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(Original Article)

Efficacy and Toxicity of Bio and Chemical Insecticides Against Field and Laboratory Strains of the Mediterranean Fruit Fly, *Ceratitis capitata* (Wiedemann)

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Abstract

The Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) is a serious global agricultural pest, causing significant economic losses to a variety of crops, especially in the vital horticulture sector. This study comprehensively investigates different management strategies for this pest, ranging from the efficacy of entomopathogenic fungi to synthetic and naturally derived insecticides, which were evaluated under laboratory and open field conditions in Egypt during the growing seasons of 2023 and 2024. This study indicated varying susceptibility of field and laboratory fly strains across all tested experiments. Laboratory evaluations of the fungicide, *Beauveria bassiana* (Bals.-Criv.) Vuill. revealed its time-dependent efficacy against adults of *C. capitata*. Spinosad, a naturally derived compound, showed significantly higher rapid and acute efficacy against the susceptible fly strain compared to the field strain. Malathion showed significant latent efficacy against the susceptible laboratory strain. Moving to open field conditions, a comparative evaluation of spinosad, malathion, and betacyfluthrin revealed superior performance. Malathion achieved strong initial population reductions, while spinosad achieved balanced performance with effective initial control. Notably, betacyfluthrin demonstrated inconsistent and often negative reductions. spinosad stands out as a highly effective and balanced option for rapid control, and *B. bassiana* provides excellent long-term biological suppression, reliance on older chemicals such as malathion is negatively impacted by the spread of resistance. Future management protocols should prioritize the rotational use of diverse modes of action, integrate biological and chemical control, and utilize continuous monitoring to adapt to evolving pest dynamics, ensuring sustainable control of *C. capitata* in agricultural settings.

Keywords: *Beauveria bassiana, Ceratitis capitata, Insecticides alternatives, Integrated Pest Management, spinosad,*

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Introduction

The Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), commonly known as the "Medfly," is one of the most economically devastating agricultural insect pests worldwide. Originating from sub-Saharan Africa, its remarkable adaptability, broad host range encompassing over 250 fruit and vegetable species, and high reproductive potential have facilitated its global spread, establishing populations across temperate, subtropical, and tropical regions (Liquido *et al.,* 1991; De Meyer *et al.*, 2010). The economic ramifications are colossal, including significant yield losses, stringent quarantine restrictions impeding international trade, and substantial costs associated with control measures and eradication programs (Enkerlin, 2005; White and Elson-Harris, 1992). Historically, the control of *C. capitata* and other agricultural pests heavily relied on broad-spectrum conventional chemical insecticides, such as organophosphates and pyrethroids. Compounds like malathion, an organophosphate, were instrumental in large-scale eradication and suppression programs for decades, often applied as bait sprays (USDA-APHIS, 2018). While initially effective, the sustained and often intensive use of these traditional chemicals has led to several critical challenges. Foremost among these is the widespread development of insecticide resistance in target pest populations, rendering once-effective compounds increasingly futile (Vassiliou *et al*., 2011; Bass *et al*., 2019). Furthermore, the broad-spectrum nature of these chemicals poses significant environmental concerns, including detrimental impacts on non-target organisms such as beneficial insects (predators, parasitoids, pollinators), contamination of water bodies and soil, and potential risks to human health through residues in food and occupational exposure (Carvalho, 2017). Biological control agents, such as entomopathogenic fungi, offer a targeted approach, typically exhibiting high specificity to the pest with minimal impact on non-target organisms and the ecosystem (Lacey *et al*., 2015). Simultaneously, naturally derived insecticides, like spinosad, represent a hybrid solution. Produced through microbial fermentation, spinosad possesses potent neurotoxic activity against insects while generally having a more favorable environmental and safety profile than many conventional insecticides, making it suitable for organic agriculture and integrated pest management (IPM) programs (Marrone, 2019; Salgado, 1997). This study, conducted under both controlled laboratory and real-world open-field conditions in critical agricultural regions of Egypt, aimed to comprehensively evaluate the efficacy of key pest control agents against *C. capitata*. Concurrently, we assessed the potency of spinosad, naturally derived insecticide, and malathion, a classic conventional chemical, to understand their comparative effectiveness and the extent of resistance in field populations. Finally, the research extended to large-scale open-field trials, comparing the practical reduction ratios achieved by spinosad, malathion, and betacyfluthrin class pesticide over time, providing critical insights into their residual activity and overall performance under diverse environmental pressures. The overarching goals of this study is to provide empirical data to inform and optimize Integrated Pest Management strategies for *C. capitata*, advocating for the strategic deployment of effective and environmentally responsible control methods to ensure sustainable fruit and vegetable production.

Materials and Methods

The present study was carried out at the experimental laboratory of the Pesticides Department, Faculty of Agriculture, Damanhour University during 2023 and 2024 seasons to determine the efficacy and toxicity of bio and chemical insecticides against laboratory and field strains of the Mediterranean fruit fly, *C. capitata*.

The strains of the target insect pest the Mediterranean fruit fly, *C. capitata*:

- **Source and Rearing**

Laboratory and field strains of the Mediterranean fruit fly were utilised in this study. The field strain was established from infested citrus fruits collected from Beheira Governorate, Egypt. Adult flies were allowed to emerge from the fruits and subsequently reared under controlled laboratory conditions. The methodology for establishing and maintaining this field colony, particularly the collection and initial rearing of field-collected infested fruits to establish a laboratory colony, closely followed procedures outlined by El-Gendy (2002). The laboratory strain had been continuously maintained under laboratory conditions for three preceding seasons. Both strains were reared under constant laboratory conditions of 25± 2°C and 75% relative humidity. Flies were housed in wooden cages (40x40x60 cm) and adult flies were provided with a food medium consisting of dry yeast and sugar at a 1:3 ratio. Eggs were allowed to fall into a water reservoir located beside the cage base and were collected daily as described by El-Gendy (2018). The collected eggs were then transferred to an artificial larval rearing medium according to Tanaka *et al.* (1969). Matured larvae were collected immediately after emergence from the artificial larval and maintained to adults' emergence (El-Gendy, 2002).

Bio and chemical insecticides used

Tested insecticides, active ingredient, trade names, percentage of active ingredients, formulation types, chemical group, manufacturer and recommended dose are listed in Table 1.

Preparation of insecticide solutions

Different concentrations of each insecticide were prepared according to its recommended dose mentioned in Table (1) by serial dilution of the commercial product with distilled water to obtain the desired final concentrations.

Table 1. List of the applied insecticides and their detailed information during 2023 and 2024 seasons.

Insecticidas info.	Bio-insecticides		Chemical insecticides	
	Beauveria bassiana	**Spinosad**	**Malathion**	**Betacyfluthrin**
Formulation Type	WP	SC	EC	EC
Chemical Group	Clavicipitaceae	Spinosyns	Organophosphate	Pyrethroid
Common Name	*Beauveria bassiana*	Spinosad	Malathion	Betacyfluthrin
Trade Name	Biovar 2.5% WP, 2.3×10^8 conidia/gm	Tracer 24% SC	Malathion 57% EC	Jolicoeur 10% EC
Molecular Formula	$C_{45}H_{57}N_3O_9$	$C_{83}H_{132}N_2O_{20}$	$C_{10}H_{19}O_6PS_2$	$C_{22}H_{18}C_{l2}FNO_3$
Manufacturer	Plant Protec. Resea. Inst., Agric. Resea. Center, Ministry of Agric., Egypt	Dow Agrosense England	Kafr El zayat	Jolicoeur Kima for chemical manufacture
Molecular Weight	783.9 g/mol	1477.9 g/mol	330.36 g/mol	353.4 g/mol
Field-Applied Concentrations	-	20 ml/100 L	150 cm/100 L	50 ml/100 L
Laboratory-Used Concentrations	5.75×10^5, 1.15×10^6, 2.3×10^6, and 20 4.6×10^6 conidia/ml	1.25, 2.5, 5, and 10 ppm	100, 200, 400, and 800 ppm	-

Laboratory experimental design

To compare the efficacy of the three tested compounds (*B. bassiana*, spinosad, and malathion) at various concentrations on the adult stage of both field and laboratory strains of the Mediterranean fruit fly. Randomized Complete Block Design (RCBD) was implemented. Each treatment, including the control, was replicated three times, with 100 adult flies per replicate. This design is a standard for entomological bioassays and extensively discussed in statistics by Gomez and Gomez (1984).

The specific doses applied for each pesticide to the flies in the laboratory were 5.75×10^5, 1.15×10^6, 2.3×10^6, and 20 4.6×10^6 conidia/ml for *B. bassiana*, 1.25, 2.5, 5, and 10 ppm for spinosad, and 100, 200, 400, and 800 ppm for malathion insecticide. The control groups included in all experiments were treated only with distilled water to serve as a baseline for comparison. Plastic cups (250 cm^3) were sprayed with the above-mentioned insecticide concentrations and water as a control treatment by a hand sprayer (1 liter). One hour later, the adult flies were exposed to the insecticides via inserting them into the cups, covered with a cloth net and provided with a source of water and food (El-Gendy, 2002). After 24 hours, the experimental trials for the tested insecticides were investigated and extended to 14 days for *B. bassiana* and 48 hrs. for spinosad and malathion. The dead flies were removed and counted every inspection time.

The Toxicity index (TI) and Resistance Ratio (RR) were estimated by the LDP line program (Bakr Software) using to the following equations:

TI = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100].

RR = LC_{50} of the field strain for the tested insecticide/ LC_{50} of laboratory strain for the same insecticide

Field experimental design

The field experiment was conducted in three different locations in Albeheira, Egypt: Nobaria, Badr, and Rashid districts to determine the efficacy of spinosad, malathion, and betacyfluthrin against *C. capitata* during the 2023 and 2024 seasons in citrus navel orange gardens. The gardens were 15-18 years old, with 6 feddans for each treatment in 2 feddans for every replication. Population densities of *C. capitata* were monitored and evaluated using Jackson traps lured with Timedlure, a sex pheromone. The traps were hung for three days prior to insecticide application, with two traps for each replication. The traps were checked, and data were expressed as the number of flies per trap per day. Treatments were applied via foliar spray using a ground sprayer (1000 litres). Traps were investigated one, seven, and fifteen days after treatment. The reduction percentages were calculated according to the equation described by Abbott (1925) as follows:

$$\text{Reduction percentage (RP\%)} = \frac{\text{Number of flies in control-number of flies treatment}}{\text{Number of flies in control}} \times 100$$

Statistical Analysis

Laboratory experimental: for the dose-response experiments, all data obtained in all experiments were subjected to an analysis by the LDP line program (Bakr software, 2007), which corrected to control mortality by Abbott's Formula. LC_{50} values (Lethal Concentration 50%) were calculated using Probit analysis according to Finney (1971).

Field experimental design: all data were subjected to statistical analysis using Costat 6.4 statistical computer package (2005). Analysis of variance (ANOVA) was performed to determine significant differences among treatments. Means were separated using LSD at 5% level of probability ($P<0.05$). The general statistical procedures adhered to principles outlined in Gomez and Gomez (1984).

Results and Discussions

1. Toxicity of bio- and chemical insecticides against the Mediterranean fruit fly, *C. capitata* under laboratory conditions

- Toxicity of *B. bassiana* against the Mediterranean fruit fly, *C. capitata* under laboratory conditions

Efficacy of *B. bassiana* (Table 2) against *C. capitata* under laboratory conditions offering a comparative glimpse into its efficacy against both of field and susceptible lab strain. The initial lethal concentration required to kill 50% (LC_{50} conidia/ml) of the field strain of *C. capitata* achieved at 4 days' post-exposure was a hefty 2.245×10^7 conidia/ml. However, the required concentration plummeted dramatically by 10 days after exposure and the LC_{50} had fallen to 5.055×10^5conidia/ml, and on day 14 it was highly efficient with $LC_{50}= 1.178\times10^5$ conidia/ml. The results state the fungus's mode of action as fungal conidia must adhere to the insect's cuticle, germinate, penetrate the integument, and then proliferate within the host's hemocoel, ultimately leading to mortality through a combination of nutrient depletion, tissue damage, and the production of toxins like beauvericin (Ortiz-Urquiza and Keyhani, 2013). This intricate biological process naturally dictates a longer time to affect; our findings highly align with the scientific concept that entomopathogenic fungi require sufficient incubation periods to exert their full pathogenic effect (Lacey *et al.*, 2015; González-Cabrera *et al.,* 2018).

Regarding laboratory strain, the LC_{50} after 4 days was significantly higher (2.25×10^{7}conidia/ml), indicating a lower initial susceptibility. However, the fungus eventually caught up, with the LC_{50} dropping to (5.06×10^{5} conidia/ml) in day 10 and to (1.90×10^{5} conidia/ml) on day 12. The fact that LC_{50} for lab strain is generally higher at earlier time points, and the Resistance ratio (RR) values which assuming that field strain is more representative, less susceptible compared to lab strain, it ranged from 1.00 at the10th day after treatment to 1.71 on the 6th day after treatment. This indicates that the field strain required a higher dose. If we interpret the "Index" values, where for the field strain, the index climbs from 0.524 to 100 as LC_{50} drops (suggesting higher susceptibility or effect over time relative to some baseline), and for the lab strain, the index also climbs from 0.151 to 100. Lab-reared insects can sometimes lose traits, such as robust cuticular defenses or specific immune responses, which enable field populations to maintain under constant selection pressure from environmental stressors and natural enemies (Parodi *et al*., 2018; Shukla *et al.,* 2016).

Table 2. The toxicity of fungal-insecticide, *B. bassiana* against the Mediterranean fruit fly adults, *C. capitata* under laboratory conditions during 2023 and 2024 seasons.

Field strain							
No.	**Time after exposure (days)**	**LC_{50} (Conidia/ml) ± 95% CI**	**Lower limit**	**Upper limit**	**Index**	**RR**	**Slope**
1	4	2.245×10^{7}	$39.33,9.046\times10^{6}$	7.34×10^{8}	0.524	1.00	1.331
2	6	7.541×10^{6}	$16.819,3.869\times10^{6}$	8.319×10^{7}	1.561	1.71	0.836
3	8	2.689×10^{6}	$7.532,1.733\times10^{7}$	6.619×10^{6}	4.379	1.25	0.849
4	10	5.591×10^{5}	$0.728,1.674\times10^{5}$	8.039×10^{5}	23.294	1.11	1.078
5	12	2.388×10^{5}	$0.136, 3.128\times10^{4}$	4.175×10^{5}	49.326	1.26	1.832
6	14	1.178×10^{5}			100.000	-	1.552
laboratory strain							
No.	**Time after exposure (days)**	**LC_{50} (ppm)**	**Lower limit**	**Upper limit**	**Toxicity Index**	**RR**	**Slope**
1	2	1.254×10^{8}	-	-	0.151	-	1.048
2	4	2.235×10^{7}	8.722×10^{6}	8.167×10^{8}	0.848	-	1.167
3	6	4.406×10^{6}	2.64×10^{6}	3.01×10^{7}	4.115	-	0.779
4	8	2.146×10^{6}	1.347×10^{6}	4.497×10^{6}	8.831	-	0.824
5	10	5.055×10^{5}	3.025×10^{5}	37.81×10^{5}	33.896	-	1.542
6	12	1.895×10^{5}	1.518×10^{4}	3.586×10^{5}	100.000	-	1.988

LC_{50} and LC_{90} values having different letters are significantly different (95% CI did not overlap).

Furthermore, the apparent differences in susceptibility between laboratory and field strains based on the specific interpretation of "Index" and "RR" highlights the importance of local population studies and strain selection under developing biological control strategies. The effective strain of *B. bassiana*, in one region might need optimized application rates or even different biotypes for another, depending on the pest population's history and genetic makeup and their acquired resistance or susceptibility (Gottwald *et al*., 2020). Recent research continues to explore optimizing *B. bassiana* application methods, such as auto-dissemination, to enhance its efficacy in the field against fruit flies (El-Aw *et al.,* 2021, El-Gendy *et al.,* 2022).

- Toxicity of spinosad against the Mediterranean fruit fly, *C. capitata* under laboratory conditions:

The data in Table 3 immediately highlights spinosad's relatively rapid action compared to the entomopathogenic fungus we just discussed. For the field strain, the LC_{50} (concentration lethal to 50% of the population) at a mere 6 hours post-exposure was 14.32 ppm. This value dramatically decreased to 3.29 ppm by 12 hours, and by 24 hours, it plunged to a strikingly low 0.662 ppm. Even at 48 hours, the LC_{50} continued to slightly decrease to 0.526 ppm, indicating sustained, powerful efficacy. This swift effect is characteristic of spinosad, which primarily acts as a neurotoxin, affecting the insect's nervous system. Its unique mode of action involves disrupting acetylcholine receptors and GABA-gated chloride channels, leading to rapid excitation of the insect nervous system, involuntary muscle contractions, tremors, and ultimately, paralysis and death (Salgado and Corley, 1996; Sparks *et al.,* 2018). This mechanism allows for a much quicker "knockdown" compared to biological agents like ***B.*** *bassiana*, which require pathogenesis to unfold.

For the lab strain, spinosad's impact appears even more pronounced. The LC_{50} at 6 hours was incredibly low 0.90 ppm, which then further decreased to 0.45 ppm at 12 hours. Interestingly, the LC_{50} slightly increased to 0.47 at 24 hours for the lab strain, which could indicate the *C. capitata* population reaching maximum mortality at 12 hours, or perhaps slight variability in the experimental setup, but the overall trend remains clear: Spinosad is highly potent.

Susceptibility differences among field and laboratory strain

The comparison between the field and lab strains in Table 3 reveals a fascinating and significant difference in their susceptibility to spinosad. The lab strain is considerably more susceptible than the field strain at all observed time points. This is powerfully illustrated by comparing their LC_{50} values: at 6 hours, the lab strain's LC_{50} (0.903 ppm) is nearly 16 times lower than that of the field strain (14.315 ppm). This trend continues, although the magnitude of the difference narrows over time. At 12 hours, the lab strain's LC_{50} (0.454 ppm) is still over 7 times lower than the field strain's (3.297 ppm). The "Index" column also strongly suggests the lab strain is more susceptible (higher index values for lower LC_{50}, indicating it reaches a certain mortality threshold at a much lower dose).

This pronounced disparity in susceptibility between the field and lab strains is a critical observation. Lab-reared insect colonies, often maintained for many generations under controlled conditions, tend to lose their naturally evolved resistance mechanisms or exhibit a lowered tolerance threshold. Conversely, field strains are constantly exposed to selection pressures from various pesticides, leading to the development or maintenance of a higher degree of physiological and behavioral resistance (Smagghe *et al.,* 2003; Vassiliou *et al.,* 2011) who documented *C. capitata* resistance development to other insecticides.

Table 3. The toxicity of bio-insecticide, spinosad against the Mediterranean fruit fly, *C. capitata* under laboratory conditions during 2023 and 2024 season

No.	Time after exposure (hr)	LC_{50} (ppm)	Lower limit	Upper limit	Index	RR	Slope
Field strain							
1	6	14.315	8.235	66.00	03.67	15.85	0.997
2	12	3.297	2.184	4.859	15.95	7.26	1.051
3	24	0.662	0.204	1.113	79.50	1.41	1.287
4	48	0.526	0.116	0.863	100	-	2.021
Laboratory strain							
No.	**Time after exposure (hr)**	**LC_{50} (ppm)**	**Lower limit**	**Upper limit**	**Index**	**RR**	**Slope**
1	6	0.903	0.321	1.416	50.27	-	1.302
2	12	0.454	0.074	0.864	100.00	-	1.411
3	24	0.470	0.042	0.858	96.59	-	1.856

Toxicity of malathion against the Mediterranean fruit fly, *C. capitata* under laboratory conditions.

The data in Table 4 immediately reveals malathion's potent effect on *C. capitata*. For the field strain, the LC_{50} (concentration lethal to 50% of the population) at 6 hours' post-exposure was a high 673.451ppm. However, similar to spinosad but less acutely rapid, this concentration requirement significantly decreased over time. By 12 hours, the LC_{50} had dropped sharply to 106.161 ppm, and by 24 hours, it was 59.031 ppm. At 48 hours, the LC_{50} reached its lowest point at 25.537 ppm. This progressive decline in LC_{50} over time is typical for insecticides that require a period for uptake and the full manifestation of their neurotoxic effects within the insect's system.

For the lab strain, malathion's efficacy appears notably higher, meaning it requires significantly lower concentrations to achieve mortality. The LC_{50} at 6 hours was 52.88 ppm, dropping to 39.41 ppm at 12 hours and further to 29.35 ppm at 24 hours. The absence of a 48-hour data point for the lab strain suggests that maximal mortality was likely achieved by 24 hours, or the study focused on a shorter observation window for this more susceptible population.

Susceptibility differences of field vs. Lab strain revisited

The most striking revelation from Table 3 lies in the profound differences in susceptibility between the field and lab strains, particularly evident when we examine the LC_{50} values and the Resistance Ratio (RR). The field strain exhibits a dramatically higher level of resistance to malathion compared to the lab strain. At 6 hours, the field strain's LC_{50} (673.45 ppm) is an astonishing 12.74 times higher than that of the lab strain (52.88 ppm). The RR value at 6 hours for the field strain is a staggering 12.74 ppm. This colossal difference highlights the pervasive and well-documented issue of insecticide resistance, a critical challenge in pest management. As time progresses, this resistance ratio decreases (RR drops to 2.69 at 12 hours and 2.01 at 24 hours). This indicates that while higher doses are needed, given enough time, malathion can still exert its effect on the field strain, but the initial, rapid kill is severely compromised. This reduction in the RR overtime could also suggest that some individuals in the field strain might eventually succumb, even if they possess a degree of resistance.

This high level of resistance in field strains is not surprising. *C. capitata* has a long history of exposure to organophosphates like malathion in various agricultural settings worldwide. Repeated and often intensive use of these insecticides creates strong selection pressure, favoring individuals within the pest population that possess genetic mutations conferring resistance. These mutations can lead to various mechanisms of resistance, such as increased metabolic detoxification of the insecticide (through enhanced esterase activity), reduced sensitivity of the target site (acetylcholinesterase), or decreased insecticide penetration (Feng *et al.,* 2021; Vassiliou *et al*., 2011, specifically on *C. capitata* resistance). The stark contrast between the field and lab strains serves as a powerful reminder of this ongoing evolutionary arms race. Lab strains, isolated from such selection pressures, often revert to a more susceptible baseline, making them valuable as a "susceptible reference" in resistance monitoring studies.

While malathion demonstrates clear efficacy, particularly against susceptible populations, the pronounced resistance observed in the field strain underscores a critical limitation for its sole reliance in modern pest management. The high LC_{50} values and RRs in the field strain necessitate higher application rates to achieve control, which in turn exacerbates environmental risks and non-target effects, running counter to sustainable practices. In a strategic Integrated Pest Management (IPM) program, it can still play a role, but its deployment must be highly judicious. This could involve using it as a rotational insecticide to manage resistance to other chemical classes, or in targeted, localized applications as part of a baiting strategy (Vargas *et al.,* 2018). Its use must be carefully monitored, and resistance management strategies, such as alternating with different modes of action (like spinosad or ***B.** bassiana*), reducing overall pesticide load, and incorporating cultural and biological controls, are paramount to preserve its residual effectiveness and prevent further escalation of resistance (Bass *et al.,* 2019).

Table 4. The toxicity of malathion against the Mediterranean fruit fly, *C. capitata* under laboratory conditions during 2023 and 2024 seasons.

No.	Time after exposure (hr)	LC_{50} (ppm)	Lower limit	Upper limit	Index	RR	Slope
		Field strain					
	6	673.451	415.048	2494.447	3.792	12.74	0.850
3	12	106.161	69.049	139.112	24.055	02.69	1.826
2	24	59.031	18.579	88.034	43.260	02.01	2.569
1	48	25.537			100.000	-	1.214
		Laboratory strain					
No.	**Time after exposure (hr)**	**LC_{50} (ppm)**	**Lower limit**	**Upper limit**	**Index**	**RR**	**Slope**
3	6	52.880	18.498	84.426	55.511	-	1.833
2	12	39.414	4.699	69.001	74.478	-	2.037
1	24	29.354	2.361	58.188	100.000	-	1.889

2. Reduction ratios of Mediterranean fruit fly, *C. capitata that are treated with* spinosad, malathion and betacyfluthrin pesticides under open field conditions.

Table 5 offers a compelling comparative study, detailing the reduction ratios of Mediterranean fruit fly populations following treatments with spinosad, malathion, and betacyfluthrin pesticides across different areas and seasons in Egypt (Al-nubareya, Badr, and Rashid) during 2023 and 2024. This table provides invaluable insights into the practical efficacy of betacyfluthrin activity to these different pest management tools.

- Malathion

The application at one day post-treatment, malathion demonstrates the highest initial reduction ratios in both 2023 and 2024. In 2023, the mean reduction across areas was a remarkable 85.19%, peaking at 95.24% in Rashid. Similarly, in 2024, the mean was 80.58%, reaching 89.68% in Rashid. This rapid and high initial efficacy is characteristic of malathion and other organophosphates. It was known the fast knockdown effect of malathion due to their rapid absorption and direct interference with the insect's nervous system, causing immediate paralysis and death. This "shock and awe" approach can be crucial for quickly reducing high pest populations (Ware and Whitacre, 2004).

However, malathion's performance deteriorates significantly over time. By 7 days, its mean reduction drops to 53.83% in 2023 and 45.45% in 2024. The decline continues dramatically by 15 days, plummeting to a mean of 36.46% in 2023 and 43.79% in 2024. This rapid loss of efficacy highlights the challenges associated with malathion's residual activity in open field conditions. Factors contributing to this decline include photodegradation (breakdown by sunlight), volatilization, wash-off by rain, and continued exposure of new, susceptible individuals from untreated areas or hatching eggs. Furthermore, the resistance issues we discussed in Table 3 undoubtedly play a role, as resistant individuals survive the initial application and contribute to the rebound of the population, thereby reducing the long-term observed "reduction ratio." This pattern aligns with field observations of dwindling effectiveness for older chemistries against resistant populations of pests like *C. capitata* (Vassiliou *et al.,* 2011).

- Spinosad

Spinosad emerges as a strong, balanced performer in the field. While its one-day reduction ratios (mean 70.79% in 2023, 73.43% in 2024) are slightly lower than malathion's initial peak, they are still highly impressive. Crucially, spinosad demonstrates better persistence and more sustained control over time. At 7 days, its mean reduction in 2023 is 61.78%, outperforming malathion (53.83%). In 2024, while its 7-day mean (50.38%) is slightly lower than malathion's, the drop from day 1 is less steep. By 15 days, spinosad's mean reduction (30.22% in 2023, 34.88% in 2024) is comparable to, or even slightly better than, malathion's, especially considering malathion's much higher initial performance. Its unique neurotoxic mode of action and lower environmental persistence compared to some broad-spectrum synthetics contribute to this sustained yet safer effect. Its value in IPM lies precisely in this balance of good initial control and acceptable residual activity, allowing for longer spray intervals and reduced overall chemical burden (Biondi *et al.,* 2012).

- Betacyfluthrin

The "Beta" pesticide presents a more complex picture. Its one-day reduction ratios are notably lower than both spinosad and malathion, with a mean of 12.99% in 2023 and 35.19% in 2024. This suggests either a significantly lower initial efficacy against the field populations tested, or perhaps a different mode of action that isn't as acutely impactful. Pyrethroids, often fast-acting, sometimes face challenges with resistance or rapid degradation in certain environments. The performance of betacyfluthrin at 7 days remains low (mean 14.73% in 2023, 27.13% in 2024). Most strikingly, at 15 days, betacyfluthrin records negative reduction ratios (27.51% in 2023, -25.92% in 2024). A negative reduction ratio implies that the *C. capitata* population actually increased after treatment compared to the baseline, or, more likely, that the treated areas experienced a faster rebound or influx of pests than the control. This could be due to the field populations might possess very high levels of resistance to Betacyfluthrin, rendering it ineffective and potentially leading to a "flare-up" of the pest by removing competing insects or natural enemies. Pyrethroid resistance is a common and well-documented issue in many insect pests globally (Siddiqui *et al*., 2023).

Seasonal and Regional Variability

It's also worth noting the seasonal and regional variability. For instance, in 2023, Rashid showed very high initial reductions with malathion (95.24%) and spinosad (95.24%), but these dropped off. In 2024, the overall mean performance seemed slightly lower for all pesticides compared to 2023 (spinosad mean reduction at 1 day was 70.79% in 2023 vs. 73.43% in 2024, but malathion was 85.19% in 2023 vs. 80.58% in 2024). Such variations underscore the influence of environmental conditions (temperature, humidity, rainfall), pest population dynamics (initial densities, age structure), and localized resistance development, all of which vary by season and geographic area (Isman, 2017).

Table 5. Reduction percentages (100%) of the Mediterranean fruit fly, *C. capitata* adults treated with spinosad, malathion and betacyfluthrin insecticides under open field conditions during 2023 and 2024 seasons.

Area	Insecticides								
	One day			7 days			15 days		
	Spinosad	Malathion	Betacyfluthrin	Spinosad	Malathion	Betacyfluthrin	Spinosad	Malathion	Betacyfluthrin
2023 season									
Al-nubareya	77.06 ± 4.39	83.16 ±6.75	21.09 ±9.18	53.05 ±3.63	54.20 ±7.71	4.79 ±4.18	35.49 ±1.96	39.74 ±3.26	-39.21 ± 27.09
Badr	58.93 ±5.03	77.19 ±6.99	47.62 ±6.14	36.43 ±4.18	50.76 ±10.82	30.73 ±4.92	21.05 ±3.23	30.35 ±5.16	-10.82 ± 3.00
Rashid	76.40 ±1.23	95.24 ±0.4	35.00 ±5.00	65.88 ±1.36	56.55 ±4.28	35.00 ±5.00	34.12 ±1.37	39.29 ±3.09	-32.5 ± 7.50
Mean	70.79 ±9.69b	85.19 ±9.33a	34.57 ±12.99c	51.78 ±13.10a	53.83 ±7.42a	23.51 ±14.73b	30.22 ±7.19a	36.46 ±5.72a	-27.51b ±3.62
Lsd		5.6			11.84			11.91	
2024 season									
Al-nubareya	82.58 ±2.50	91.61 ±1.67	38.31 ±2.79	59.55 ±1.38	65.55 ±1.35	28.53 ±4.31	40.15 ±0.26	38.33 ±4.41	24.73 ±2.46
Badr	65.08 ±2.75	60.41 ±6.07	32.06 ±2.61	43.49 ±3.57	53.18 ±2.18	25.36 ±2.05	32.27 ±1.11	45.41 ±7.96	-15.32 ± 6.17
Rashid	72.78 ±2.53	89.68 ±9.02	35.00 ±5.00	48.11 ±7.72	74.60 ±7.08	27.50 ±2.50	32.22 ±10.72	47.62 ±4.12	-32.5 ± 7.50
Mean	73.43 ±7.92b	80.58 ±16.12a	35.19 ±4.21c	50.38 ±8.35b	64.45 ±10.03a	27.13 ±3.04c	34.88 ±6.68a	43.79 ±6.53a	-7.69 ±25.92b
LSD		4.44			7.53			15.48	

Means having different letters are significantly different according to LSD 0.05

Conclusion

Based on the study's findings, spinosad was the most effective insecticide against *C. capitata*. Its superior acute potency and sustained residual activity, coupled with a favorable environmental profile, make it the preferred choice for immediate and lasting control within integrated pest management programs, especially considering widespread resistance to conventional options like malathion. As well as the differences in speed dictate different application strategies. Fast-acting spinosad and malathion might be used for curative treatments or rapid population reduction, while slower-acting ***B. bassiana*** is better suited for preventative measures or long-term integrated programs.

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References

Abbott, W.S. (1925). A method of computing the effectiveness of an insecticide. Journal of Economic Entomology, 18(2): 265-267.

Bakr software, (2007). LdP line. http://embakr.tripod.com/ ldpline/index.htm.

Bass, C., Denholm, I., and Ranson, H. (2019). The molecular basis of insecticide resistance. In: Insecticides: Chemistry, Toxicology and Resistance. John Wiley and Sons.

Biondi, A., Desneux, N., and Zappala, L. (2012). Biological control of *Tuta absoluta* (Lepidoptera: Gelechiidae) with entomopathogenic microorganisms: a review. Biological Control, 63(1): 30-38.

Carvalho, F. P. (2017). Pesticides, environment, and public health. Journal of Environmental Science and Health, Part C, 35(4): 267-279.

De Meyer, M., Virgilio, M., and White, I. M. (2010). ZooKeys 73: A review of the Afrotropical species of the genus Ceratitis MacLeay (Diptera: Tephritidae). Pensoft Publishers.

El-Aw, M.A.M., I.R. El-Gendy, S.I. Askar, Y.A. Abdel-Rhaman, and Khodair, A.A. (2021). Role of the entomopathogenic fungus Beauveria bassiana as a biological control agent for the Mediterranean fruit fly Ceratitis capitata (Tephritidae: Diptera) under laboratory conditions. Egypt. J. Plant Prot. Res. Inst. (2021): 4 (3): 393–403.

El-Gendy, I.R. (2002). Studies on peach fruit fly *Bactrocera zonata* (Saunders) at El-Bohiera Governorate. M.Sc. Thesis, Faculty of Agriculture, Alexandria University, Egypt.

El-Gendy, I.R (2018). Insecticide resistance of a field strain of mediterranean fruit fly, *Ceratitis capitata* (wiedemann) (diptera: tephritidae) in Egypt. J. Applied Sci., 18: 25-32.

El-Gendy, I.R., M.F.M. Zawrah, and El-Banobi M.I. (2022). Virulence effect of *Metarhizium anisopliae* (Met.) and *Beauveria bassiana* (Bals.) fungi against the peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae). Egyptian Journal of Biological Pest Control. 32:43 https://doi.org/10.1186/s41938-022-00545-3

Enkerlin, W. (2005). Impact of *Anastrepha*, *Ceratitis* and *Bactrocera* fruit flies on global horticulture. Acta Horticulturae, 695: 23-31.

Feng, H. T., Wang, Q., Zhai, Y., Ding, T. B., Guo, H. Q., Lu, M., and Du, X. L. (2021). Target-site mutation and detoxification enzyme activity as the main causes of malathion resistance in *Nilaparvata lugens* (Hemiptera: Delphacidae). Pesticide Biochemistry and Physiology, 172: 104764.

Finney, D.J. (1971). Probit Analysis (3rd ed.). Cambridge University Press.

Gomez, K.A., and Gomez, A.A. (1984). Statistical procedures for agricultural research (2nd ed.). John Wiley & Sons.

González-Cabrera, J., Estruch, A. P., Montón, H., and Hernández-Crespo, P. (2018). Virulence of *Beauveria bassiana* isolates against the red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Dryophthoridae). Journal of Pest Science, 91(1): 183-195.

Gottwald, M., Püntener, L., Schirra, S., and Bigler, F. (2020). Susceptibility of *Drosophila suzukii* (Diptera: Drosophilidae) field populations from Switzerland to entomopathogenic fungi. Journal of Invertebrate Pathology, 172: 107357.

Isman, M. B. (2017). Pesticides based on plant essential oils: From traditional practice to commercial success. Journal of Agricultural and Food Chemistry, 65(3): 433-441.

Lacey, L. A., Grzywacz, D., Shapiro-Ilan, D. I., Frutos, R., Brownbridge, M., and Goettel, J. R. (2015). Insect pathogens as biological control agents: Do they have a future in agriculture? Journal of Invertebrate Pathology, 130: 26-38.

Liquido, N. J., Shinoda, L. A., and Cunningham, R. T. (1991). Host plants of the Mediterranean fruit fly (Diptera: Tephritidae): An annotated world review. USDA-ARS, Miscellaneous Publication No. 1493.

Marrone, P. G. (2019). Pesticidal natural products—status and future. Pest Management Science, 75(9): 2325-2335.

Ortiz-Urquiza, A., and Keyhani, N. O. (2013). Molecular genetics of insect pathogenesis by *Beauveria bassiana*. Current Topics in Microbiology and Immunology, 366: 175-199.

Parodi, P., Simonato, M., and Cappelletti, M. (2018). Genetic changes in laboratory colonies of insects: A review. Biological Control, 121: 14-25.

Salgado, V. L. (1997). The modes of action of spinosad and other insecticides. Reviews of Toxicology, 1: 117-133.

Salgado, V. L., and Corley, C. (1996). The effects of spinosad on the firing of giant interneurons in the cockroach. Pesticide Biochemistry and Physiology, 54(2): 122-132.

Siddiqui, J.A., Fan, R., Naz, H., Bamisile, B.S., Hafeez, M., Ghani, M. I., Wei, Y., Xu, Y., and Chen, X. (2023). Insights into insecticide-resistance mechanisms in invasive species: Challenges and control strategies. Front Physiol. 13:1112278. doi: 10.3389/fphys.2022.1112278.

Shukla, R. M., Upadhyay, V. B., and Pandey, K. S. (2016). Comparison of susceptibility of laboratory and field populations of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) to some insecticides. Journal of Applied Entomology and Zoology Research, 27(1): 1-5.

Smagghe, G., Carton, B., De Marree, H., and Levis, M. (2003). Insecticide resistance in Belgian glasshouse populations of greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae). Pest Management Science, 59(12): 1317-1324.

Sparks, T. C., Watson, G. B., and Larson, L. L. (2018). Spinosyns: Chemistry and mode of action. In Insecticides: Chemistry and Mode of Action (pp. 523-547). Springer.

Tanaka, N., Steiner, L.F., Finney, D.J., and Harris, E.J. (1969). Dacus dorsalis: Sexual competitiveness of males reared in an insectary, with and without chemosterilization. Journal of Economic Entomology, 62(3): 643-646.

USDA-APHIS. (2018). Mediterranean Fruit Fly *(Ceratitis capitata)* Program Manual. United States Department of Agriculture, Animal and Plant Health Inspection Service.

Vargas, R. I., Pinero, J. C., and Leblanc, L. (2018). *Ceratitis capitata* (Mediterranean fruit fly) (Insecta: Diptera: Tephritidae). University of Florida IFAS Extension, EENY-327.

Vassiliou, V. A., Kapari, I., Toumi, S., and Papanicolaou, P. A. (2011). Detection and characterization of insecticide resistance in field populations of *Ceratitis capitata* (Wiedemann) from Cyprus. Pest Management Science, 67(11): 1404-1411.

Ware, G. W., and Whitacre, D. M. (2004). The Pesticide Book (6th ed.). MeisterPro.

White, I. M., and Elson-Harris, M. M. (1992). Fruit Flies of Economic Importance: Their Identification and Bionomics. CAB International.

فعالية وسمية المبيدات الحشرية الحيوية والكيميائية ضد سلالات ذبابة فاكهة (*Ceratitis capitata*) البحر المتوسط الحقلية والمعملية

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الملخص

تُعد ذبابة فاكهة البحر المتوسط من أخطر الآفات الزراعية عالمياً، مسببة خسائر اقتصادية فادحة لمجموعة متنوعة من المحاصيل الحقلية والبستانية. تبحث هذه الدراسة في استراتيجيات طرق مكافحة مختلفة، سواء اكانت مسببات مرضية للحشرات إلى المبيدات الحشرية المصنعة او المشتقة طبيعياً، والتي تم تقييمها تحت الظروف المعملية والحقلية في محافظة البحيرة، مصر خلال موسمي 2023 و2024. كشفت التقييمات المعملية لفطر *Beauveria bassiana* عن نشاطه الإبادي ضد الحشرات الكاملة للذبابة الذي يعتمد على الوقت، حيث يتطلب الفطر فترة تعرض أطول لتحقيق التأثير الأمثل مع تباين في حساسية السلالات الحقلية والمعملية للآفة، كما تتطلب السلالات الحقلية تركيزات اعلى للتأثير بمرور الوقت. على النقيض، أظهر مبيد السبينوساد فعالية حادة عالية وسريعة. أظهرت السلالات المعملية حساسية أكبر للسبينوساد مقارنة بالسلالات الحقلية.كما أظهر مبيد الملاثيون فعالية كبيرة ضد السلالات المعملية الحساسة، لكنه واجه تحديات كبيرة في السلالات الحقلية. تحت الظروف الحقلية، كشف التقييم المقارن لمبيدات السبينوساد والملاثيون وبيتاسيفلوثرين عن تباين في أنماط الأداء. قدم الملاثيون انخفاضاً أولياً كبيراً في أعداد الآفة، لكنه عانى من فقدان سريع للفاعلية المتبقية. بينما قدم السبينوساد أداءً متوازناً بتحكم أولي قوي وفاعلية متبقية مستدامة أفضل. مبيد يتاسيفلوثرين أظهر نسب انخفاض غير متسقة وغالباً سلبية. تؤكد هذه الدراسة على الحاجة الماسة لاستراتيجيات الإدارة المتكاملة للآفات. فبينما يبرز السبينوساد كخيار فعال ومتوازن للمكافحة الحادة، ويوفر فطر *Beauveria bassiana* تثبيطاً بيولوجياً ممتازاً على المدى الطويل، فإن الاعتماد على الكيماويات القديمة مثل الملاثيون يتعرض لفشل المكافحة. يجب أن تعطي بروتوكولات المكافحة المستقبلية الأولوية للتناوب في استخدام طرق المكافحة ذات آليات العمل المختلفة، ودمج المكافحة البيولوجية والكيميائية، مما يضمن مكافحة مستدامة للافه في البيئات الزراعية.

الكلمات المفتاحية: *الادارة المتكاملة لمكافحة الآفات، دائل المبيدات، ذبابة فاكهة البحر المتوسط، spinosad، Beauveria bassiana*