However, the gut microbiome provides alternatives to chemical-free, sustainable pest control [8]. These obligate inhabitants in the fruit flies' digestive tracts help with digestion of their food and emit chemical compounds, the 'olfactory,' that influence the fruit flies population by attracting adult fruit flies to oviposition and feeding sites.

This symbiotic association *Bactrocera zonata* and their effects on mating, foraging, and attractive behaviors to assist gut microbiology and immunology, while becoming a means for solving *Bactrocera zonata* infestation problems in agriculture. Therefore the research goal is to evaluate the effects of gut microbiota on *Bactrocera zonata* with emphasis on the effects on its physiological processes, behavior and possible application in the ecological management of the pest. The remaining vital nutrition, feeding, mate selection/ recognition, and foraging bacterial strains are *Enterobacter*, *Lactobacillus*, *Acetobacter*. These microbes also synthesize volatile metabolites that improve reproductive fitness by increasing mate choice and determining oviposition and feeding site preferences. Further, certain bacteria disrupt the chemical nature of mating signals e.g. *Lactococcus lactis* and *Providencia*, which in turn affect pheromone-released behaviors and pest control. Alteration of the stomach flora influences nutrition, reproduction, and immune responses; these discoveries are significant for looking at biological control and intelligent pest management. *B. zonata* can affect yield losses of up to 90% in areas such as Pakistan; therefore, pest management combinations that focus on the alteration of the pest's gut microbiota are one approach to pest control that does not rely on chemical reinforcements, and which can help consider economic agricultural problems.

1.1. Understanding Life Stages Of Drosophila Melanogaster

The life cycles of *Drosophila melanogaster and Bactrocera zonata* consist of four key stages: eggs, larvae, pupae, and adults. To describe each stage of species, as they have similar developmental processes. The life cycle stages of *Bactrocera zonata*, fruit flies, and *Drosophila melanogaster* are divided according to their proper duration. It starts with transparent and white shiny eggs that are about 1.3 mm by 1.3 mm: these have one end is pointed, the other is not pointed. The action began with laying shiny and white-colored eggs that stretched for 1.3 mm in length, tapered at one end, and rounded at the other end. [9].

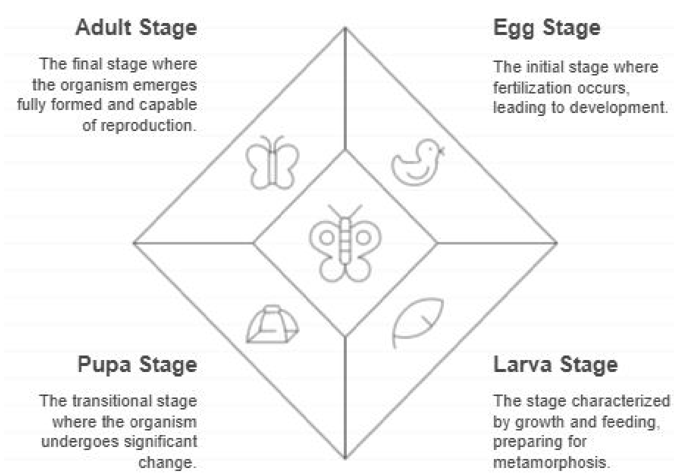

Figure 1: Development Stages of Fruit fly Drosophila Melanogaster

These eggs are small, round in shape, laid on the flowers or the tender fruits or in the angular pit, set vertically or slightly inclined, and may just touch each other. Fostering these eggs requires time about a period of 24 to 36 hours and it's an average of 1.25 days. These are ready for the larvae to hatch in this short period. It involves one period of suspension, known as the preoviposition phase, and lasts for 12–15 days which averagely 13.5 days [10]. The second is the oviposition phase, which is an average of 18 days and may be as long as 12 to 24 days. These durations were mainly detected in ridge form evidence of the versatile nature of the species with respect to climatic conditions . The larva hatches and ultimately infests the fruit pulp less as it increases from the first instar stage to the third instar stage. First-instar maggots are elongated and white in color and transform into the second instar at 15 and 24 h of larval development, respectively This second instar appears to be larger, creamish, and distinctively ellipsoidal shaped, with a development time of approximately 1.5 days. Maggots are fragile, slim, colorless, and usually turn at least once in the span of 15-24 hours. Additionally, the second instar is pale and bigger in size, creamy white in color, has a well-defined round, ellipsoidal body, and takes about 1.5 days of development [11]. In the third and last stages, the proleg sprouts out in sprawling form and the pointed mandibular hooks and spiracles [12]. Maggot development lasts 4.1 to 6.5 days on average at 25 ° C, but in among its may be 5.18 days total according to environmental condition [13].

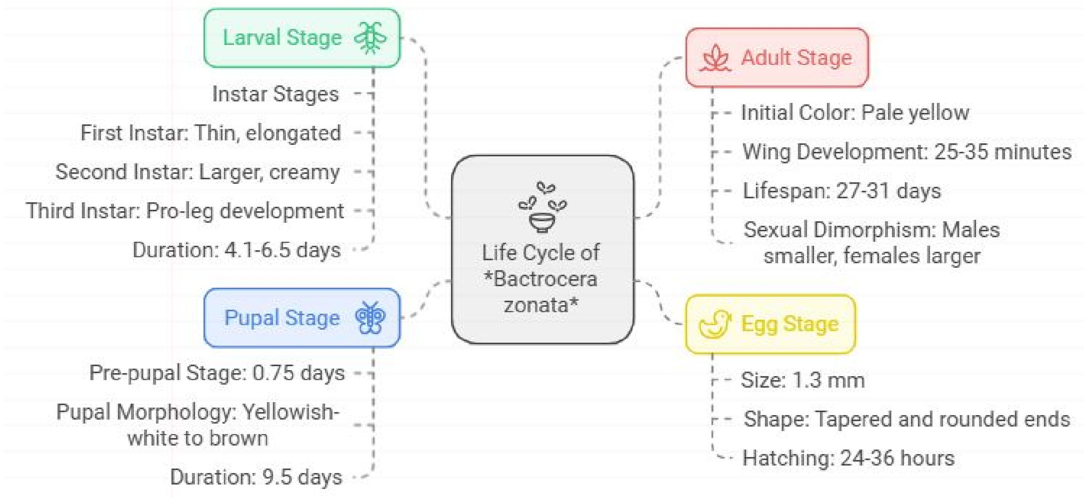

Figure 2: Life Cycle & Stages of *Bactrocera Zonata*

There is a pre-pupal stage that prepares for transformation, which lasts about 0.75 day and the maggots now burrow in the soil hoping to pupate. Actually, the pupal stage establishes a completely different morphology. Initially, it is yellowish white, becoming darker to brownish, while it progresses to reveal its distinct eleven (11) segmented barrel form. The pupa does not move until matures within an estimated 9.5 days in the soil at 2–6 cm deep, or up to 15 cm deep [14]. Once they have gone through the pupal stage, adult flies look pale yellow, not at all active, and then wings will unfold completely and turn brown with lemon yellow coloring for about 25 to 35 minutes. In the adult the male is smaller than the female, and the female's abdomen is elongate and pointed. The rate of change may vary greatly between them per few days in some instances per few weeks in others depending on the prevailing climate and feeding periods. Most significantly, all these stages are timed and synchronized in an exact manner and each one of them reflects the complication and flexibility of this species' life cycle, the possibilities for its survival and the 'clock mechanisms' vital for its survival and existence [11]. The development of Bactrocera zonata is highly precise and clear in all of their morphological and behavioral changes at the adult stage which was beautifully well managed. Newly enclosed pupae, are dorsoventrally compressed with the wings pressed against the pilose sternum, un-pigmented and yellow; they require 25–35 min to acquire functional wings. Within 2-3 hours after pupation, they assume their general reddish brown color and lemon yellow curved stripes across the thorax and fuscous along the wing margin. Females are slightly smaller than males; females are more prominent with longitudinally narrowed abdomens and sharp, pointed ovipositors absent in males [15].

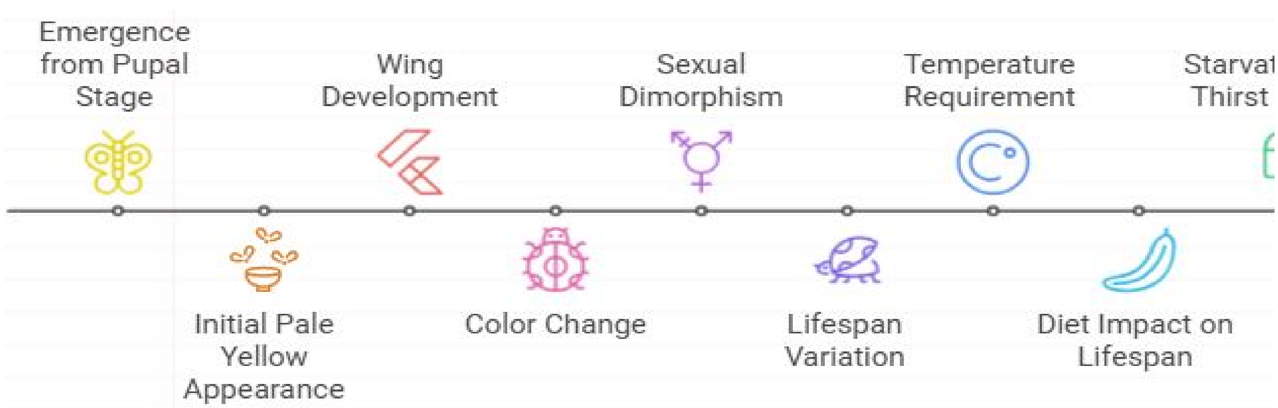

Figure 3: Characteristics of *Bactrocera Zonata and* Developmental Changes in Fruit Flies

No (3) states that the measurements further reflect these differences: males with expanded wings have body length of 8.5–9.0 mm and wingspans of 11–12 mm, while females have body length of 9.0–10.0 mm and wingspan of 15.75–16.50 mm [16]. Adults require a stabilized temperature of 27 °C for an average of 27-31 days to get on pumpkin, squash gourd, bitter gourd, guava, and mango gardens. On average, it may last for several weeks; however, it can be prolonged considerably and the maximum life-span in males and females can reach 249 and 133.5 days, respectively, under favorable conditions only [17]. For instance, females in a laboratory environment survived up to 123 days when fed on the fruit while being kept in a box incubator at 24°C, with atmospheric specific humidity and light at room controlled temperature. [18]. On the other hand adults die of starvation in 1-2 days after emergence while this period is prolonged by 2-4 days assuming that water and diet are available. Adults can live 12 to 15 days on the diet, whereas the duration of adult lifespan on the diet ranges from 13 to 52 days, depending on the habitat conditions and biotic and abiotic factors.

1.2. Gut Microbiota Association With Host Microbe Intercation And Response In *Drosophila Malanogster*

Microbiota plays a significant role in food intake, reproduction, development, behavior, and immunity of fruit flies *Bactrocera zonata* and these microbes, specifically bacteria, are present in the gut of fruit flies and have mutual association with their host. They have significant implications for the biology of fruit flies, control of other pests, including fruit flies, and even horticultural crop production.

Figure 4: Factors Influencing Fruit Fly Behavior and Reproduction

Fruit flies feed on compounds related to nutrition and digestion. These gut microbes in fruit flies help decompose fruit pulpa and fruit skin [19]. Specifically, *Lactobacillus* and *Acetobacter* help digest the sugar and carbohydrates in the fruit into other simpler nutrients. After degradation, these nutrients are absorbed by fruit flies. The gut microbiota synthesizes vitamin B, which is needed for healthy fly development, reproduction, and sustenance under warm conditions. In particular, the fruit fly gut microbiota can significantly influence behavior, especially mating, foraging and host attraction [19]. Furthermore, some species of bacteria such as *Lactococcus lactis* & *Providence* tend to increase the probability of mating. The volatile compounds produced by these bacteria influence the chemicophysical processes and chemical stimuli (pheromones) of sexual attraction and copulation. The direct effect of these bacterial associations helps fruit fly reproduction and mating processes. One of the investigations states that gut bacteria are capable of regulating immune emitting signaling systems, including the KEGG-Toll and IMD-system, produced by the antimicrobial peptides (AMP) in fruit flies, which have paramount importance in the fight against fungal and bacterial infections [20].

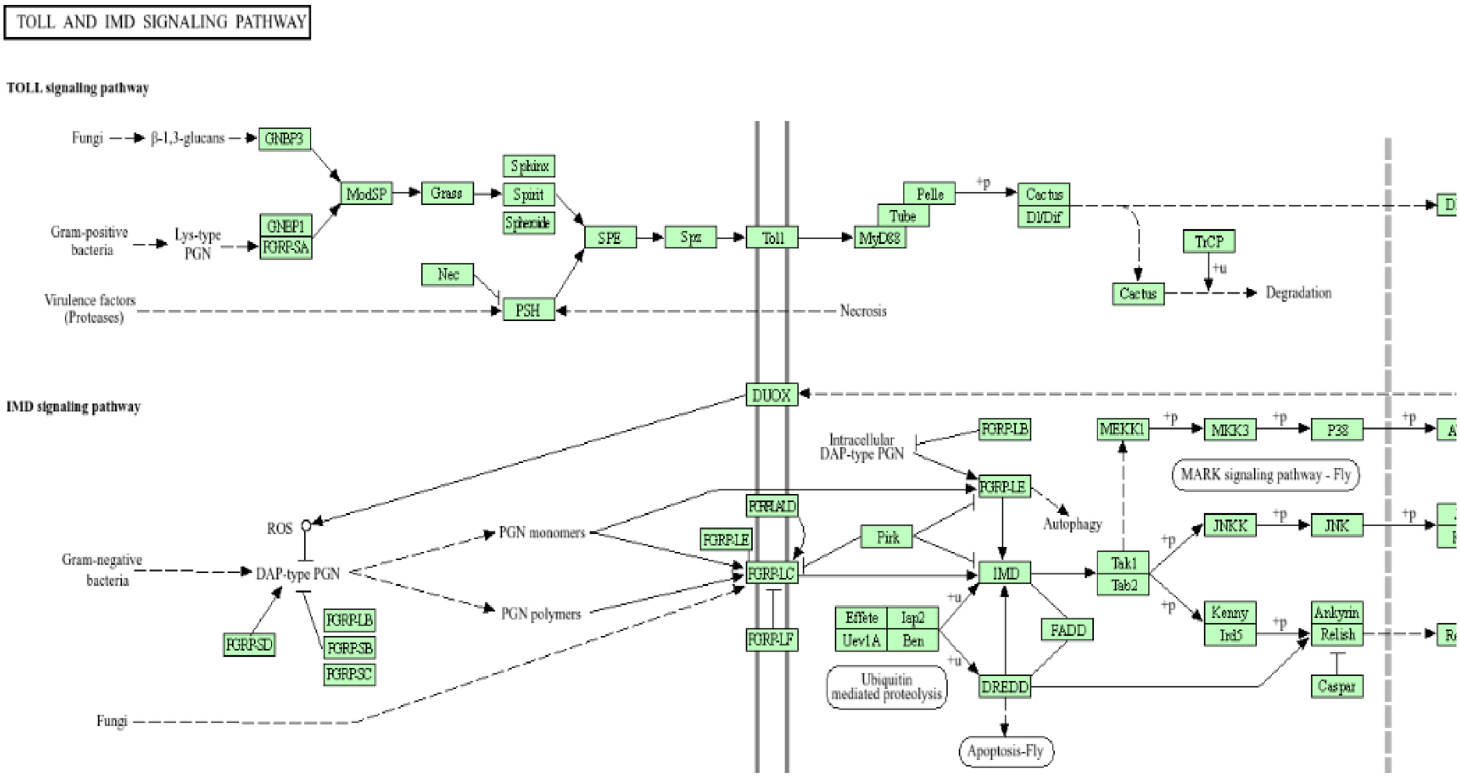

Figure 5: Antimicrobial Peptide (AMP) of Drosophila Melanogaster Produces The KEGG Toll & IMD System

Fig no (5) By understanding these immune responses governed by microbiome, researcher said they could tackle biological control approach that manipulates the microbiota to weaken the fly's immune system in order to lower the barrier to control. One example of gut bacteria altering immune pathways, such as the Toll and IMD pathways for fighting against fungal and bacterial infections in *Drosophila melanogaster*. Researcher's use of the knowledge of these microbiome-mediated immune responses to explore biological control methods by reducing an attacking fly's immune defenses by positing that by manipulating its microbiota, the fly will become more susceptible to biological control agents. The impact of the gut microbiota on the intestinal gut-immune system may also modulate patterns of Drosophila reproductive fitness and the relative costs of mate recognition. Gut bacteria of the genus Rhodobacter can directly influence the KEGG-Toll and IMD pathways, which are important for immunity against bacterial and fungal infections [21]. By understanding and improving the immune system and microbiome-mediated immune responses, scientists can use biological control management strategies. Additionally, gut micro bacteria can modulate immune pathways such as the Toll and IMD pathways, which are essential to fight off bacterial and fungal infections in. Understanding these microbiome-mediated immune responses also allows the exploration of biological control mechanisms, such as manipulating the microbiota to weaken a fly's immune defenses and enhancing susceptibility to biological control agents.

Reference	Years	Key findings	Methodology
Attributes such as mating behavior, foraging behavior, and immune response behavior are among the attributes that the control by gut microbiota affects the reproductive capacity and population density of fruit flies. For this reason, changes that occur in the dynamics of microbes influence the fitness of the larvae, reproductive capability of the adults, and rate of growth of population density (John G. *et al*. 2021; McMullen. II, *et al*. 2020). For instance, some bacteria are involved in the dietary conversion of substrates into volatile 'inviting' molecules and attract and stimulate the reproductive activities. However, according to a previous study on *Drosophila melanogaster*, gut microbes gazetted Toll and IMD immune responses that handle bacterial and fungal infections (R, Schlötterer *et al*. 2021). For instance, bacterial symbiotic associations with fruit flies are also involved in the dietary conversion of substrates into volatile compounds that increase host attraction and reproductive activity. The mating, foraging, and immune condition of the fruit fly is influenced by the effects of the gut microbiota, which in return affects the reproductive output of the fruit fly and the population density. This affects the survival of the larvae, reproduction among the adults, fertility variation, and consequently the fly population (John G. *et al*. 2021; Bueno.E, *et al*. 2020). The fermentation of dietary substrates by bacteria is coupled with the production of volatile compounds that enhance host attraction and reproductive behavior. Consequently, eggs are laid more often on appropriate substrates suitable for the populations and their reproduction. New avenues to address pest problems potentially open up between the fruit fly gut microbiota and the behavior of the fruit fly. Modifications in the microbiota, or introduction of microbial antagonists' interruptions, can be made to basic physiological processes, such as reproduction and protection (Robert. K, *et al*. 2019). Through this essential goals of life, pest management through microbiome is achieved. Because the gut microbiota of *Bactrocera zonata* has been shown to negatively influence mating success and foraging behaviors, their control by interfering with the gut microbiota in a way that takes advantage of this negative effect on mating success while minimizing the use of chemical pesticides, and promoting sustainable agriculture should be considered. The survival and ecological adaptation of *Bactrocera zonata* requires an essential role of gut microbiota association that helps fruit flies survive in warm and cold environmental conditions (Broderick. N.A, *et al*. 2010). The obligatory mutualistic bacteria are central to processes ranging from feeding and immunity to mate selection and offer new avenues for biological pest management. These interactions between the fruit fly and its microbiota are leading to new and innovative tactics in the BCH platform that are bio-safe and eco-friendly (Naaz.H *et al*. , 2020). ference			
Antimicrobial Resistance and Recent Alternatives to Antibiotics for the Control of Bacterial Pathogens with an Emphasis on Foodborne Pathogens	(Deng et al. 2021; Hanan et al. 2023).	For digestion, *Enterobacter*, for immunity *Lactobacillus*, for reproduction *Acetobacter* are found to be important gut microbiota in *Bactrocera zonata*.	Molecular methods including metagenomic sequencing and culturing methods are employed to quantify and characterize the gut bacteria in *Bactrocera zonata*. These techniques made it possible to separate gut-associated bacteria.

Functions of Gut Microbiota Metabolites, Current Status and Future Perspectives	(Liu et al. 2022).	Some gut microbiota improve reproductive output through transforming molecules that act on sexual behaviors	To investigate microbial composition, Scientist used 16S rRNA gene sequencing; for microbiota-derived metabolites, they used metabolomics; and they used behavioral tests to measure reproductive and sexual behaviors. Microbiota-positive and negative models animals were compared to decipher individual microbial contributions. Molecular biology techniques as well as quantified enzyme activity mapped the remaining pathways of metabolite transformation.
Combining experimental evolution with next-generation sequencing: a powerful tool to study adaptation from standing genetic variation	(Schlötterer et al. 2021; Takahiro et al. 2007).	Microbial entries influencing the immune pathways like KEGG-Toll and Interrupting Defense like System (IMD) were seen to protect the fruit flies *Bactrocera zonata* and *Drosophila melanogaster* from bacterial and fungal infections.	Scientist used traditional Darwin's process of natural selection with biochemical technology of next-generation sequencing for analyzing adaptation based on standing genetic variation. They examined how microbes impact immune systems through Toll and IMD pathways through genomics from sequences and their immune response assay. These method showed that microbial entries safeguard of fruit flies Drosophila melanogaster from bacterial and fungal diseases.
The Microbiota-Gut-Brain Axis	(John et al. 2021; McMullen et al. 2020).	Alteration of gut microbiota was suggested as an effective and eco-friendly pest management, as it lowers the immune response and fertility.	Scientist investigated the microbiota–gut–brain axis and considered the disruption of gut microbiota as an environmental friendly approach toward pest control. Using real-world samples and model organisms, they applied microbiome profiling via 16S rRNA gene sequencing; they also manipulated gut microbial ecosystems and assessed effects on immunity and reproduction. Pest susceptibility and reproductive changes were studied using behavioral and physiological bioassays.
Selecting aggressiveness to improve biological control agents efficiency	(Royer. P.F et al. 2024; Vargas et al. 2015).	Pest management with bacterial bio-control and protein baits along with pheromones proved its potential for effective population management reducing chemical pesticides use.	Scientist examined the effectiveness of bacterial bio control agents products for biological control pest with special emphasis on protein baits and pest pheromones. This called for field trials in population suppression, laboratory assays in the determination of the aggressiveness of biocontrol agents, and behavioral assays in pheromone attraction. Regarding the approach of crop rotation and integrating the culture of the BT cotton plant, this was shown to possess good prospects in eliminating the use of chemical pesticides.

Application of response surface Methodology coupled with Artificial Neural network and genetic algorithm to model and optimize symbiotic interactions between *Chlorella vulgaris* and *Stutzerimonas stutzeri* strain J3BG for chlorophyll accumulation	(Salma et al. 2022; International Journal of Entomology, 2023).	Guava and mango fruits were established as the preferred hosts of *Bactrocera zonata* with guava giving the highest pupal recovery. Most population found in them	They implemented response surface method together with ANNs (artificial neural networks) and genetic algorithms to maximize the relationships' symbiosis. They also established that *Bactrocera zonata* mostly breeds on guava and mango, with the highest number of pupae recovered from guava. Population trends and sex/age preferences were assessed using fruit- infestation trials and the number of pupae recovered.
Olfactory receptors in neural regeneration in the central nervous system	(Royer. P.F et al. 2024; Lillo et al. 2023).	As can be seen for both methyl eugenol and cue lures, innovative trapping techniques are found to increase the effectiveness of fruit fly capture.	Scientist focused on olfactory receptors matter about neural regeneration in the central nervous system. The methodology used by authors which stated thatd examining how methyl eugenol and cue lures, which are modern methods of trapping, improve capturing of fruit flies.
Automatic Detection and Monitoring of Insect Pests—A Review	(Lima et al. 2020;	Instant control by using video surveillance and sensor equipped traps are presented as pest populations monitoring tools that provide possibilities of timely correctives.	Scientist used the methods of automatic identification and continuous control of insect pests pointing to video capture and sensor-based luring traps. Their strategy only involved population monitoring devices for pest's control which ensure that corrective actions are taken immediately. The study brought out how these modern technologies offer sustainable and preventive pest control since pest invasion can be foreseen and checked.
Farm field assessments of fruit flies (Diptera: Tephritidae) in Pakistan: distribution, damage and control	(Stonehouse et al. 2019; Jose et al. 2013).	High population of *B. zonata* in mangoes resulted in yield loss of up to 40% reduced yield and post-harvest losses due to poor refrigeration.	They conducted farm field assessments in Pakistan to evaluate the distribution, damage, and control of fruit flies (Diptera: Tephritidae). They used population and yield data and data on the incidence of *Bactrocera zonata* on mangoes and found up to 40% reduced yield and high post-harvest losses due to poor cool storage. Field trials were also used also to validate the management techniques which were to be used in practice.
Organic management promotes natural pest control through enhanced plant resistance to insects	(Robert et al. 2019).	Hypothesis for affected climate models suggest that habitat suitable for *B. zonata* could expand by 15–20% by the year 2050, something that calls for increased pest control interventions.	Scientist investigated organizational management as a factor in increasing biological control through plant resistance to pests. Information from climate models was used to predict an increase in favorable locations of about 15–20% by mid-century for *Bactrocera zonata*. Climate modeling for their habitat-suitability assessment, as well as field survey to assess implementation of pest control measures.

Health outcomes of 100% orange juice and orange flavored beverage: A comparative analysis of gut microbiota and metabolomics in rats	(John et al. 2020).	It is established that gut microbiota synthesised vitamin B which enhanced reproductive fitness as well as survival under fluctuating environments.	Scientist investigated the effect of 100% orange juice and orange flavored non-juice beverages using gut microbiota and metabolomics in experimental model. For their study, they used 16S rRNA sequencing to characterize gut microbiota, and metabolomic assays to determine vitamin B synthesis capabilities. The experiment proved that the vitamin B obtained from microbiota improved fecundity and overall survivability in changing climate.
The micro-eukaryotic community: An underrated component of the mammalian gut microbiota	(Vargas et al. 2015).	Microbial symbiosis works in extending the concept of environment interference as pheromone through microbiota manipulation affect the rate of successful mating.	Microbial symbiosis works in extending the concept of environment interference as pheromone through microbiota manipulation affect the rate of successful mating.
Efficacy of lure mixtures in baited traps to attract different fruit fly species in guava and vegetable fields	(Ahmad et al. 2023).	Protein-based baits along with ammonium acetate were able to capture female flies bringing down the overall population as well.	Scientist assessed the effectiveness of lure mixtures in baits used in traps to capture varied fruit fly species in guava and vegetable plantations. Their technique included employment of proteinaceous lures, accompanied with ammonium acetate in cage trapping for collection of female fruit flies. The results showed a significant reduction in the overall fly population, demonstrating the effectiveness of these lure mixtures in pest control.
Studies on Biology and Management of Melon fruit fly, Bactrocera cucurbitae (Coquillett) on Cucumber	(Koul & Bhagat et al. 2004).	Interactions of *Bactrocera zonata* with soil depth and environmental conditions affects the pre-pupal phase very much highlighting species flexibility.	Scientist investigated the biology and control of Bactrocera *cucurbitae* on cucumber with reference to the physical environment. To this end, their method included determining how the selected factors such as soil depth and environmental conditions influenced the pre-pupal stage of Bactrocera zonata. Environmental parameters were also shown to affect the species' plasticity and thus the high propensity of the fruit fly to alter its conditions.
Meta-analysis of Diets Used in *Drosophila Microbiome* Research and Introduction of the Drosophila Dietary Composition Calculator (DDCC	(Broderick et al. 2019).	This study shows that gut microbiota *Bactrocera zonata* adapts the microbiota for survival in various climates to increase the pest's resistance and dissemination.	Scientist performed a meta-analysis of the diets employed in *Drosophila microbiome* studies and presented the Drosophila Dietary Composition Calculator. The technique used was diet intervention and microbiota characterization to analyze the change in microbial signatures as a result of the diets. This study highlights how *Bactrocera zonata* adapts its gut microbiota to survive in varying climates, thereby enhancing the pest's resistance and facilitating its spread.

The scent of royalty: a P450 gene signals reproductive status in a social insect	(Lemaitre & Hoffmann, 2007).	Consequently, tailored biological control of fruit fly mediated by manipulating the immune system in response to microbial stimuli is possible without resort to chemical pesticides.	Scientist explored P450 gene can indicate reproductive condition in social insects while studying the immune function. They conducted genetic and behavior experiments to understand the effects of microbial signals on the immune response. According to this research, there is a possibility of likely developing a Specific organic control of fruit flies through modulation of the host innate immune system upon recognition of microbial associated molecular patterns, thus eliminating the use of chemical sprays.
Pesticide handling practices, health risks, and determinants of safety behavior among Iranian apple farmers	(Baghari et al. 2017).	Pheromone enhanced traps were useful for remote attractiveness and sexually competitive suppression to male flies for the MAT.	The researchers have therefore sought to examine the outcomes of applied pesticide handling and the health implications among the Iranian apple growers. They also used their study to evaluate the efficiency of traps with pheromones in control of male fruit flies. The technique used hatching experiments to assess the efficacy of the traps in terms of attraction and the applicability of mating disruption (MAT) in the pest control without the use of insecticides.
Learning experiences in IPM through concise instructional videos	(Thomas et al. 2013).	Microbiome-targeted approaches integrated into existing Integrated Pest Management (IPM) frameworks improve ecological pest control effectiveness	Scientist concerned with learning experiences in Integrated Pest Management (IPM) with the use of instructional videos. They also observed their approach that deals with the inclusion of microbiome-directed tactics into IPM models with help of educational videos. This approach demonstrated that, by integrating a microbiome approach within the framework of IPM, ecological pest control efficacy can be optimized due to increased interactions with microbial natural enemies.
Parallel gene expression evolution in natural and laboratory evolved populations	(Schlötterer et al. 2021).	This feature was evident in the Drosophila melanogaster model where similarities in gut microbiota involvement in mating and immune processes assisting in enhanced pest control solutions were also investigated.	Scientist investigated conditionality patterns of gene expression in both nature and laboratory-constructed populations, with *Drosophila melanogaster*. Some of their approaches used were gene expression profiling of molecules associated with gut microbiota's role in mating and immune functions. These pathways were seen to have a great potential towards the development of improved pest management systems; the microbiota patterns were demonstrated on how they can be incorporated into the pest management systems.

Evolutionary and ecological consequences of gut microbial communities	(Moran et al. 2019).	Specific microbial interactions were associated with fruit fly fitness across indicators of population dynamics, including larval survival rates, reproductive rates and overall population density.	Scientist extended the analysis of evolutionary and ecological aspects of gut microbial consortia. They utilized microbial relationship in the fruit flies, and measuring its impact on the fitness by various factors such as larval viability, reproductive output and population density. The research showed that certain interactions of microorganisms affect population density, which could be of interest to pest management programs.
Biological control of root knot nematode, *Meloidogyne incognita*, in vitro, greenhouse and field in cucumber	(Naaz et al. 2020).	The biological control measures of using symbiotic bacteria as a pest control method was found appropriate in pest management while enhancing ecology.	Studied the use of symbiotic bacteria in controlling the *Meloidogyne incognita* in cucumber. Their approach was to use in vitro, greenhouse and field studies to test the potential of using symbiotic bacteria to manage root-knot nematodes. The study revealed that pest control using biocontrol agents from symbiotic bacteria is a more environmentally friendly method for suppressing pests and supporting the improvement of soil quality and overall species diversification.
Automatic detection and identification of brown stink bug, *Euschistus servus*, and southern green stink bug, *Nezara viridula*, (Heteroptera: Pentatomidae) using intraspecific substrate-borne vibrational signals	(Mankin et al. 2011).	Real-time pest surveillance technologies such as automatic surveillance systems were suggested for use to allow early intervention.	Scientist created scientifically significant real time pest monitoring technologies (SSRTPM) based on intraspecific substrate borne vibratory signals for the automatic identification of Brown Stink Bug (*Euschistus servus*) and Southern Green Stink bug (*Nezara viridula*). The study's approach was based on the analysis of vibrational signals obtained through computerized monitoring and control systems that enabled early identification of pest likelihood and subsequent pest control.
Cultivating sustainable solutions: integrated pest management (ipm) for safer and greener agronomy	(Sharma et al. 2023).	Integrating digital control with an Art-based approach offers up a powerful protective mechanism towards pests.	Scientist emphasized the application of an IPM that was linked with digital control and an art-based strategy to boost the pest defense. The Integrated Pest Management plan used technological techniques of surveillance alongside artistic approaches in addressing the pest issues. This integration provided a viable and revolutionary method of protection and streamlined pest results while encouraging the effective utilization of environmentally friendly methodologies in agronomical ventures.

Conspecific and heterospecific pheromones stimulate dispersal of entomopathogenic nematodes during quiescence	(Kaplan et al. 2020).	Some other outstanding strategies such as microbiome target disruption and pheromone interruption have been proposed for being environmentally friendly control methods compared to chemicals molecules.	Scientist examined the effect of conspecific and heterospecific pheromones on triggering the movement of entomopathogenic nematodes during the dormant state. In this work their experimental approach was based on examining how pheromone treatments influenced the motility and spread of the nematodes. Among the proposed approaches such as microbiome dissonance and pheromone interference are potential gentle-green ways of pest control by providing durable solutions.
Biological control of human disease vectors: a perspective on challenges and opportunities	(Thomas et al. 2013).	It was stressed that field validation of microbiome-based tools for integrated pest management was essential for their application in the field	Scientist discussed about the biological control of human diseases and possible difficulties and prospects of pest control. In their approach they highlighted the field validation of microbiome-based tools utilized in Integrated Pest Management (IPM). The study highlights that if the application of these tools has to be done practically under a favorable system, field experiments need to be conducted for these tools to identify their efficiency in disease vector and pest control.
Antimicrobial Resistance and Recent Alternatives to Antibiotics for the Control of Bacterial Pathogens with an Emphasis on Foodborne Pathogens	(Deng et al. 2021; Hanan et al. 2023).	For digestion, *Enterobacter*, for immunity *Lactobacillus*, for reproduction *Acetobacter* are found to be important gut microbiota in Bactrocera zonata.	Molecular methods including metagenomic sequencing and culturing methods are employed to quantify and characterize the gut bacteria in Bactrocera zonata. These techniques made it possible to separate gut-associated bacteria.
Functions of Gut Microbiota Metabolites, Current Status and Future Perspectives	(Liu et al. 2022).	Some gut microbiota improve reproductive output through transforming molecules that act on sexual behaviors	To investigate microbial composition, Scientist used 16S rRNA gene sequencing; for microbiota-derived metabolites, they used metabolomics; and they used behavioral tests to measure reproductive and sexual behaviors. Microbiota-positive and negative models animals were compared to decipher individual microbial contributions. Molecular biology techniques as well as quantified enzyme activity mapped the remaining pathways of metabolite transformation.

Table 1: Key findings and Methodologies of Bactrocera Zonata

1.3. Microbiome In Bactrocera Zonata Lifecycle And Control; Understanding Of Reproductive Interference And Biological Control

Gut microbiota serves as a cornerstone in the physiology and pest management of *Bactrocera zonata*, a critical agricultural pest that severely impacts fruit crops worldwide. Some of the important lumen types of bacteria are *Enterobacter*, which are involved in digestion; *Lactobacillus*, necessary for immunity; and *Acetobacter* for reproduction. These bacteria are involved in nutrient acquisition, immune modulation and of course, sexual selection via pheromone imitating activities [22]. New molecular tools like metagenomic sequencing, and culturing techniques have made it possible to describe the gut microbiota, and their complex roles in the pest's physiological system. Recent studies suggest that gut bacteria-derived metabolites influence mating behaviors through the synthesis of volatile compounds can affect sexual behaviors and enhance fertility. For instance, some compounds that are synthesized by *Acetobacter* species are used as sexual pheromones, which demonstrate the capacity of microbiome-mediated reproductive manipulation, and conversely, certain *Lactococcus lactis* genera are reputed to interfere with pheromone communication [23]. Microbial communities have been successfully used in behavioral assays and fertility and immune response regulation, which makes microbiome manipulation a more environmentally friendly approach as an alternative to chemical pesticides.

For Sustainable intervention techniques; microbiome disruption and biocontrol, protein bait, bacterial control agents, and Pheromone traps are using. For instance, the use of protein-based baits with further enhancement through ammonium acetate deals mainly with female fruit flies and result in low overall population numbers [25]. Methyl eugenol and cue lures have gone a step further to increase trapping efficiency since they aid in suppressing *B. zonata* population . These methods reduce the use of pesticides also fits well with the green pest management approach to managing pests and their impacts. Analyzing the field investigations it is evident *that B. zonata* is predominantly associated with the guava and mango fruits, out of which guava shows the highest pupal recovery rate and acts as the major breeding hub. In addition, the depth of soil and other environmental factors have direct effects on the pre-pupal and the pupal stages of this pest, social factors that prove the adaptive ability of the pest to different environs [14]. This adaptability presents emphasizing for pest management because climate modeling estimates that by the year 2050 there will be a 15–20% increase in suitable environments for B. zonata [27]. Besides, the old approaches are being replaced by new emergent technologies such as digital surveillance and automated monitoring devices in controlling pests. Constant pests' population inspection through cameras and smart traps contribute to the proactive pest control, increased effectiveness in combating pest outbreaks [28]. These technologies easily fit into Integrated Pest Management (IPM) systems, making pest management programmes more accurate and sustainable.

It is proposed that pest management strategies based on the manipulation of microbiome targets specific to pests, including interference with microbial pathways that control pheromone signaling and general reproductive activities. For instance, changes in gut microbiota have been identified to weaken immunity and decrease the reproductive ability and, therefore, lower population numbers [31]. Furthermore, microbiome induced baits are being fine-tuned for the enhanced capturing of male and female flies, as an effort to have the pest population at the target point [32]. Hence, independent field validation of the utility of microbial-based tools is critical for their deployment in applied IPM strategies. Traditionally, IPM approaches are supplemented by new perspectives associated with microbiome work to develop more efficient or environmentally friendly pest control systems [33]. Besides, this approach also help minimizes the reliance on chemical pesticides besides considering ecological objectives, benefitting beneficial organisms and enhancing biological diversity.

1.4. Microbiome-Based Pest Management: Exploiting Gut Microbiota For Environmental Friendly Management Of *Bactrocera Zonata*

This new avenue for pest control involves understanding the association between fruit fly gut microbiota and their behavior. Researchers have developed microbiome-based pest management by disturbing the microbiota or complementary microbes that interfere with essential physiological functions, for example, reproduction and immune behavior. If *Bactrocera zonata* gut microbiota can be manipulated to decrease mating success or disrupt foraging behavior, then the use of chemical pesticides to control it is unnecessary and can promote sustainable agriculture [34]. The survival and ecological success of fruit flies *Bactrocera zonata* require the gut microbiota. Essential behaviors, including mating, feeding, and immune function, are influenced by these symbiotic bacteria, and their role in maintaining these behaviors has been identified as a potential asset in innovative pest management strategies. Researchers can use associations between flies and their microbiota to create new biological controls that are both bio-safe and environmentally friendly (Deutscher T.A *et al*. 2019).

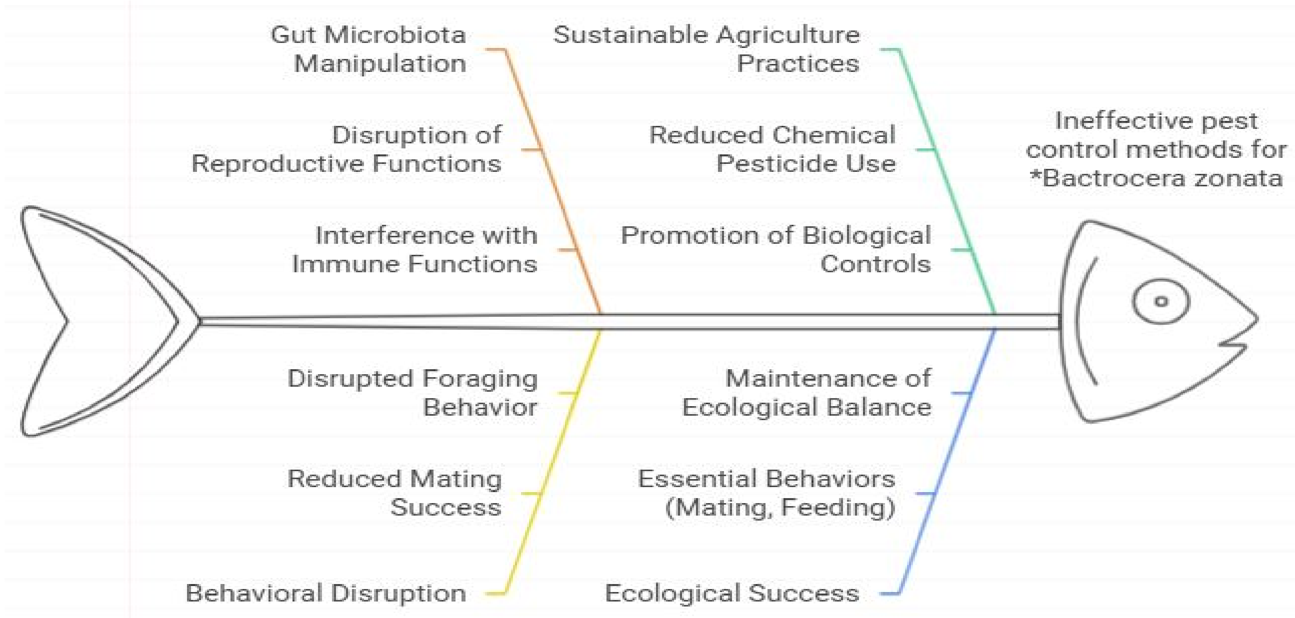

Figure 6: Innovative Pest Management Strategies

1.5. Innovative Trapping Techniques And Comprehensive Strategies For The Effective Control Of Drosophila Melanogaster Fruit Flies

Studies have shown that the effectiveness of fruit fly trapping can be improved when methyl eugenol and cue lure are used [24]. Female *Bactrocera zonata* mainly prefer protein-based substrates for laying eggs and are well trapped scientifically with protein hydrolysate baits mixed with ammonium acetate or tri-methylamine. These protein baits not only affect females but also, when combined with traps, affect the fly population as a whole while simultaneously utilizing male-targeted pheromone traps to minimize reproductive capability . In other experiments, it has been stated that these lures and baits increase attractiveness and work better for both male and female flies and at any stage of infestation of fruit preparation; is effective when sprinkled with guava pulp and papaya powderWhere *B. zonata* infestations are recurrent, tagging technologically advanced systems, such as sensor-enhanced smart traps, offer information on the fruit fly in the process of actively searching for fruits to infest. These systems facilitate timely responses to population density increases, such that targeted spraying of pesticides for intervention can occur quickly, which is critical for areas of high volatility [35].

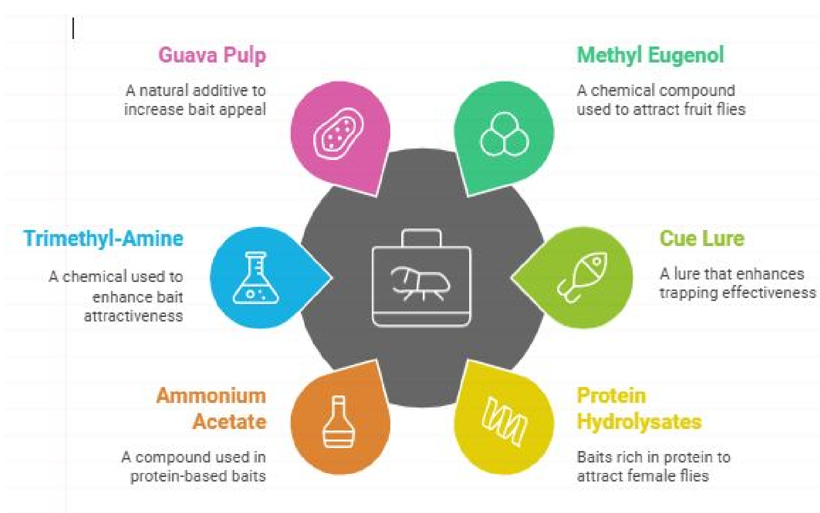

Figure 7: Effective Baits for The Bactrocera Zonata

Moreover, the Male Annihilation Technique (MAT) uses methyl eugenole blended with insecticides to trap male flies, and hence limits their ability to reproduce across vast areas, including fruit plantations [36]. The limitation of breeding with male targets only helps to practice a sustainable form of population control and is in agreement with the order to control mosquitoes without the use of broad-spectrum insecticides that act as dangerous organisms to beneficial insects [37].

Baits & Lures Names	Species of Fruit Flies	Crossponding Authors
Protein Hydrolizate	*B. Zonata, B. Dorsalius*	(Abbas. M. *et al*. 2021)
GF-120	*B. Zonata*	(Nisar. N *et al*. 2020)
Methyl.Eugenole	*B. Zonata, B. Dorsalius*	(Muhammad. K *et al*. 2021)
Methyl.Eugenole	*B. Zonata*	(Murtaza.K *et al.* 2012 b)
Methyl.Eugenole		B. Zonata, B. Dorsalius
MAT + Methyl.Eugenole	*B. Zonata, B. Dorsalius*	(Ghanim, M.N *et al*. 2023)
Ammonium Acetate	*B. Zonata*	(Lillo *et al*.2023)
Trimethylamine + protein hydrolysate (mixture)	*B. Zonata, B. Dorsalius*	(Royer *et al*. 2023).

Table 2: Uses of Baits and Lures to attract Bactrocera zonata (Ahmad.S et al.2023)

Both the sexes of *Bactrocera zonata* and other related fruit fly species respond positively to the use of baits and lures. Consequently, many formulations of attractants have been created to effectively lure these pests. Efficient protein hydrolysate has been seen to trap male *B. zonata* and *B. dorsalis* according to Abbas et al. (2021). It also means that while there are multiple bait formulations, such as GF-120, a specific bait formulation is more effective against. Among them, methyl eugenol is one of the most investigated and applied attractants for both *B. zonata and B. dorsalis* some recent work include [38]. In addition, there has been improvement on the attractive aspect of these species through the mixed use of methyl eugenol and Male Annihilation Technique (MAT) which provide broader control hence more effective methods of pest control [39]. Ammonium acetate as another specific attractant of *B. zonata* as an alternative to conventional attractants for pest control [40]. Recent innovations have also involved the application of trimethylamine with protein hydrolysate which the study has shown is very effective against both *B. zonata and B. dorsalis* [24]. This mixture with new novel lures, is part of a growing trend toward more sustainable and integrated pest management (IPM) strategies, reducing the reliance on chemical insecticides.

Such modified baits like methyl eugenol together with cue lure have also been employed to enhance the trapping effectiveness and efficiency. Research reveals that high frequencies of flies are caught out by this combinations of methyl eugenol with cue lure [24]. One of the most frequent ways to capture female *Bactrocera zonata* is to use Protein Hydrolysates Bait; because female fruit flies require protein for egg maturation, they can be easily attracted to protein-based baits such as ammonium acetate and tri-methyl-amine. The artificial hydrolysate baits offer the best place for the landing of female flies and lay her eggs into it. These protein-based baits can be used together with traps to capture female flies, which in turn targets the entire population of the fly species. This approach provides a complementary strategy to male-targeted pheromone traps, helping to further reduce reproductive potential [25]. Volatiles are added to enhance the protein baits include; Guava pulp, papaya powder among others are added to the protein baits as they have the ability to make the baits more attractive. With these blends, traps have been shown to be successfully attractive for both sexes, resulting in their efficiency at different developmental stages of infestation when used in a Y-tube olfactometer.

In some countries Remote Surveillance and Smart Trap Systems are being implemented by the researcher. Where *B. zonata* infestations are frequent or severe, digital traps fitted with sensors and an automated counter are used in one of the modern Digital Monitoring system. These smart traps capture data of the activities of fruit flies in real time, providing valuable information on the peak population. As per the research, it is concluded that Methyl Eugenole has an impact on different species of fruit flies. Automated systems decrease the labor required for surveillance and allow for quicker and more analytical counteraction of the infestation table (1) [26]. Alternatively, this modern research, Real-Time Data Integration surveillance trap system, was conducted by the scientist. Such digital traps are normally programmable with databases and may, in some instances, reach managerial pest control teams through application. This rapid response potential allows for prompt actions, such as targeted pesticide application, when the population thresholds are exceeded. Such preemptive steps have been vital, especially where farming areas are highly susceptible to loss [29]. Another technique that is being mostly used by researchers in the field is the Pheromone Lures and the Male Annihilation Technique (MAT). It consists of Methyl Eugenol and Cue Lure. MAT uses high-efficiency pheromone bait, such as methyl eugenol, together with insecticides to eradicate male *Bactrocera zonata* [41].

This method can be particularly used in mass trapping campaigns, where it has played a very big role in reducing male populations to levels that they cannot reproduce and mating with female fruit flies. Because the high attractiveness of methyl eugenol can attract males from up to 800 m, the use of this attractant is appropriate for large area uses in orchards and near fields [42]. In this way, we are able to Target Sterilization for controlling long-term population growth by only targeting the male species. MAT substantially reduces the number of breeding occurrences; therefore, over time, the population decreases. This male Annihilation Technique (MAT) is most effective in integrated pest management as it decreases the use of nonselective insecticides, broad-spectrum insecticides, and pesticides that are harmful and lethal to helpful insects [43].

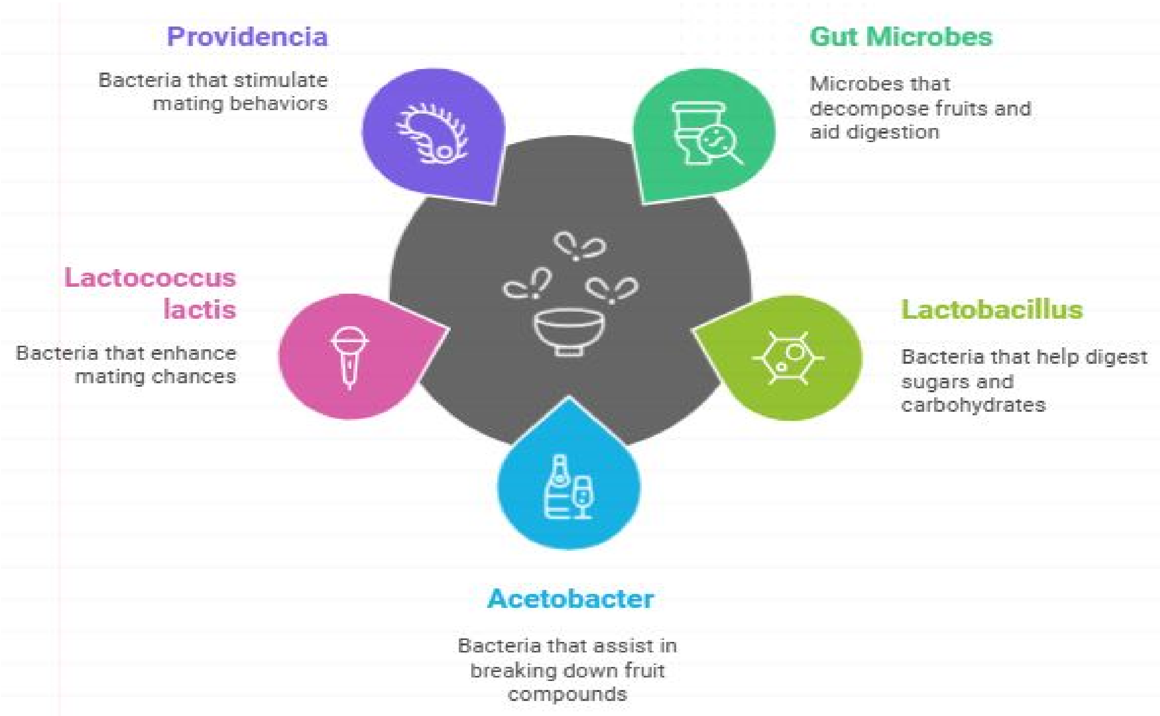

Figure 8: Enhancing Fruit Fly Trapping Efficiency and baits functions

Integrated Pest Management (IPM) Framework consists of combining traps, bait stations, digital monitoring, and MAT using an IPM strategy, enabling the selective and environmentally sustainable management of pests. The monitoring ability of pest population density through traps, using suppressive and controlling males through MAT, and incorporating protein baits to reduce the female pest population at an economical threshold, while minimizing insecticide use and its impact on the environment. c Through these combined surveillance and control techniques, *Bactrocera zonata* populations are effectively monitored and managed, providing robust solutions to protect valuable crops.

1.6. Global Review Of The Extent And Impact Of *Bactrocera Zonata* On Fruits Crops With Special Emphasis On Its Economic Loss

Bactrocera zonata also known as the peach fruit fly is a key pest that affects numerous fruits worldwide causing significant pre and post-harvest losses. The short generation period and host range of this pest damage multiple fruits, mainly in Pakistan and South Asia, causing significant losses to valuable fruit crops. Evaluation of the damage caused by this pest shows that it has very high reproductive potential and infests more than one type of fruit, thus making it a devastating pest in Pakistan and South Asia. By the researcher, infestation at post-harvest rates were calculated in Different Fruits such as guava, citrus, and Mangoes Mango fruits are the favorite host of *B. zonata*, infestation of which ranges from 10 to 50% in Pakistan depending on the extent of infested orchards. It has been estimated that in India and Pakistan, mango losses caused by this pest may decrease the yield by–30-40% during periods of maximum pest incidence of infestation [44]. Although Guava is one of the most important hosts, guava bear a 40-60% infestation level in some areas of Pakistan, particularly during the later summer.

This is particularly a concern because guavas mature and are harvested in warmer months that are ideal for *B. zonata* reproduction. *B. zonata* also affects citrus fruits, but the rates are usually slightly lower than with mangoes and guavas. Damage in citrus can still range from 20-30%, especially when pest populations are not effectively managed. Citrus orchards located near mango or guava plantations often experience higher infestation rates due to pest migration across host plants . *B. zonata* post-harvest losses can be regarded as an important economic issue, especially if the country is oriented on export. For example, post-harvest losses could be as low as 5-10 percent in mangoes and approximately 15 percent losses in guavas because fruit fly larvae normally survive in traditional handling and storage systems. Such losses are compounded by the fact that fruits are expected to be immediately refrigerated or subjected to some post-harvest handling .

Bactrocera zonata has now extended beyond its belt of origin to the Middle East and parts of Africa, where it still ails the fruit industry. In Egypt, *B. zonata* attacking guava and mango fruits reduces the yield by nearly 30 % or more during the fruiting seasons. In Sudan, the overall infestation level in mango and citrus crops varies from 20-40% resulting in millions of dollars lost every year

[45]. While the researcher revealed that climate modelling system indicates that, as the global climate changes such as warms, *B. zonata* could establish populations in new regions that will support its infestations. Scientist assume, under this type of climate circumstances expected that upto 2050, *B. zonata* might have 15-20% more of suitable habitats; consequently, the global rates of infestation and post-harvest losses will arise. These significant observations call for enhanced efforts in pest control measures such as better trapping, early warning, and efficient post-harvest controlling strategies to deal with *B. zonata* and effect reduction to East African and global fruit markets [46].

1.7. Systematic Study Of Host Related Activities And Life Cycle Characteristics Of *Bactrocera Zonata*

Through the research and experiments, the scientist observed significant variations in pupal recovery, adult emergence, host preference, and sex ratio of *Bactrocera zonata* among different fruit species. In the guava experiment, 434 pupae per fruit and 266 pupae per fruit were observed for banana pests. In contrast, apple and tomato had low pupal populations, with an average of 8-14 pupae per fruit . The pupal weight was at its maximum in guava at 11.65mg per pupa while citrus fruits had lighter pupae which were approximately 4.27mg and chikoo were slightly heavier at 10.50 mg (International Journal of Entomology, 2023).

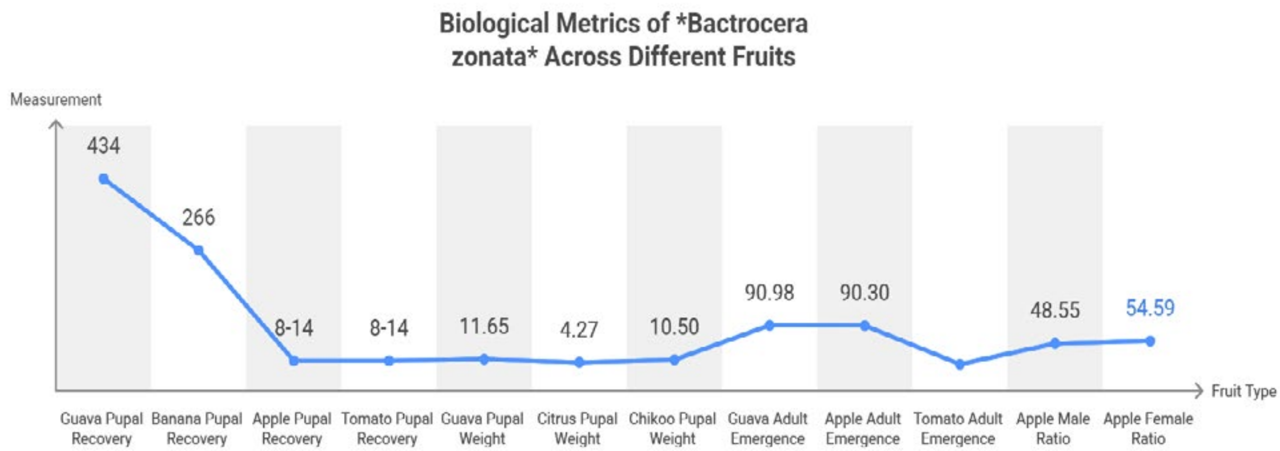

Table 3: No. Of Pupae, Weight, Sex Ratio, Deformity And Adult Emergence *Bactrocera Zonata*

In addition, there was a trends of consistently high adult emergence rates in treatments with guava and apple, 90.98% and 90.30 % under controlled condition banana and chikoo maintained high level of emergence in free-choice conditions. However, the lowest emergence rate was recorded for tomato regardless of the conditions [47]. The sex ration also differ significantly in ber the male are 48.55% and female 54.59% in apple. Free choice test revealed sex bias toward male only in banana, while persimmon and apple were either balanced or had slight female bias Abnormal emergence in the adult was the highest in chikoo 8.93% and in apple 7.47% suggesting that fruit type and condition could affect fly development these studies should serve as a reminder that more knowledge is needed on host-specific behavior of *Bactrocera zonata* to make effective pest control measures [48-49].

1.8. Microbiota-Based Strategies Against *Bactrocera Zonata* With Regard To Integrated Pest Management In Sustainable Agriculture

This research focuses on how the gut microbiota influences the physiological and behavioral characteristics of *Bactrocera zonata* and is therefore useful in directing future concoction of manageable pest control strategies. The results showed that particular bacterial communities in the gut microbiota of *B. zonata,* including *Enterobacter*, *Lactobacillus*, and *Acetobacter* species, are critically involved in the digestive capacity, immune system, and reproduction of the pest. Such microbial symbiosis not only allows the insect to thrive in different environments but also to overcome different fruit hosts, offering the farmer a hard nut to crack and representing challenges in agriculture pest management. One of the most significant findings derived from the present literature review is the influence of gut microbiota on mating behavior, feeding behavior and foraging behavior. Specifically, gut bacteria in *B. zonata* release volatile compounds that can be used as pheromones which disrupt mating attraction and as such have potential impact on reproductive and mortality rates. Such microbiome-mediated regulation of mating behaviors accelerates pest reproduction within host crops, increasing the threats it poses to agricultural production.

These microbial processes form the basis of pest control, and the possibility of interfering with such processes offers a great opportunity for extermination. Perhaps manipulating the gut microbiota that is involved in pheromone synthesis could limit mating ability and thus population explosion, translating to managing pest insect populations without need to use poisonous chemicals, a key sustainable agriculture objective. Moreover, the microbiota is closely involved in regulation of the immune system in the form of KEGG-Toll and IMD pathways, which are turned on by pathogenic danger signals. These pathways are very important in helping *B. zonata* defend itself against microbial infections hence adapting to the different pressures from the surrounding environment. This approach provides a method to manage *B. zonata* populations and conforms to various ecological objectives due to the minimal use of traditional pesticides. This integration of product knowledge into IPM frameworks could therefore result in highly specific and biologically sustainable pest control approaches. Some of the approaches that are made in a microbiome technique include protein and volatile-enhanced baits and it has been established that they enhance the trap outcomes and are friendly to the environment rather than the GoC chemically laced baits.

For example, proteinaceous baits to capture female *B. zonata* can be employed; since both male and female populations are affected, reproductive capacity is slowed down. In addition, the pheromone trap controls pests besides the microbiome-targeted strategies that can be integrated into the existing IPM practices, thereby increasing the overall specificity of control and minimizing environmental hazards. Besides changes in bait and trap techniques, possibilities of digital monitoring and automated surveillance systems provide useful approaches for monitoring pest populations in their real time. Since *B. zonata* activity patterns and population density are recorded, it provides a timely response to pest control and is hence more efficient. Combining microbiome-based strategies with digital monitoring could offer a reliable adaptive system for combating pests, reduce invasions into their habitat to a minimum, and be conducive to the goal of delivering sustainable agriculture.

1.9. Future Aspects Outcome & Stratiges To Control Fruit Flies

Considering the effects of gut microbiota on the changing physiological and behavioral characteristics of *Bactrocera zonata*, involving digestion, immunity, and the reproductive system, there are additional directions for developing innovative biological methods of pest control. If we Target Microbial Manipulation for Pest Control; involvement of gut bacteria's such as *Enterobacter*, *Lactobacillus* and *Acetobacter* helps in enhancing *B. zonata* immunity, digestion as well as reproduction. identified that insects have symbiotic bacteria which have vital functions in insect biology and have possibilities of pest management. A design for microbial disruption will be useful in that it may find microbial strains or metabolic pathways essential to pests' survival and reproduction useful when it comes to the design of non-toxic microbial disruptors that can eliminate reliance on chemical pesticides [31]. Other related research targeted the tactics to selectively disrupt volatiles produced by gut bacteria associated with pheromones. Microbiota has also been described to affect pheromones, which are important for reproductive point of view [50]. If the mechanisms that dictate pheromone synthesis in pests are targeted, then more effective methods of pest control through the use of pheromones could be developed through mating disruption to reduce reproduction levels with beneficial ecological impacts. The approach to disrupt specific pheromones is known as Pheromone Disruption through Microbiome Interference. The use of protein-based bait which is Optimization of Microbiome-Enhanced Baits is a promising approach in *B. zonata* regulation. Therefore revealed that future studies can help isolate intersectional microbial metabolites or proteins that enhance bait appeal.

Optimized baits could then lower pest populations in an environmental friendly manner thereby increasing the effectiveness of IPM. *B. zonata* uses Immune pathway learning like KEGG Toll, Immune deficiency (IMD) to attempt to combat microbial dangers, learning that is streamlined by gut bacterium [33]. Interference or adjustment on these pathways may have a negative impact on the immune-surveillance status of the pest and hence becoming vulnerable to natural diseases. Studies on immune-microbiota crosstalk, including that Lemaitre &Hoffmann *et al*. 2019 understand that symbiotic gut bacteria modulation could help reduce resorting to pest resistance. In future another advance technology is automated surveillance and digital monitoring of *B. zonata* populations, which when used together with microbiome based management, is an innovative way to control the pest. Presumably, information about population density and behavior can be obtained in real time and contribute to timely microbiome interventions in case of pest density above a certain level, thereby increasing the efficiency of control [51].

This Study explores how digital technologies augment microbiome-anchored strategies in enhancing response mechanisms in pest control. The scientists prefer conducting field trials to test microbiome-targeted approaches alongside the traditional IPM tools, like pheromone traps and baits, as an approach that is critical in determining the reality of microbiome-targeted tools on diversified agricultural fields. point out that field validation is very important in assessing the effectiveness of the IPM methods. Studying how interaction occurs could help fine-tune updated methods for conventional usage. Knowledge of Microbiome Dynamics has been acknowledging the versatility of *B. zonata* in different settings and subsequent research on the dynamics of intestinal microbiota at different geographical or climate-grown bacterial populations [52]. This study may contribute to site-specific pest management strategies and offer additional precision and efficiency in the implementation of microbiome innovations. The above recommendations are in favor of non-chemical biologically based control techniques contributing to sustainable agriculture, at the same time which is a major issue related to *B. zonata*. Planned studies using microbial symbiosis, pheromone manipulation, and immunomodulation will support the development of new components of IPM that are consistent with ecological goals of decreasing dependence on chemical inputs and developing more effective pest management strategies.

2. Conclusion

This comprehensive review on concludes that future research on microbiota manipulation has bright chances to play a decisive role in *Bactrocera zonata* control. The effect of the gut microbiome on mating behavior, reproductive potential, and immune function serves as a framework for new specific bio-control approaches. With these insights, it becomes easier to develop solutions to pest control problems that are biologically based without having to interfere with the biosphere. Hence, these findings suggest a more attractive proactive transition to microbiome-based IPM, with the gut microbiota emerging as a key strategic resource in the development of sustainable agriculture systems worldwide[53-91].

References

1. Haider, F. U., Cheema, S. A., & Farooq, M. (2019). Impact of cover crops in improving agro-ecosytems including sustainable weed suppression–a review. *Pakistan Journal of Weed Science Research, 25*(1), 47.
2. Maqsood, S., Shafi, M. U., Javaid, A., Khan, I. H., Ali, M., & Ferdosi, M. F. (2023). Control of insect pests and yield improvement in brinjal by plant extracts. *International Journal of Biology and Biotechnology, 20*(2), 329-335.
3. Gupta, R., Malik, P., Rani, R., Solanki, R., Ameta, R. K., Malik, V., & Mukherjee, T. K. (2024). Recent Progress on Nanoemulsions Mediated Pesticides Delivery: Insights for Agricultural Sustainability. *Plant Nano Biology*, 100073.
4. Cheng, S., Lin, R., Yu, C., Sun, R., & Jiang, H. (2021). Toxic effects of seven pesticides to aphid parasitoid, Aphidius gifuensis (Hymenoptera: Braconidae) after contact exposure. *Crop Protection, 145*, 105634.
5. Stonehouse, J., Mahmood, R., Poswal, A., Mumford, J., Baloch, K. N., Chaudhary, Z. M., ... & Huggett, D. (2002). Farm field assessments of fruit flies (Diptera: Tephritidae) in Pakistan: distribution, damage and control. *Crop protection, 21*(8), 661-669.
6. Nawaz, A., Ali, H., Sufyan, M., Gogi, M. D., Arif, M. J., Ranjha, M. H., ... & Ghramh, H. A. (2019). Comparative bio-efficacy of nuclear polyhedrosis virus (NPV) and Spinosad against American bollwormm, Helicoverpa armigera (Hubner). *Revista Brasileira de Entomologia, 63*(4), 277-282.
7. Napitupulu. T. P., 2023. Antagonistic fungal volatiles as potential biocontrol countermeasure for microbial postharvest fruit diseases. *Egyptian Journal of Biological Pest Control. 33*(12):92-100.
8. Behar, A., McCormick, L. J., & Perlman, S. J. (2010). Rickettsia felis infection in a common household insect pest, Liposcelis bostrychophila (Psocoptera: Liposcelidae). *Applied and environmental microbiology, 76*(7), 2280-2285.
9. Prasad, R., & Shivay, Y. S. (2021). Enhanced efficiency fertilizers or slow-release and NI/UI blended nitrogen fertilizers. *Indian J. Fert, 17*, 316-321.
10. Lanjar, A. G., Solangi, A. W., Khuhro, S. A., Bukero, A. S. L. A. M., Buriro, R. A., & Rais, M. N. (2014). Insecticide application tactics to suppress population of drosicha mangiferae (green). *European Academic Research, 2*(8).
11. Doharey, R. K., & Kumar, M. (2022). Adoption Level of Rural Women about Storage Structure and Practices for Storing Grains. *Asian Journal of Agricultural Extension, Economics & Sociology, 40*(11), 352-359.
12. Gupta, S., Radhakrishnan, A., Raharja-Liu, P., Lin, G., Steinmetz, L. M., Gagneur, J., & Sinha, H. (2015). Temporal expression profiling identifies pathways mediating effect of causal variant on phenotype. *PLoS genetics, 11*(6), e1005195.
13. Hollingsworth, R. G., Aristizábal, L. F., Shriner, S., Mascarin, G. M., Moral, R. D. A., & Arthurs, S. P. (2020). Incorporating Beauveria bassiana into an integrated pest management plan for coffee berry borer in Hawaii. *Frontiers in Sustainable Food Systems, 4*, 22.
14. Koul, O. (2008). Phytochemicals and insect control: an antifeedant approach. *Critical reviews in plant sciences, 27*(1), 1-24.
15. Mir, S. A., Mohammad, I., Khan, M. R., Myint, M. Z., Mansoor, T., Amin, Z., ... & Mir, M. S. (2022). Role of intercropping in sustainable insect-pest management: a review. *International Journal of Environment and Climate Change, 12*(11), 3390-3404.
16. Mir, S. A., Mohammad, I., Khan, M. R., Myint, M. Z., Mansoor, T., Amin, Z., ... & Mir, M. S. (2022). Role of intercropping in sustainable insect-pest management: a review. *International Journal of Environment and Climate Change, 12*(11), 3390-3404.
17. Khan, F. Z., Manzoor, S. A., Gul, H. T., Ali, M., Bashir, M. A., Akmal, M., ... & Joseph, S. V. (2021). Drivers of farmers' intention to adopt integrated pest management: a case study of vegetable farmers in Pakistan. *Ecosphere, 12*(10), e03812.
18. Vargas, R. I., Piñero, J. C., & Leblanc, L. (2015). An overview of pest species of Bactrocera fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific region. *Insects, 6*(2), 297-318.
19. Zhang, F. Q., McMullen, J. G., Douglas, A. E., & Ankrah, N. Y. (2021). Succinate: A microbial product that modulates Drosophila nutritional physiology. *Insect science, 29*(1), 315.
20. Hsu, S. K., Lai, W. Y., Novak, J., Lehner, F., Jakšić, A. M., Versace, E., & Schlötterer, C. (2024). Reproductive isolation arises during laboratory adaptation to a novel hot environment. *Genome Biology, 25*(1), 141.
21. Dion, W. A., Steenwinkel, T. E., & Werner, T. (2021). From Aedes to Zeugodacus: A review of dipteran body coloration studies regarding evolutionary developmental biology, pest control, and species discovery. *Current opinion in genetics & development, 69*, 35-41.
22. Deng, J. Y., Chen-yi-hang, L. A. N., Zhou, J. X., Yao, Y. B., Yin, X. H., Fu, K. Y., ... & Fumin, W. A. N. G. (2023). Analysis of sex pheromone production and field trapping of the Asian corn borer (Ostrinia furnacalis Guenée) in Xinjiang, China. *Journal of Integrative Agriculture, 22*(4), 1093-1103.
23. Liu, Y., Geng, Y., Huang, Z., Feng, J., & Jiang, T. (2024). Pest suppression services and dietary niche differentiation of bats in Chinese smallholder farming systems: implications for integrated pest management. *Journal of Pest Science, 97*(3), 1587-1603.
24. Royer, P., Dumont, F., Provost, C., & Lucas, E. (2024). May biocontrol agents artificially selected for their aggressiveness improve crop protection?. *Journal of Pest Science*, 1-9.
25. Ahmad, I., Sohail, M., Hameed, M., Fatima, S., Ahmad, M. S. A., Ahmad, F., ... & Ahmad, K. S. (2023). Morpho-anatomical determinants of yield potential in Olea europaea L. cultivars belonging to diversified origin grown in semi-arid environments. *Plos one, 18*(6), e0286736.
26. Ahmad, S., Jamil, M., Jaworski, C. C., Wu, Y., Palma-Onetto, V., Lyu, B., & Luo, Y. (2023). Knockdown of the ecdysone receptor disrupts development and causes mortality in the melon fly, Zeugodacus cucurbitae. *Insect Molecular Biology, 32*(6), 738-747.

27. Parsons, L., Ross, R., & Robert, K. (2020). A survey on wireless sensor network technologies in pest management applications. *SN Applied Sciences, 2*(1), 28.
28. Diller, Y., Shamsian, A., Shaked, B., Altman, Y., Danziger, B. C., Manrakhan, A., ... & Nestel, D. (2023). A real-time remote surveillance system for fruit flies of economic importance: sensitivity and image analysis. *Journal of Pest Science, 96*(2), 611-622.
29. Cardim Ferreira Lima, M., Damascena de Almeida Leandro, M. E., Valero, C., Pereira Coronel, L. C., & Gonçalves Bazzo, C. O. (2020). Automatic detection and monitoring of insect pests—A review. *Agriculture, 10*(5), 161.
30. Asif, M., Khakwani, K., Hasnain, M., Ilahi, F., Babar, M. H., Chuhan, S. M., ... & Hussnain, H. (2024). Evaluation of Cotton Genotypes for Agro-Morphological Traits and Resistance to Insect Pests in Faisalabad, Pakistan. *Sarhad Journal of Agriculture, 40*(2), 386-394.
31. Kaplan, M., & Bayram, Y. (2021). Occurrence, population development, infestation and damage caused by olive fly (Bactrocera olea GMEL.)(Diptera: Tephritidae) in olive orchards of Mardin province, Turkey. *JAPS: Journal of Animal & Plant Sciences, 31*(2).
32. Vargas, R. I., Piñero, J. C., & Leblanc, L. (2015). An overview of pest species of Bactrocera fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific region. *Insects, 6*(2), 297-318.
33. Broderick, N. A., & Lemaitre, B. (2012). Gut-associated microbes of Drosophila melanogaster. *Gut microbes, 3*(4), 307-321.
34. Tait, G., Mermer, S., Stockton, D., Lee, J., Avosani, S., Abrieux, A., ... & Walton, V. M. (2021). Drosophila suzukii (Diptera: Drosophilidae): a decade of research towards a sustainable integrated pest management program. *Journal of Economic Entomology, 114*(5), 1950-1974.
35. Bibi, A. (2025). Gut Microbiota and Its Ecological Interactions in Bactrocera zonata and Its Impact on Food Security & Agricultural Pest.
36. Fezza, T., Shelly, T. E., Fox, A., Beucke, K., Rohrig, E., Aldebron, C., & Manoukis, N. C. (2024). Less is more: Fewer attract-and-kill sites improve the male annihilation technique against Bactrocera dorsalis (Diptera: Tephritidae). *Plos one, 19*(3), e0300866.
37. El-Afify, A. H., Shreef, R. M., Hendawy, M. A., & Ghanim, N. M. (2023). Seasonal Activity of Bactrocera zonata (Saunders) and Ceratitis capitata in a Navel Orange Orchard in Dakahlia, Egypt. *Arab Journal of Plant Protection, 41*(2).
38. Murtaza, G., Ramzan, M., Bilal, H., Ejaz, A., Khan, M. A. A., Riaz, T., & Waqas, M. (2021). Monitoring of fruit fly, Bactrocera zonata (Diptera: Tephritidae) population by installing traps in mango orchard Bahawalnagar, Pakistan. *Journal of Applied Research in Plant Sciences, 2*(2), 148-151.
39. Elkelany, M. N., Elbokl, M. M., Elmetwally, M. M., & Ghanim, N. M. (2024). Modifications in male annihilation technique for attracting Bactrocera zonata under field conditions. *Egyptian Academic Journal of Biological Sciences. A, Entomology, 17*(3), 13-24.
40. Lillo, G., Calia, C., Cice, D., Petriccione, M., & Camposeo, S. (2024). Blooming Phenograms, Pollen Production, and Pollen Quality during Storage of Pistachio Cultivars in New Mediterranean Growing Areas. *Plants, 13*(18), 2606.
41. Manoukis, N. C., Vargas, R. I., Carvalho, L., Fezza, T., Wilson, S., Collier, T., & Shelly, T. E. (2019). A field test on the effectiveness of male annihilation technique against Bactrocera dorsalis (Diptera: Tephritidae) at varying application densities. *PLoS One, 14*(3), e0213337.
42. Bagheri, A., Kolyaee, R., Askari Seyahooei, M., Modaress Najafabadi, S. S., & Faraji, G. (2017). Efficacy of methyl eugenol bait traps for controlling the mango fruit fly Bactrocera zonata (Diptera: Tephritidae). *Journal of Crop Protection, 6*(2), 181-189.
43. Nisar, M. J., Gogi, M. D., Atta, B., Tufail, M., Ali, R. A., Naveed, W. A., & Iqbal, M. (2021). Pathogenicity of fungal and bacterial bioinsecticides against adult peach fruit fly, Bactrocera zonata (Saunders)(Diptera: Tephritidae) admixed with adult diet under controlled conditions. *Egyptian Journal of Biological Pest Control, 31*, 1-20.
44. Ayaz, B., & Altunsoy, F. (2024). Effects of heavy metal pollution on population dynamics of another important pollinator insect group: Horseflies (Diptera: Tabanidae). *Biological Diversity and Conservation, 17*(2), 148-155.
45. Entling, W., & Hoffmann, C. (2020). Single and combined effects of Drosophila suzukii and Drosophila melanogaster on sour rot development in viticulture. *Journal of Applied Entomology, 144*(3), 153-160.
46. Ndlela, S., Niassy, S., & Mohamed, S. A. (2022). Important alien and potential native invasive insect pests of key fruit trees in Sub-Saharan Africa: advances in sustainable pre-and post-harvest management approaches. *CABI Agriculture and Bioscience, 3*(1), 7.
47. Rabha, A., Sharma, D. K., Baruah, C., & Das, A. N. (2024). Impact of corn meal and wild yeast media on Drosophila diversity in the Assam-Meghalaya rolling terrain. *Journal of Entomological Society of Iran, 44*(3), 329-348.
48. Baloch, N., Memon, R. M., Khuhro, N. H., & Shaikh, I. (2023). Population Fluctuations of Bactrocera Species (Diptera: Tephritidae) in Guava and Mango Orchards at Different Climatic Conditions of Sindh. *Pakistan Journal of Zoology, 55*(1), 37.
49. Rehman, M. F. U., & Khan, M. M. (2024). Application of nanopesticides and its toxicity evaluation through Drosophila model. *Bioprocess and Biosystems Engineering, 47*(1), 1-22.
50. Ben-Yakir, D., Hadar, E., & Chen, M. (1997). Evaluating insecticides for the control of narcissus flies under field conditions in Israel. *Phytoparasitica, 25*, 93-97.
51. Mankin, R. W., Rohde, B., & McNeill, S. (2015, November). Vibrational duetting mimics to trap and disrupt mating of the devastating Asian citrus psyllid insect pest. In *Proceedings of Meetings on Acoustics* (Vol. 25, No. 1). AIP Publishing.
52. Toledo, J., Morán-Aceves, B. M., Ibarra, J. E., & Liedo, P. (2023). Can Entomopathogenic Nematodes and Their Symbiotic Bacteria Suppress Fruit Fly Pests? A

Review. *Microorganisms, 11*(7), 1682.
53. Azam, A., & Shafique, M. (2017). Agriculture in Pakistan and its Impact on Economy. A Review. Inter. *J. Adv. Sci. Technol, 103*, 47-60.
54. Bhagat, D., Samanta, S. K., & Bhattacharya, S. (2013). Efficient management of fruit pests by pheromone nanogels. *Scientific reports, 3*(1), 1-8.
55. Boulahia-Kheder. S., 2021. Advancements in management of major fruit flies (Diptera: Tephritidae) in North Africa and future challenges: A review. Journal of Applied Entomology. 145(10): 939-957.
56. Broderick, N. A., Raffa, K. F., & Handelsman, J. (2010). Chemical modulators of the innate immune response alter gypsy moth larval susceptibility to Bacillus thuringiensis. *BMC microbiology, 10*, 1-13.
57. Bueno, E., Martin, K. R., Raguso, R. A., Mcmullen, J. G., Hesler, S. P., Loeb, G. M., & Douglas, A. E. (2020). Response of wild spotted wing drosophila (Drosophila suzukii) to microbial volatiles. *Journal of chemical ecology, 46*, 688-698.
58. Das, K., Pramanik, S., Rajak, P., Biswas, G., & Mandi, M. (2024). Monocrotophos induced changes in the life cycle parameters of fruit fly. *Environ Sci Arch, 3*, 6-13.
59. Deutscher, A. T., Chapman, T. A., Shuttleworth, L. A., Riegler, M., & Reynolds, O. L. (2019). Tephritid-microbial interactions to enhance fruit fly performance in sterile insect technique programs. *BMC microbiology, 19*, 1-14.
60. Dominiak, B. C. (2019). Components of a systems approach for the management of Queensland fruit fly Bactrocera tryoni (Froggatt) in a post dimethoate fenthion era. *Crop Protection, 116*, 56-67.
61. Doherty, E. M., Meagher, R. L., & Dale, A. G. (2019). Turfgrass cultivar diversity provides associational resistance in the absence of pest resistant cultivars. *Environmental entomology, 48*(3), 623-632.
62. Diller, J. G. P., Hüftlein, F., Lücker, D., Feldhaar, H., & Laforsch, C. (2023). Allelochemical run-off from the invasive terrestrial plant Impatiens glandulifera decreases defensibility in Daphnia. *Scientific Reports, 13*(1), 1207.
63. Engel, P., & Moran, N. A. (2013). The gut microbiota of insects–diversity in structure and function. *FEMS microbiology reviews, 37*(5), 699-735.
64. Nisar, M. J., Gogi, M. D., Atta, B., Tufail, M., Ali, R. A., Naveed, W. A., & Iqbal, M. (2021). Pathogenicity of fungal and bacterial bioinsecticides against adult peach fruit fly, Bactrocera zonata (Saunders)(Diptera: Tephritidae) admixed with adult diet under controlled conditions. *Egyptian Journal of Biological Pest Control, 31*, 1-20.
65. Ganie, S. A., REHMAN, S. A., NISAR, T., Paray, M. A., BANO, P., & KHURSHID, R. (2022). Fruit Fly Management and Control Strategies: A Review. *Biopesticides International, 18*(2).
66. Hanan, A., Basit, A., Nazir, T., Majeed, M. Z., & Qiu, D. (2020). Anti-insect activity of a partially purified protein derived from the entomopathogenic fungus Lecanicillium lecanii (Zimmermann) and its putative role in a tomato defense mechanism against green peach aphid. *Journal of invertebrate pathology, 170*, 107282.
67. John, M. A., Bankole, I., Ajayi-Moses, O., Ijila, T., Jeje, O., & Lalit, P. (2023). Relevance of advanced plant disease detection techniques in disease and Pest Management for Ensuring Food Security and Their Implication: A review. *American Journal of Plant Sciences, 14*(11), 1260-1295.
68. McMullen, J. G., Peters-Schulze, G., Cai, J., Patterson, A. D., & Douglas, A. E. (2020). How gut microbiome interactions affect nutritional traits of Drosophila melanogaster. *Journal of Experimental Biology, 223*(19), jeb227843.
69. John, M. A., Bankole, I., Ajayi-Moses, O., Ijila, T., Jeje, O., & Lalit, P. (2023). Relevance of advanced plant disease detection techniques in disease and Pest Management for Ensuring Food Security and Their Implication: A review. *American Journal of Plant Sciences, 14*(11), 1260-1295.
70. Stonehouse, J., Mahmood, R., Poswal, A., Mumford, J., Baloch, K. N., Chaudhary, Z. M., ... & Huggett, D. (2002). Farm field assessments of fruit flies (Diptera: Tephritidae) in Pakistan: distribution, damage and control. *Crop protection, 21*(8), 661-669.
71. Bibi, A. (2025). Gut Microbiota and Its Ecological Interactions in Bactrocera zonata and Its Impact on Food Security & Agricultural Pest.
72. Laskar, N., Das, K., Kancheti, M., Senthilkumar, M., Kumar, V., Tewari, K., & Nath, C. P. (2024). Dissipation Kinetics and Residue Distribution of Imazethapyr in Urdbean (Vigna mungo (L.) Hepper) and Urdbean Field soil and its Effect on soil Microbial Population. *Bulletin of Environmental Contamination and Toxicology, 113*(2), 21.
73. Lello, F., Dida, M., Mkiramweni, M., Matiko, J., Akol, R., Nsabagwa, M., & Katumba, A. (2023). Fruit fly automatic detection and monitoring techniques: A review. *Smart Agricultural Technology*, 100294.
74. Lillo, P., Delgado, M. D. M., Porcel, M., & Sánchez-Moreno, S. Quality of Organic Amendments Drives Agroecosystem Multifunctionality and Soil Micro-Food Web Short-Term Responses to Organic Matter Inputs. *Available at SSRN 4973445*.
75. Lillo-Saavedra, M., Espinoza-Salgado, A., García-Pedrero, A., Souto, C., Holzapfel, E., Gonzalo-Martín, C., ... & Rivera, D. (2022). Early estimation of tomato yield by decision tree ensembles. *Agriculture, 12*(10), 1655.
76. McCormack, K. (2016). Enhancing the monitoring and trapping of protected crop pests by incorporating LED technology into existing traps.
77. McMullen, J. G., Peters-Schulze, G., Cai, J., Patterson, A. D., & Douglas, A. E. (2020). How gut microbiome interactions affect nutritional traits of Drosophila melanogaster. *Journal of Experimental Biology, 223*(19), jeb227843.
78. Moran, P. J., Miskella, J. J., Morgan, C. M., & Madsen, J. D. (2023). Toxicity of herbicides used for control of waterhyacinth in the California Delta towards the planthopper Megamelus scutellaris released for biological control. *Biocontrol Science and Technology, 33*(5), 448-466.
79. Siddiqui, J. A., Fan, R., Naz, H., Bamisile, B. S., Hafeez, M., Ghani, M. I., ... & Chen, X. (2023). Insights into insecticide-

resistance mechanisms in invasive species: Challenges and control strategies. *Frontiers in Physiology, 13*, 1112278.
80. Rasouli, F., Abbasipour, H., & Rezazadeh, A. (2024). Evaluation of the chinaberry Melia azedarach extract against the tomato leafminer, Tuta absoluta (Lepidoptera: Gelechiidae) in vitro: Evaluación del extracto de paraíso Melia azedarach contra el minador de las hojas del tomate, Tuta absoluta (Lepidoptera: Gelechiidae) in vitro. *Revista de la Sociedad Entomológica Argentina, 83*(1), 1-8.
81. Royer, J. E., Mille, C., Cazeres, S., Brinon, J., & Mayer, D. G. (2019). Isoeugenol, a more attractive male lure for the cue-lure-responsive pest fruit fly Bactrocera curvipennis (Diptera: Tephritidae: Dacinae), and new records of species responding to zingerone in New Caledonia. *Journal of economic entomology, 112*(3), 1502-1507.
82. Lirakis, M., Dolezal, M., & Schlötterer, C. (2018). Redefining reproductive dormancy in Drosophila as a general stress response to cold temperatures. *Journal of insect physiology, 107*, 175-185.
83. Ramniwas, S., Singh, D., & Sharma, A. (2023). Efficacy of Artificial diets on biological characteristics of oriental fruit fly, Bactrocera dorsalis (Diptera: Tephritidae) in India. *International Journal of Tropical Insect Science, 43*(5), 1691-1700.
84. Yu, S., Luo, F., Xu, Y., Zhang, Y., & Jin, L. H. (2022). Drosophila innate immunity involves multiple signaling pathways and coordinated communication between different tissues. *Frontiers in Immunology, 13*, 905370.
85. Shields, G. F. (2014). Incipient speciation and additional diversity within the Simulium arcticum complex of black flies (Diptera: Simuliidae). *The American Midland Naturalist, 172*(1), 1-13.
86. Smith, D. J., Helmy, M., Lindley, N. D., & Selvarajoo, K. (2022). The transformation of our food system using cellular agriculture: What lies ahead and who will lead it?. *Trends in Food Science & Technology, 127*, 368-376.
87. Srivastava, R., & Shukla, A. C. (2021). Fusarium pallidoroseum: A potential entomopathogenic agent for the biological management of Aphis gossypii. *Journal of Applied and Natural Science, 13*(2), 775-785.
88. Susanna, D., & Pratiwi, D. (2022). Current status of insecticide resistance in malaria vectors in the Asian countries: a systematic review. *F1000Research, 10*, 200.
89. Hosokawa, T., Kikuchi, Y., Shimada, M., & Fukatsu, T. (2007). Obligate symbiont involved in pest status of host insect. *Proceedings of the Royal Society B: Biological Sciences, 274*(1621), 1979-1984.
90. Naeem-Ullah, U., Ramzan, M., Bokhari, S. H. M., Saleem, A., Qayyum, M. A., Iqbal, N., ... & Saeed, S. (2020). Insect pests of cotton crop and management under climate change scenarios. *Environment, climate, plant and vegetation growth*, 367-396.
91. Verma, N., & Bhardwaj, A. (2015). Biosensor technology for pesticides—a review. *Applied biochemistry and biotechnology, 175*, 3093-3119.