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INTEGRATED MANAGEMENT OF THE PEACH FRUIT FLY (BACTROCERA ZONATA) ON MANGO TREES UNDER CONDITIONS OF ISMAILIA GOVERNORATE, EGYPT

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The peach fruit fly (*Bactrocera zonata* Saunders) is one of the most economically damaging Tephritidae species infesting mango (*Mangifera indica* L.) and other fruit crops across subtropical and tropical regions, particularly in Egypt. This study aimed to evaluate and compare the effectiveness of 25 Integrated Pest Management (IPM) programs under field conditions in Ismailia Governorate over two consecutive mango fruiting seasons (2021–2022). The tested IPM strategies encompassed complete cover sprays with synthetic insecticides, applications of bioinsecticides (e.g., Spinosad, *Bacillus thuringiensis*, marine algae), particle film technologies based on inert minerals (kaolin, Aglev Si 300, diatomaceous earth), combinations of minerals with insecticides, partial bait sprays, and fruit bagging. Data were collected on the cumulative infestation of fruits and larval presence, with statistical comparisons across all programs. Results demonstrated that integrated programs combining mineral particles with either chemical or biological insecticides (programs 10–21) were the most effective, consistently achieving over 90% reduction in fruit and larval infestation. Programs using only bioinsecticides (programs 4-6) or mineral films (programs 7-9) also showed promising results, with efficacy ranging from 66 to 85%. Partial bait spray programs (22-24) and fruit bagging (Program 25) offered moderate control (55-83%) and serve as important control components of IPM. The findings support the incorporation of environmentally friendly approaches especially particle film technology and bioinsecticides into routine mango pest management. These alternatives not only reduce reliance on synthetic insecticides but also align with sustainable agriculture goals through IPM strategies at scale.

Keywords: *Bactrocera zonata,* integrated pest management, control, mango

INTRODUCTION

Mango (*Mangifera indica* L.) is a very popular fruit in many countries especially Egypt (FAO, 2007 and El-Mahdy, 2017). Mango yield has been drastically decreased by the attack of certain diseases and pests (Siam and Othman, 2020). *Bactrocera* sp. is an important agricultural invasive pest that causes significant economic losses in tropical and subtropical fruit (Chen et al., 2024). It was concluded that the attack of fruit flies caused directly damaging the important export crops which may lead to losses of 40 to 80% or even more (Reddy et al., 2020; Saeed et al., 2020; Grechi et al., 2021 and Zida et al., 2023). The peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae), ranks among the most destructive polyphagous pests affecting fruit orchards globally. Targeting its damaging stage, the larvae, is particularly challenging because they feed beneath the fruit's skin (Khan et al., 2023). Newly hatched larvae consume the fruit internally, rendering it unsuitable for human consumption. As they mature, the affected fruit ripens prematurely and eventually falls to the ground, potentially due to accelerated physiological processes (Boinahadji et al., 2019). Where, full-fed larvae bore out of the fruit and pop to find a suitable place on the soil to pupate. During pupation, it completes all the body parts and after three to five days passing as pupae, it emerges as a little golden fly with attractive wings, ready to infest new fruits after mating. The adult fruit fly has a life of up to three months and lays up to 1000 eggs (Kumbirai et al., 2020). This high fecundity rate and overlapping generations during the fruiting period make it a devastating pest of almost all fruits and vegetables. (Zida et al., 2023).

Managing fruit flies in mango production has become increasingly challenging, especially as the focus shifts from synthetic pesticides to alternative pest control methods (Grechi et al., 2021). Integrated Pest Management (IPM) offers a more sustainable and environmentally friendly solution compared to the extensive use of broad-spectrum conventional insecticides. Adopting an IPM plan can significantly reduce mango losses caused by fruit fly infestations, lower production costs, improve producer incomes and enhance both market access and processing quality. This approach ultimately increases mango quality and productivity to meet the demands of domestic and export markets. IPM relies on a comprehensive strategy that combines various complementary practices, rather than relying on individual management methods alone (Singh et al., 2020).

Control of fruit flies is somewhat challenging because eggs and larvae are protected inside the fruits and pupae in the soil. Therefore, the relatively exposed adult stage is the usual target of pest control action. To manage the adult fruit flies, mainly in Egypt, synthetic pesticides are used protein hydrolysate, a food attractant, is a prerequisite for females to lay mature eggs. It is mixed with toxicant and applied intermittently on foliage to attract and kill the females. All these control tactics have been evaluated by many authors

(Abdullah et al., 2024). Several innovative technologies have been developed by agricultural scientists, such as the particle film technology (PFT). They are basically aqueous formulations made from chemically inert clay or mineral particles, which are specifically formulated for coating to reduce the damage caused by insects, diseases, solar injury, freeze injury and to improve fruit finish, color, carbon assimilation rate, yield and postharvest fruit quality (Sharma et al., 2015). Particle Film Technology entails covering the surface of a plant or its product with a mineral-based film designed with specific functional properties. This film is chemically non-reactive, has an average particle size of less than 2 µm and is formulated to achieve even distribution, forming a uniform layer. It permits gas exchange through the leaf surface, supports the transmission of photosynthetically active radiation (PAR) and partially reflects harmful ultraviolet (UV) and infrared (IR) radiation. Additionally, it influences the behavior of insects and pathogens interacting with the plant and can be easily washed off when necessary. Particle Film Technology utilizes water-based formulations made with chemically inert kaolin mineral particles, specifically engineered to shield crops from insect pests and environmental stressors. Research conducted in the field demonstrates that this technology offers a safe and efficient alternative to traditional insecticides for managing particular pest issues across a diverse range of crops. These include apples, pears, grapes, blackberries, melons, tomatoes, onions, papayas, peaches, nectarines, olives, pineapples, mangos and citrus fruits. In the realm of organic farming, Particle Film Technology stands out as the first widely applicable solution that effectively controls pests while ensuring the production of high-quality organic fruits and vegetables. Particle Film Technology represents a groundbreaking method for insect control, with the potential to transform pest management practices in a manner comparable to the introduction of the first synthetic insecticides, all while being environmentally safe. In addition, it offers agriculture an effective solution for mitigating sunburn and heat stress by modulating UV light, PAR and IR radiation (Glenn and Puterka, 2005 and Ali et al., 2024).

The utilization of marine algae represents one of the most promising techniques for pest management without the application of insecticides. Algae can decrease crop pests by functioning as pesticides (Ali and Sallam 2023). Additionally, Asimakis et al. (2022) indicated that the growing population necessitates the production of additional food. Biotoxins represent an essential category of agricultural protectants as they typically exhibit fewer residual impacts compared to traditional pesticides and are safer for humans and the ecosystem (Copping and Menn, 2000). Algae demonstrated certain effects in inhibiting aquatic fauna components, yet there are few reports regarding the insecticidal properties of algae. Cyanobacteria generate various metabolites that demonstrate a range of bioactivities (Wiegand and Pflugmacher, 2005). The *Cyanobacterium aquae* exhibited insecticidal effects on lepidopteran insects and contained polysaccharides that provided biological properties against certain pests (Philippe, 2018).

The attract-and-kill strategy relies on manipulating pest insect behavior by combining long-range olfactory or visual stimuli to lure a specific pest species toward a killing agent or a collection device. Bait stations, a key component of this system, are described as compact units containing attractants and toxins, sometimes paired with a visual element, designed to target specific pests. These stations may or may not require maintenance to stay effective throughout the season. However, any attracted and killed insects that are retained should be discarded and excluded from further counts, as noted by Shelly et al. (2014).

Various studies have highlighted the bagging technique as a highly effective method for controlling fruit flies in commercial mango orchards (Hossain et al., 2020). Evidence suggests that enclosing fruits in bags at least 30 days before harvest can significantly reduce infestation rates of the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), with declines reaching up to 100% (Sarker et al., 2009). Additionally, bagging has been recognized as a reliable approach for organic pest management (Graaf, 2010). Research conducted by Chonhenchob et al. (2011) demonstrated that bagged mangoes experience lower susceptibility to damage from anthracnose, insects, animals, mechanical injuries, abrasions and skin discoloration compared to unbagged mangoes. As a result, this physical protection method provides an excellent non-chemical alternative for incorporation into existing IPM strategies in mango production.

This study aimed to evaluate and compare the effectiveness of 25 IPM programs in the control of the peach fruit fly, *Bactrocera zonata* (including complete cover spray by chemical insecticides, bioinsecticides, particle film technology, mixture of chemical insecticides, mixture of bioinsecticides, partial spray and fruit bagging programs) under field conditions in Ismailia Governorate over two consecutive mango fruiting seasons (2021–2022).

MATERIALS AND METHODS

This study was carried out over two consecutive seasons, 2021 and 2022, on the Ewais mango cultivar grown in a private orchard located in El-Mostakbal City, Ismailia Governorate, Egypt. The trees, aged 20 years, were cultivated in sandy soil and irrigated using a drip irrigation system, with a planting distance of 6 x 6 meters. Fifteen trees of uniform vigor and size were chosen to evaluate the impact of various IPM programs applied as sprays to control the peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae), in mango trees. All the selected trees were maintained under the standard horticultural practices routinely implemented in the orchard.

1. Sampling Techniques

The test integrated control programs were evaluated during the experimental period of growth, from May to August against peach fruit fly *Bactrocera zonata* infesting mango trees. The effect of pretreatment was examined by evaluating the effect of pretreatment on the following parameters. In this study five replications of the control and twenty-five integrated control programs were used. Each sample consisted of three mango trees. Five fruits samples were randomly collected from each tree (replicate) representing different levels and orientations of the tree to study peach fruit fly insects that damage fruits (Zida et al., 2023).

2. Materials Sources

Material sources were as represented in Table (1).

Table (1). Different formulations.

Trade names	Active ingredient	Rate of application
Malatox 57% EC	Malathion	2 ml/ liter of water
Dimetox 40% EC	Dimethoate	2 ml/ liter of water
Extra power	Chloroprimiphos	1 ml/ liter of water
Axcon 5% EC	Lmbada cyhalthrin	0.5 ml/ liter of water
Domaneit 2.5% EC	Beta-cyfluthrin	2 ml/liter of water
Radient 12% SC	Spinetoram	0.3 ml/ liter of water
Proxyidne 10% EC	Pyriproxyfen	0.5 ml/ liter of water
Buminal 38.67% SL	Protein hydrostat	25 ml/ liter of water
Tracer 24% SC	Spinosad	0.5 ml/ liter of water
Biosad 22.8% SC	Spinosad	0.5 ml/ liter of water
Spencer 24% SC	Spinosad	0.5 ml/ liter of water
Dipel DF 6.4%	*Bacillus thuringiensis*	0.6 g / liter of water
Zentary 54% DF	*Bacillus thuringiensis*	0.6 g / liter of water
Biocontra	Different kinds of algae species	1 g/ liter of water
Spirulina	Spirulina	1 g/ liter of water
kaolin	Aluminum Silicate	3 g/ liter of water
Aglev Si 300	Magnesium Aluminum Silicate	1 g/ liter of water
Diatom	Diatom	3.5 g/ liter of water
Conserv CB % 0.024	Spinosad + food attractant	50 ml/ liter of water
Shoot 2.5% EC	Deltamethrin + 5% Buminal	0.2 ml/ liter of water
Super Alpha 10% EC	Alpha-cypermethrin + 5% Buminal	7.5 ml / liter of water

3. Insect Observations

Samples were gathered and analyzed in the laboratory utilizing a stereoscopic microscope. The samples were preserved in canvas bags within a refrigerator. The reduction percentage in infestation was determined using the formula established by Topps and Wain (2008) as follows:

$$R\,\% = \frac{C - T}{C} \, X\, 100$$

Where, C: Number of insects recorded in the control samples.
T: Number of insects recorded in treatment samples

Control trees remained untreated, while all other trees were thoroughly coated with the treatment solutions. Eight spraying sessions were conducted, beginning in early May and continuing through August, with two-week intervals between applications. The sprayings were performed using a six-horsepower motor sprayer, referred to as "Beem", which was outfitted with a 600-liter tank. The application rate was 25 liter per tree, as outlined by Ali et al. (2024).

4. Integrated Control Programs of Peach Fruit Fly on Mango Trees

4.1 Complete cover spray programs against peach fruit fly

To determine the effect of some integrated pest programs by using some chemical insecticides (programs 1, 2 and 3), bioinsecticides (programs 4, 5 and 6), minerals (programs 7, 8 and 9), minerals with chemical insecticides (programs 10, 11, 12, 13, 14 and 15) and minerals with bioinsecticides (programs 16, 17, 18, 19, 20 and 21) in the following sprayings every two weeks with different formulations in different mode of actions against peach fruit fly *Bactrocera zonata* infestation, two criteria are used, the total number of infested fruits and the occurrence of larvae inside the fruits on mango trees. Every formulation was used separately in single spraying. Two sprayings were used every month at 1 and 15 days. The spraying started from May to August (8 sprayings) for four months to control *Bactrocera zonata* insect. All the experiments were conducted for two successive seasons through 2021 and 2022 as follows:

4.1.1 Using chemical insecticides programs against peach fruit fly

Program 1: Using chemical insecticides Malatox 57% EC, Dimetox 40% EC and Extra power, respectively.

Program 2: Using chemical insecticides Axcon 5% EC, Domaneit 2.5 EC, shoot 2.5% EC, respectively.

Program 3: Using chemical insecticides Dimetox 40% EC, Radient 12% EC and Proxyidne10% EC, respectively.

4.1.2 Using bioinsecticides programs

Program 4: Using bioinsecticides (Spinosad) Tracer 24% SC, Biosad 22.8% SC and Spencer 24% SC, respectively.

Program 5: Using bioinsecticides (*Bacillus thuringiensis*) Dipel DF 6.4%, Zentary 54% DF, respectively.

Program 6: Using bioinsecticides (algae) Biocontra, Spirulina two weeks spraying, respectively.

4.1.3 Using particle film technology (minerals) programs

Using the mixture of three minerals (particle film technology), kaolin, ataboglite (Aglev Si 300) and diatom in three rates (programs 7, 8 and 9) (Ali, 2016; Ali et al., 2021; Morsi, 2021 and Ali et al., 2024) as follows:

Program 7: Using three minerals (kaolin, Aglev Si 300 and diatom) in concentrations 100: 100: 100%, respectively.

Program 8: Using three minerals (kaolin, Aglev Si 300 and diatom) in concentrations 75: 75: 75%), respectively.

Program 9: Using three minerals (kaolin, Aglev Si 300 and diatom) in concentrations 50: 50: 50%), respectively.

4.1.4 Programs that use minerals mixed with chemical insecticides

Using the mixture of three minerals (kaolin, Aglev Si 300 and diatom) in three rates (programs 10, 11, 12, 13, 14 and 15) with different chemical insecticides (Ali, 2017) as follows:

Program 10: Using minerals in concentrations (1: 1: 1) with Dimetox 40% EC in 100 % concentration.

Program 11: Using minerals in concentrations (1: 1: 1) with Dimetox 40% EC in 50% concentration.

Program 12: Using minerals in concentrations (0.75: 0.75: 0.75) with Dimetox 40% EC in 100 % concentration.

Program 13: Using minerals in concentrations (0.75: 0.75: 0.75) with Dimetox 40% EC in 50% concentration.

Program 14: Using minerals in concentrations (0.5: 0.5: 0.5) with Dimetox 40% EC in 100% concentration.

Program 15: Using minerals in concentrations (0.5: 0.5: 0.5) with Dimetox 40% EC in 50% concentration.

4.1.5 Using minerals were mixed with biochemical insecticide programs

Using the mixture of three minerals (kaolin, Aglev Si 300 and diatom) in three rates (programs 16, 17, 18, 19, 20 and 21) with different bioinsecticides as follows:

Program 16: Using minerals in concentrations (1: 1: 1) with Tracer 24% SC in 100% concentration.

Program 17: Using minerals in concentrations (1: 1: 1) with Tracer 24% SC in 50% concentration.

Program 18: Using minerals in concentrations (0.75: 0.75: 0.75) with Tracer 24% SC in 100% concentration.

Program 19: Using minerals in concentrations (0.75: 0.75: 0.75) with Tracer 24% SC in 50% concentration.

Program 20: Using minerals in concentrations (0.5: 0.5: 0.5) with Tracer 24% SC in 100% concentration.

Program 21: Using minerals in concentrations (0.5: 0.5: 0.5) with Tracer 24% SC in 50% concentration.

4.2. Partial spray programs against peach fruit fly

The bait mixture was added to a CP3 sprayer. The lower part of the mango tree trunk (to about one meter height from the earth) was sprayed with different formulations. The trees were sprayed nine times from the end of June to the end of mango season in August every ten days (Ali, 2007 and Essam et al., 2019) as follows:

Program 22: Using bioinsecticides Conserv CB % 0.024 each two weeks spraying, respectively.

Program 23: Using chemical insecticides Super Alpha 10%EC, Domaneit 2.5% EC, shoot 2.5% EC that were mixed with food attractant (Buminal 38.67% SL in rate 5%), respectively.

Program 24: Using chemical insecticides Saymex 5% EC and Yamason 15% EC that were mixed with food attractant (Buminal 38.67% SL in rate 5%), respectively.

4.3. Bagging fruit programs against peach fruit fly

Fruit bagging (program 25) was applied to all fruits on the tree one week after hand thinning using paper bags 15 x 20 cm (Ali, 2017; Karara et al., 2019 and Islam et al., 2024). Each mango fruit was wrapped with paper bag. Fruits of 2 cm diameter were bagged individually (from May to August month after fruit setting). Bags were tied at the fruit peduncle with a jute string. The bags were removed only after harvesting of the fruits. The control treatment was without wrapping or any insecticides.

5. The Statistical Analysis

The data of experiment were analyzed by analysis of variance (ANOVA) in randomize complete block design. The significant between means of all tested characters carried out using L.S.D. test (0.05).

RESULTS AND DISCUSSION

1. Integrated Management Programs of Peach Fruit Fly in Mango Groves throughout Seasons 2021 and 2022

Keeping in view the human health and environmental hazards resulted from the indiscriminate use of synthetic pesticides, it was thought to be important to control mango fruit fly through non-chemical means. To achieve this goal, different methods were used to control peach fruit fly before ripening fruits through integrated pest management. The results are presented and discussed in the following heads:

1.1 Complete Cover Spray Programs against Peach Fruit Fly

1.1.1. Effect of chemical insecticide programs against peach fruit fly

As shown in Table (2) the results obtained through the first season 2021 indicate that infestation was significantly lower in the treated mango fruits than untreated ones. The data proved the superiority of programs (1 and 2) in controlling the peach fruit fly over program (3) and the untreated control treatments. The mean number of infested fruits and larvae as affected by program 1 and 2 complete coverage spray by chemical insecticides were (1.0 and 0.8) and (1.5 and 1.1), respectively as compared with 15.8 and 16.8 in the control treatment. These results represented a reduction (93.7 and 90.5%) in fruit infestation, a reduction (95.2 and 93.5%) in larval infestation after program 1 and 2 treatments. In program (3) treatment was the lowest reduction percentage that had potential effects less than 90% (84.8 and 86.3% in infested fruits and larval stage, respectively). Complete agreement was found between the above results in the first season (2021) and those obtained from the second season (2022) which revealed that programs (1 and 2) were the most effective programs followed by program (3). They reduced fruit infestation by 92.3, 90.9 and 85.3% and larval infestation by 95.2, 92.5 and 87.1%, respectively against peach fruit fly insect. In the previous results, the data indicated that programs (1 and 2) reduced the infestation of peach fruit fly on mango trees more than 90% reduction but program (3) gave accumulative effects less than 90% reduction through the infested fruits and larval stages in the two seasons (2021 and 2022).

Table (2). Cumulative effect of chemical insecticide programs on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	**2021**				**2022**			
	***Infested fruits**		***Larvae**		***Infested fruits**		***Larvae**	
	Mean	**%R**	**Mean**	**%R**	**Mean**	**%R**	**Mean**	**%R**
1	1.0	93.7	0.8	95.2	1.1	92.3	0.7	95.2
2	1.5	90.5	1.1	93.5	1.3	90.9	1.1	92.5
3	2.4	84.8	2.3	86.3	2.1	85.3	1.9	87.1
Control	15.8		16.8		14.3		14.7	
LSD	**0.190**		**0.173**		**0.150**		**0.153**	

% R = Reduction Percentage

*Cumulative number of infested fruits all over the growing season (8 dating samples)

These results were similar with the studies of many authors; Maulid et al. (2015) in their study on integrated pest management against *Bactrocera dorsalis* in mango recommended broadcast spray of karate (Lambda cyhalothrin) for commercial farmers, mostly targeting regional markets. Saji et al. (2023) said that among the insecticides evaluated lowest reduction of percent fruit infestation was observed in treatments lambda cyhalothrin 5 EC @ 25 g.a.i/ha (23.87%) and azadirachtin 0.03% @ 3 ml/l (25.18%) which are at par with each other. The next effective treatment was imidacloprid 17.8 SL @ 30 g.a.i /ha which recorded an infestation of 34.78%. The highest percent fruit infestation was recorded in the treatment *Beauveria bassiana* WP 2% @ 20 g/L (58.35%). Lambda cyhalothrin 5 EC was the superior treatment in comparison with the mean yield per plant, net monetary return and benefit cost ratio, followed by azadirachtin 0.03% and imidacloprid 17.8 SL. Nath et al. (2014) indicated that the average of two rainy seasons data showed that the treatment schedule fenthion + fenthion + fenthion had least fruit damage (1.3%) by the fruit fly followed by achook + malathion bait spray + malathion (5.5%). The maximum fruit damage was recorded in control plot (46.5%) followed by neem gold + malathion bait spray (15.3%). The average effect of ecofriendly insecticides of two rainy seasons showed minimum fruit damage during 39th standard week (6.8%) followed by 41st standard week (6.84%) and the maximum fruit damage was recorded during 40th standard week (12.6%) followed by 38thstandard week (12.4%).

1.1.2. Effect of some bioinsecticide programs against peach fruit fly

The data in Table (3) indicate that in the first season (2021) there were significant differences between the mean numbers of the infested mango fruits and larval stage of *Bactrocera zonata* found in the control samples (15.8 and 16.8) when compared with those in the treated trees which were 2.6, 3.1 and 4.0) and (2.6, 3.0 and 3.9) for programs (4, 5 and 6), respectively against infested mango fruits and larval stage of *Bactrocera zonata*. All the tested compounds caused noticeable infested mango fruits and larvae stage reduction of peach fruit fly with reduction percentage (83.5, 80.4 and 74.7%) and (84.5, 82.1 and 76.8%), respectively.

Table (3). Cumulative effect of bioinsecticide programs on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	*Infested fruits		*Larvae		*Infested fruits		*Larvae	
	Mean	%R	Mean	%R	Mean	%R	Mean	%R
4	2.6	83.5	2.6	84.5	2.2	84.6	2.2	85.0
5	3.1	80.4	3.0	82.1	2.7	81.1	2.7	81.6
6	4.0	74.7	3.9	76.8	3.2	77.6	3.3	77.6
Control	15.8		16.8		14.3		14.7	
LSD	**0.246**		**0.279**		**0.209**		**0.193**	

% R = Reduction Percentage

*Cumulative number of infested fruits all over the growing season (8 dating samples)

Results of season (2022) for the tested programs against infested mango fruits and larvae of the *Bactrocera zonata* on mango trees showed that the reduction rate was high for fruits treated with program (4) (84.6 and 85%) followed by program (5) (81.1 and 81.6%) and program (6) (77.6 and 77.6). The mean infestation of mango fruits and larval stage were (2.2 and 2.2), (2.7 and 2.7) and (3.2 and 3.3) for programs (4, 5 and 6, respectively). The data in the first and the second season were the same trend that reported that program (4 and 5) were the most effective bioinsecticide in reducing the population of infested fruits and larval stage which more than 80% in causing the lowest average of population when was compared with program (6) in reduction percentage from (74.7 to 77.6%).

These results are in line with the study by Diksha et al. (2019), who claimed that insecticides were the better treatment for an infection rate of 17.4%. Although azadirachtin was less effective than pyrethroids against fruit flies, it was also quite effective in reducing fruit infestation. Verghese et al. (2020) in an effort to improve the current control strategy for *Bactrocera dorsalis* in mango, the results showed that the application of neem-based pesticides to trees during the fruiting period, along with the use of methyl eugenol traps, created a push-pull environment for female and male fruit flies, respectively; resulting in a significant reduction in fruit fly infestation.

Olfactory deterrents can confuse and repel pregnant female fruit flies, thereby preventing their egg laying and infestation. Abdullah et al. (2024) discovered that neem oil at concentrations of (5 and 3%) was successful in managing the fruit fly *Bactrocera zonata*. Abbas et al. (2021) utilized extracts from neem and watermelon plants to obtain positive outcomes. These techniques were shown to be more efficient, lowering the count of fruit fly pupae by (14.5, 10.7, 9.9, 2.9, 7.2 and 2.3%) in guava, citrus and mango orchards, respectively. Likewise, following the second application, the infection rates of fruit in guava, citrus and mango farms were reduced by (19.4, 10.3, 15.5, 10.8, 5.8, and 4.80%), respectively. When all the components were utilized together, the highest percentage decrease in fruit perforation was 14.4, 7.8 and 7.3% in guava, citrus and mango orchards, respectively. Nisar et al. (2021) demonstrated that a diet high in *Metarhizium anisopliae* was superior in adult animals for combating *Bactrocera zonata*, followed by *Beauveria bassiana*, *Lecanicillium lecanii* and *Bacillus thuringiensis* consequently, *M. anisopliae.*

1.2 Effect of particle film technology programs against peach fruit fly

1.2.1 Effects of some minerals (kaolin, Aglev Si 300 and diatom) **against peach fruit fly**

The obtained data in Table (4) indicate that infestation was significantly lower in the treated mango fruits with particle film technology programs than untreated ones. The results of the first season (2021) cleared that after the applications of the programs (7, 8 and 9) in cumulative peach fruit fly infestation and larvae average number through the season in treated trees at rates 100, 75 and 50%, were (3.9, 4.6 and 5.3) (3.8, 4.5 and 5.4), respectively as compared with (15.8 and 16.8) in the untreated trees. Programs (7, 8 and 9) treatment reduced infestation and larvae by (75.3, 70.9 and 66.5%) and (77.4, 73.2 and 67.9%) in different concentrations, respectively.

The results obtained in the second season, appeared a similar trend to the first season. Treating mango trees as particle film technology programs treatments with different rates reduced infestation and larvae by (76.2, 71.3 and 68.5%) and (78.2, 73.5 and 66%), respectively. Their cumulative average number of fruit infestation were (3.4, 4.1 and 4.5) and (3.2, 3.9 and 5) respectively, as compared with (14.3 and 14.7) in the untreated control trees. These results indicated that particle film technology programs in different rates suppressed peach fruit fly infestations. When the rates were high, the reduction percentages of infestations were high too for control peach fruit fly. The best rates of particle film technology were (100 and 75%) in (programs 7 and 8) but 50% rate was less. The data showed that the rates (100 and 75%) achieved more than 70% reduction of peach fruit fly infestations on mango trees and ranged from (66 to 78.2%) reduction of infestation of peach fruit fly in the two seasons (2021 and 2022).

Table (4). Cumulative effect of particle film technology programs on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	*Infested fruits		*Larvae		*Infested fruits		*Larvae	
	Mean	%R	Mean	%R	Mean	%R	Mean	%R
7	3.9	75.3	3.8	77.4	3.4	76.2	3.2	78.2
8	4.6	70.9	4.5	73.2	4.1	71.3	3.9	73.5
9	5.3	66.5	5.4	67.9	4.5	68.5	5.0	66.0
Control	15.8		16.8		14.3		14.7	
LSD	**0.217**		**0.172**		**0.178**		**0.250**	

% R = Reduction Percentage
*Cumulative number of infested fruits all over the growing season (8 dating samples)

1.2.2 Effect of particle film technology that were mixed with chemical insecticide programs against peach fruit fly

As shown in Table (5) the obtained results in first and second season (2021 and 2022) indicate that infestation was significantly lower in the treated mango fruits than untreated ones. All programs from 10 to 15 had reduction percentage more than 90% with two rates 100, 75 and 50% concentrations of chemical insecticides that were mixed with materials of particle film technology.

Table (5). Cumulative effect of particle film technology plus chemical insecticide on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	*Infested fruits		*Larvae		*Infested fruits		*Larvae	
	Mean	%R	Mean	%R	Mean	%R	Mean	%R
10	0.3	98.1	0.5	97.0	0.2	98.6	0.3	98.0
11	0.7	95.6	0.6	96.4	0.3	97.9	0.5	96.6
12	0.5	96.8	0.7	95.8	0.4	97.2	0.7	95.2
13	0.8	94.9	1.0	94.0	1.2	91.6	1.0	93.2
14	1.0	93.7	1.3	92.3	1.4	90.2	1.2	91.8
15	1.4	91.1	1.6	90.5	1.4	90.2	1.3	91.2
Control	15.8		16.8		14.3		14.7	
LSD	**0.133**		**0.111**		**0.122**		**0.127**	

% R = Reduction Percentage
*Cumulative number of infested fruits all over the growing season (8 dating samples)

The data proved the superiority of the program (10, 11, 12, 13, 14 and 15) treatments in controlling the peach fruit fly. However, the lower effect achieved and untreated control treatments. The cumulative average number of total infested fruits and larvae as affected by 100 and 50% rates of chemical insecticides were (0.3 and 0.5), (0.7 and 0.6), (0.5 and 0.7), (0.8 and 1.0), (1.0 and 1.3) and (1.4 and 1.6), respectively as compared with (15.8 and 16.8) in the untreated control treatment, representing (98.1 and 97%), (95.6 and 96.4%), (96.8 and 95.8%), (94.9 and 94.0%), (93.7 and 92.3%) and (91.1 and 90.5%) reduction of infestations, respectively. The similar results were in the first season and those obtained from the second season (2022). The previous results, mentioned that all program treatments gave highly control against peach fruit fly through two seasons (2021 and 2022).

1.2.3 Effect of particle film technology that were mixed with bioinsecticide programs against peach fruit fly

As shown in Table (6), results of the first season (2021) indicate great significant differences between the mean number of infested fruits and larvae of peach fruit fly found in examined control samples (15.8 and 16.8) and treated samples. The lowest infestation levels of infested fruits and larvae on peach fruit fly was recorded on fruits sprayed according to programs 16 (0.8 and 0.8), 17 (1.1 and 0.9), 18 (1.2 and 1.3), 19 (1.2 and 1.1), 20 (1.5 and 1.5) and 21(1.5 and 1.6), respectively. Program (16) caused the highest reduction percent in infested fruits and larvae of peach fruit fly insect (94.9 and 95.2%) followed by program (17, 18, 19, 20 and 21) which caused (93 and 94.6%), (92.4 and 92.3%), (92.4 and 93.5%), (90.5 and 91.1%) and (90.5 and 90.5%) reductions, respectively. The results obtained in the second season (2022) confirmed with as in the first season (2021). All programs gave reduction percentage more than 90%.

Ali (2016) and Iannotta et al. (2007) obtained that particle film technology (kaolin and bentonite) has great potential for the control of *Bactrocera oleae* population. It is sprayed onto canopy as a liquid suspension while water evaporates leaving kaolin as a white porous protective powdery film on the leaves and fruits surface. The kaolin and bentonite-based particle film caused a reduction of adult population. Although, it is not directly toxic to insects, its insecticidal properties are repellent nature, anti-ovipositional qualities or due to its highly reflective white coating. Moreover, as a consequence of the repulsion of gravid females due to abovementioned behavioral reasons and the tactile unsuitable texture of particle film treated olives, data concerning active infestation percentages in the theses treated with kaolin, bentonite and copper products registered a significant reduction. However, the environmental impact eventually associated with kaolin application should be evaluated. Kaolin clay is unequivocally non-toxic to the environment. Moreover, the obtained results are largely consistent with the research of Ali et al. (2024) concerning mango trees, demonstrating that effective control of the mango shield scale insect can be achieved using diatom and Aglev Si 300, which yield a reduction exceeding 80%. Similarly, kaolin (60-87%) and bentonite (50-70%) produce comparable effectiveness across different stages of the insect's development, including immature, adult and ovipositing adult stages. This aligns with earlier findings by Ali et al. (2021), who highlighted Aglev Si 300 and diatoms as the most efficient agents, achieving a 100% mortality rate against the preadult stage of this pest. Ali and El-Mahdy (2024) identified significant effects of diatom, kaolin, Aglev Si 300 and bentonite in powdered silicon formulations, demonstrating corrected mortality rates ranging from 40 to 100% against both adult and pupal stages of *Bactrocera zonata*.

Table (6). Cumulative effect of particle film technology plus chemical bioinsecticide on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	*Infested fruits		*Larvae		*Infested fruits		*Larvae	
	Mean	%R	Mean	%R	Mean	%R	Mean	%R
16	0.8	94.9	0.8	95.2	0.6	95.8	0.5	96.6
17	1.1	93.0	0.9	94.6	1.0	93.0	0.5	96.6
18	1.2	92.4	1.3	92.3	1.0	93.0	0.8	94.6
19	1.2	92.4	1.1	93.5	0.8	94.4	0.8	94.6
20	1.5	90.5	1.5	91.1	1.2	91.6	1.0	93.2
21	1.5	90.5	1.6	90.5	1.3	90.9	1.3	91.2
Control	15.8		16.8		14.3		14.7	
LSD	0.128		0.122		0.137		0.141	

% R = Reduction Percentage

*Cumulative number of infested fruits all over the growing season (8 dating samples)

Supporting these findings, Morsi (2021) evaluated the efficacy of mineral-organic compounds such as kaolin and calcium carbonate. Kaolin proved more effective than calcium carbonate and outperformed malathion, a commonly used insecticide. By forming a particle film on the surface of fruits, kaolin acted as a physical barrier to prevent egg-laying by *Bactrocera zonata* females. Similarly, compounds like kaolin have been widely employed in pest control strategies. Many Studies highlighted the use of kaolin in managing Mediterranean fruit flies *Ceratitis capitata*, olive fruit flies *Bactrocera oleae* and the pomegranate butterfly, *Virachola livia* (Klug) (Mozhdehi and Kayhanian 2014; Ali, 2016; Ali, 2017 and Pangihutan et al., 2022). Further research by Ali et al. (2022) demonstrated the toxic effects of silicon formulations such as kaolin, bentonite, Aglev Si 300 and diatom powders against the two-spotted spider mite *Tetranychus urticae* under laboratory conditions. Additionally, Balayara et al. (2019) emphasized the potential of kaolin and neem-based products; including oil, cake and seed powder, as alternatives to synthetic insecticides for controlling adult flies and larval-pupal stages of *Bactrocera dorsalis*, contributing positively to integrated pest management practices.

2. Effect of Partial Spray Method against Peach Fruit Fly

Data obtained from this experiment are shown in Table (7). The results indicate that infestation was significantly lower in the treated mango than untreated ones. The results of the first season (2021), showed that after the partial bait spray the cumulative peach fruit fly infestation and larvae through the season in treated trees were (3.0 and 2.7), (4.6 and 4.7) and (5.9 and 5.3) for program (22, 23 and 24), respectively as compared with (15.8 and 16.8) in the untreated trees. These treatments reduced fruit and larval infestation by (81.0 and 83.9), (70.9 and 72.0) and (62.7 and 68.5), respectively. The results obtained in the second season (2022), as represented showed the same trend as the first season. Treating mango trees with partial spray treatments in programs (22, 23 and 24) reduced infestation by (82.5 and 83.0), (72.0 and 76.9) and (69.2 and 72.8), respectively. Their cumulative mean numbers of fruit infestation and larvae were (2.5 and 2.5), (4.0 and 3.4) and (4.4 and 4.0), respectively as compared with 14.3 infested fruits and 14.7 larvae in the untreated control trees.

Table (7). Cumulative effect of partial spraying on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	Infested fruits		*Larvae		*Infested fruits		*Larvae	
	*Mean	%R	Mean	%R	Mean	%R	Mean	%R
22	3.0	81.0	2.7	83.9	2.5	82.5	2.5	83.0
23	4.6	70.9	4.7	72.0	4.0	72.0	3.4	76.9
24	5.9	62.7	5.3	68.5	4.4	69.2	4.0	72.8
Control	15.8		16.8		14.3		14.7	
LSD	0.209		0.330		0.224		0.184	

% R = Reduction Percentage.
*Cumulative number of infested fruits all over the growing season (8 dating samples)

The obtained results align with those of Sadeghi et al. (2024), who demonstrated that controlling adult *Bactrocera zonata* through trunk spraying (a combination of insecticide and protein hydrolysate) proved more effective than shade spraying alone for controlling pupae, while also showing reduced environmental impact. Hythum et al. (2020) confirmed that the use of Spinosad (0.24 g/L) significantly reduced the number of fruit flies using a partial spraying method. For instance, in April, the average number of fruit flies recorded was 947.22 in treated orchards compared to 1001.7 in untreated ones. Over the following months (May through August), the numbers of fruit flies in treated orchards steadily declined, averaging 904.7, 760.2, 609.6 and 452.7, respectively. In contrast, untreated orchards showed a progressive increase, with averages rising to 1003.7, 1103.7, 1336.7 and 1468.7 during the same period. The infestation levels in mango fruits also reflected this trend, with only 2% infestation in treated orchards compared to 64% in untreated ones. Assam et al., (2019) emphasized the effectiveness of partial spraying and thermal fogging techniques against *Bactrocera zonata* and *Ceratitis capitata*. Similarly, Abbas et al. (2021) found that combining different methods offers optimal pest control results. Other integrated strategies, such as trap baiting, trunk or soil application of diazinon insecticide, and removing infested fruits, have been successfully employed in California for many years. Khosravi et al. (2018) and Singh et al. (2020) also highlighted the crucial role of simultaneous approaches, including traps, pesticides and attractants like methyl eugenol and protein hydrolysate, in managing *Bactrocera* populations effectively. Additionally, Piñero et al. (2011) observed that the response of *Bactrocera dorsalis* females to protein baits varies with their age and protein-starvation levels. Mahmoud et al. (2017) demonstrated that GF-120 is an effective alternative to broad-spectrum insecticides when used for baiting and spot spraying and represents a significant addition to IPM programs targeting *Bactrocera zonata* and *Ceratitis capitata* in Egypt. To achieve better outcomes closer to harvest, it is recommended to increase spot-spraying frequency from three to four or five applications, with spraying halted 10 days prior to harvest. Singh et al. (2013) tested four combined modules incorporating the male annihilation technique (MAT), all of which significantly reduced fruit fly infestation compared to control orchards. The highest level of protection (94.5%) was achieved with a module that combined MAT, sanitation practices, soil drenching with 0.1% chlorpyrifos and bait cover spray (0.05% malathion + 0.2% Protinex). This was followed by MAT combined with sanitation and soil drenching (87.3% protection), MAT with sanitation and cover spray (81.8% protection) and MAT with sanitation alone (65.5% protection).

Sadeghi et al. (2024) concluded that using traps alone was the least effective method for controlling *Bactrocera zonata*. In contrast, combining shade spraying, trunk spraying, and pheromone traps provided the most effective control strategy against mango fruit fly infestations.

3. Effect of Bagging Fruit Method Against Peach Fruit Fly

Results for the efficacy of fruit bagging, programs (25, 7 and 1) on peach fruit fly, *Bactrocera zonata* are given in Table (8). Significant differences were found for the average number of infested fruits and larvae infestations of *Bactrocera zonata* among the treatments. Data of season (2021) revealed that the most effective treatment for suppressing peach fruit fly was program (1) as chemical insecticides followed by program (7) as particle film technology and program (25) as bagging fruit method, respectively for infested fruits and larvae infestations of peach fruit fly. According to the results, highest damage of peach fruit fly on the fruits was recorded for the untreated control. The average number of damage fruits by peach fruit fly reached up to (15.8 and 16.8) for infested fruits and larvae infestations in control treatment. The treatments, Program (1) as chemical insecticide gave the least effect on the damages fruits and larvae infestation (1.0 and 0.8) of *B. zonzta* and reduced the infested fruits and larvae infestation by (93.7 and 95.2%). Program (7) as Particle film technology treatment reduced the peach fruit fly damage (75.3 and 77.4%) for infested fruits and larvae infestation and the average number of infested fruits and larva infection were (3.9 and 3.8). Bagging fruit infestation method gave the least effect among the treatments and reduced the percentage of damaged fruits to (55.7 and 60.1%) for infested fruits and larva infections. The damage fruits and larvae infestations were (7 and 6.8). Results indicated that all treatments had at least (55.7 to 77.4%) reduction of damaged fruits as nature control and more than 93% reduction of damaged fruits as chemical control when comparing with the untreated control. The data in the second season (2022) was the same trend in the first season (2021).

Table (8). Cumulative effect of bagging fruit method on infestation reduction percentage of peach fruit fly (*Bactrocera zonata*) in mango groves throughout seasons 2021 and 2022.

Programs	2021				2022			
	*Infested fruits		*Larvae		*Infested fruits		*Larvae	
	Mean	%R	Mean	%R	Mean	%R	Mean	%R
25	7.0	55.7	6.8	59.5	5.8	59.4	5.3	63.9
7	3.9	75.3	3.8	77.4	3.4	76.2	3.2	78.2
1	1.0	93.7	0.8	95.2	1.1	92.3	0.7	95.2
Control	15.8		16.8		14.3		14.7	
LSD	0.452		0.159		0.192		0.191	

% R = Reduction Percentage
*Cumulative number of infested fruits all over the growing season (8 dating samples)

It was found that pre-harvest bagging of fruit could be a simple and grower-friendly technology, which is safe to use and possesses several beneficial effects on the physical appearance and quality of fruit.

Furthermore, it is the safest approach to protect fruit from insect pests, diseases and other disorders. This method is a crucial component of fruit production in various regions worldwide, including Bangladesh. Research highlights that the use of perforated white polyethylene bags for fruit bagging offers maximum protection against fruit fly infestations during summer, resulting in improved mango quality and an optimal benefit-cost ratio. While brown paper and white paper bags showed moderate effectiveness, they lacked the durability of perforated polyethylene bags. The overall cost of these bagging treatments was deemed affordable, with significant advantages, as untreated fruits of inferior quality failed to attract consumers (Begum et al., 2022). Bagging acts as a physical barrier to protect the fruit from pests. Heat convection and prolonged sun exposure, which are linked to spongy tissue disorder, are reduced through this technique (Prakash, 2004 and Karara et al., 2019). Studies revealed that all bagging materials were 100% efficient in protecting against fruit fly and borer attacks. However, different bagging materials significantly influenced the physical and chemical characteristics of the fruits (Islam et al., 2024).

Ravuri et al. (2023) further observed a notable distinction between fruit bagging practices and traditional farming methods, with bagging proving superior in minimizing pest and disease occurrences. The highest yield was recorded with fruit bagging at 9 tons per hectare, compared to farmers' conventional practices yielding 7.5 tons per hectare. Although fruit bagging incurred higher production costs (₹104,0 per hectare), the superior market price of bagged fruits allowed farmers to achieve greater net returns (₹342,3 per hectare). Nonetheless, drawbacks such as reduced fruit sweetness and the challenge of bagging all fruits on older trees were noted.

Overall, pre-harvest fruit bagging remains one of the most effective management strategies for mango production, reducing pest and disease incidences while enhancing yield and fruit quality. Hossain et al. (2020) found that using double-layer brown paper bags 42 days before harvest was highly effective against *Bactrocera dorsalis*. This treatment eliminated fruit infestation; significantly increased marketable yields compared to conventional pesticide methods and achieved nearly double the marginal benefit-cost ratio of other approaches. Its strong economic returns stem from superior fruit quality and the potential reuse of the bags for two growing seasons. These positive findings suggest that double-layer brown paper bagging is highly effective in managing oriental fruit fly infestations and should be integrated into a comprehensive IPM strategy for mango cultivation.

CONCLUSION

Bactrocera zonata (Saunders), commonly referred to as the peach fruit fly (PFF), is a highly damaging pest that poses a significant threat to fruit worldwide. Control measures should ideally commence in May and persist until the fruit has fully ripened, while strictly observing the recommended safety intervals. Given the insect's remarkable capacity to develop resistance against insecticides, it is advised to avoid repeated use of any single insecticide and instead apply them in combination. When evaluating the effectiveness of various integrated management programs (including complete cover sprays using chemical insecticides, complete cover sprays with bioinsecticides, partial sprays, fruit bagging, particle film technology and combinations of these methods) against the peach fruit fly, the results highlighted significant variations in their impact. Programs numbered (1, 2 and 10 through 21) consistently achieved a reduction rate exceeding 90%, making them the most effective options. These were followed by programs (3, 4, 5 and 22), which recorded reduction percentages ranging from (80 to 89%). Programs numbered (6, 7, 8 and 23) demonstrated efficacy within the range of (70 to 79%), while programs (9 and 24) achieved reductions between (60 and 69%).

Lastly, program 25 exhibited the lowest effectiveness, with reduction percentages falling between (50 and 59%). Based on this analysis, bioinsecticides, particle film technology, partial sprays and fruit bagging are recommended over chemical insecticide-based programs due to their added benefits in reducing environmental pollution. Future research on managing fruit flies will need to prioritize IPM strategies, broadening the scope to encompass approaches beyond traditional pest control methods.

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المكافحة المتكاملة لذبابة ثمار الخوخ (*Bactrocera zonata*) على أشجار المانجو تحت ظروف محافظة الإسماعيلية، مصرعصام احمد علي

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تُعدّ ذبابة فاكهة الخوخ (*Bactrocera zonata* Saunders) من أكثر أنواع ذباب الثمار ضررًا من الناحية الاقتصادية، إذ تصيب أشجار المانجو (*Mangifera indica* L.) ومحاصيل الفاكهة الأخرى في المناطق المدارية وشبه المدارية، لا سيّما في مصر. ونظرًا لتزايد المخاوف المرتبطة بمقاومة الآفات للمبيدات، التلوث البيئي وسلامة الغذاء، هدفت هذه الدراسة إلى تقييم ومقارنة فاعلية ٢٥ برنامجًا للإدارة المتكاملة للآفات (IPM) على ثمار المانجو تحت ظروف الحقل في محافظة الإسماعيلية خلال موسمي إثمار متتاليين (٢٠٢١-٢٠٢٢م). شملت البرامج التجريبية: الرش الكامل بالمبيدات الكيميائية التقليدية، واستخدام المبيدات الحيوية (مثل Spinosad، *Bacillus thuringiensis* والطحالب البحرية)، وتطبيق تقنيات الفيلم الجزيئي باستخدام معادن خاملة (مثل الكاولين، Aglev Si 300 والدياتوم)، وبرامج تجمع بين المعادن والمبيدات، بالإضافة إلى الرش الجزئي الطُعمي وتغليف الثمار بأكياس ورقية. وتم قياس نسب الإصابة وعدد اليرقات في الثمار وتحليل النتائج إحصائيًا. أظهرت النتائج أن البرامج التي جمعت بين المعادن والمبيدات الكيميائية أو الحيوية (البرامج ١٠-٢١) كانت الأكثر كفاءة، حيث حققت نسب خفض في الإصابة تجاوزت ٩٠٪. كما سجلت البرامج الحيوية أو المعتمدة على الفيلم الجزيئي وحدة (البرامج ٤-٩) فعالية ملحوظة تراوحت بين ٦٦ و٨٥٪. في حين قدّمت برامج الرش الجزئي وتغليف الثمار (البرامج 22-25) فعالية متوسطة (بين ٥٥ و٨٣٪)، مما يعزز دورها كوسائل مكافحة هامة في منظومة المكافحة المتكاملة للآفات. وتشير هذه النتائج إلى إمكانية إعتماد البدائل الآمنة للمكافحة بيئيًا، كالمبيدات الحيوية وتقنيات الفيلم الجزيئي ضمن استراتيجيات مكافحة الآفات في مزارع المانجو، مما يسهم في تقليل الإعتماد على المبيدات الكيميائية المصنعة، وتحقيق أهداف الزراعة المستدامة من خلال الإدارة المتكاملة للآفات على نطاق واسع.