

## Toxicity and biological effects of certain pesticides and natural oils on the peach fruit fly, *Bactrocera zonata* (Saunders, 1841) (Diptera: Tephritidae)

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**Abstract:** Toxicity and biology studies were conducted on certain insecticides that belong to different chemical groups, namely malathion (organophosphate group), lambda-cyhalothrin (pyrethroid group), and spinosad (Benzophenyl urea group), and on lemon-grass and sesame oils as natural oils against adult male and female *Bactrocera zonata* (Saunders, 1841). They were carried out under laboratory conditions, and results were taken after 24h post treatment. Lambda-cyhalothrin was the most toxic on males and females of *B. zonata* at LC<sub>25</sub> of 0.017 and 0.04, followed by spinosad with LC<sub>25</sub> of 1.15 and 1.29, respectively. However, malathion was the least toxic to males and females, showing LC<sub>25</sub> of 18.53 and 12.24, respectively. The same results were obtained at LC<sub>50</sub>, as lambda-cyhalothrin was the superior toxicant with LC<sub>50</sub> of 0.65 and 1.008, followed by spinosad of 2.56 and 3.53, respectively. Furthermore, the natural sesame oil, *Sesamum indicum* (Linnaeus, 1753), was more toxic than lemon-grass oil to the males of *B. zonata* with LC<sub>25</sub> of 0.06 and 0.08, respectively. Lemon-grass oil, *Cymbopogon citratus* (Stapf, 1906), was more toxic to females than sesame oil with LC<sub>25</sub> of 0.05 and 0.07, respectively. At LC<sub>50</sub>, lemon-grass was more toxic than sesame on both males and females. In addition to the biological effects, results showed a significant reduction in the oviposition and post-oviposition periods of adults treated with different tested compounds, compared to the control group. Moreover, all tested compounds significantly decreased fecundity, hatchability, longevity, pupation, and the emergence of *B. zonata* adults, when compared to the untreated groups.

**Keywords:** Malathion, Lambda, Spinosad, lemon grass oil, sesame oil, biological and toxicological effects

### Introduction

Recently, the peach fruit fly, *Bactrocera zonata* (Saunders, 1841) (Diptera: Tephritidae), has been considered one of the most serious pests attacking fruits of several host plants. The true fruit flies belong to the family Tephritidae, and include about 4000 species arranged in 500 genera (White & Elson- Harris 1994). Thus, it is considered the largest dipteran family, and one of the most economically important pests. The peach fruit fly originated in South-East Asia (Agarwal *et al.* 1999), and spread to other parts of the world. In Egypt, *B. zonata* was officially

identified and recorded for the first time in the nineteenth century (Al-Eryan 2008). *Bactrocera zonata* is active throughout the year in Egypt with four to six generations per year (El-Gendy & El-Saadany 2012). The larvae mainly attack the soft fruit of various commercial host plants. Females lay their eggs in the fruit and hatched maggots devour the pulp. Subsequently, secondary infections with frequent bacterial and fungal diseases are detected, and the infested fruit drop (White & Elson-Harris 1992, Abdel-Sabour 2003). *Bactrocera zonata* has a wide host range, causing significant damages to Egyptian agriculture, estimated at around 190

million EGP per year. The control of such pests, associated with relevant problems, results from the hazardous use of insecticides (El-Aw *et al.* 2008). Using chemical insecticides that are relatively safe or have low mammalian toxicity, such as pyrethroid, may contribute in solving the problem. Malathion is an organophosphate insecticide that is mostly used in the control group of fruit flies. Mode of action of malathion inhibits the activity of the cholinesterase enzyme (anticholinesterase). Low mammalian toxicity and low price have rendered malathion good option for the control group of fruit flies (Hasanuzzaman & Idris 2019). Spinosad is a novel insect control agent derived by the fermentation of the *Actinomyces bacterium*, *Saccharopolyspora spinosa*. The active ingredient is composed of two metabolites, spinosyn A and spinosyn D (Thompson *et al.* 1997). Mode of action of spinosad is completely new making it a useful resistance management tool. A new activity mechanism on the nicotinic acetylcholine receptors was identified as the primary cause of death (Salgado 1997). Lambda-cyhalothrin belongs to pyrethroid insecticides that disrupt the function of the nervous system, causing paralysis or death (Soderlund *et al.* 2002). Recent studies are heading towards the use of natural materials as safer and more eco-friendly alternatives to insecticides. Natural oils are one of the most promising materials in pest control. They are produced from several plant parts, such as the leaves, stems, or roots, and seeds. The oils are generally composed of complex mixtures of monoterpenes, biogenetically-related phenols, and terpenes (Ali 2018). Their rapid breakdown is crucial because it means less persistence in the environment, which reduces risk to non-targeted organisms. Natural oils generally have broad-spectrum as pesticides, and are also safe for the environment (Sendi & Ebadollahi 2014).

In this study, the toxicological and biological effects of certain insecticides of

malathion, lambda-cyhalothrin, and spinosad, as well as some plant oils (lemon-grass and sesame oils) against male and female *B. zonata* adults were determined under laboratory conditions.

## Material and Methods

### *Bactrocera zonata* colonies

Colonies of *B. zonata* were reared and maintained at the Horticulture Insect Research Department, Plant Protection Research Institute, Agriculture Research Center, Dokki, Giza, under conditions of  $25\pm 2^{\circ}\text{C}$  and  $60\pm 5\%$  R.H. Insect colonies were kept according to the method described by Shehata *et al.* 2008.

### Tested compounds

- Malathion (Malatox 57% EC, KafirElzayat Pesticides & Chemicals company<sup>®</sup>) – organo-phosphate group.
- Lambda-cyhalothrin (Super lambda 10% EC, Bass limited Egypt<sup>®</sup>) – pyrethroid group.
- Spinosad (Conserve 0.024% EC, Diagro Science<sup>®</sup>) – benzophenyl urea group.
- Sesame oil extracted from *Sesamum indicum* (Linnaeus, 1753) and lemon-grass essential oil from *Cymbopogon citratus* (Stapf, 1906) was purchased from the National Research Centre, Dokki: Giza, Egypt.

### Insecticidal effects on peach fruit fly adults

Six to eight concentrations diluted with distilled water were used for each insecticidal compound. For malathion, concentrations of 31.25, 62.5, 125, 250, 500, 1000, and 2000 ppm were tested. Lambda concentrations were 0.3, 0.6, 1.25, 2.5, 5 and 10 ppm. Spinosad dilutions of 0.24, 0.47, 0.94, 1.87, 3.75, 7.5, 15, and 30 ppm were applied. Each of the sesame and lemon-grass natural oils was mixed with water using Tween 80, and was prepared in six concentrations (0.3, 0.6, 1.25, 2.5, 5, and 10 ppm).

The newly emerging adults were isolated and relocated by an aspirator in small cages for treatment. Twenty individuals of *B. zonata* (10 males and 10 females) were located in each cage, in three replicates. 2 ml of sugar solution (5%) was mixed with different concentrations of pesticides, and were placed on plastic covers then left to air-dry for 30 minutes. Afterwards, the mixture was placed inside each cage to feed the adults. Three replicates were also set up as a control group with sugar solution only. Mortality was recorded after 24 h.

### *Biological studies*

The effect of each insecticide and natural oil on some biological aspects of *B. zonata* adults treated with LC<sub>50</sub> was evaluated in three replicates for each treatment. Soon after emergence, adults were transferred via glass aspirators to small cages with muslin. Five pairs of adults (5 males and 5 females) were confined in each cage. Adults were supplied with water in small plastic jars, and some sugar in small Petri dishes for feeding. Small colorful plastic vials (representing the plastic fruits) with a number of small pores (as a receptacle for oviposition) were used. These plastic vials were filled with 1 ml of water to receive the eggs, and prevent their dryness.

Fecundity, fertility, the longevity of both males and females, and the percentage of adult emergence from eggs laid by the emerged females were estimated.

### *Statistical analysis*

Mortality percentage of the tested adults was calculated and corrected using Abbott's formula (Abbott 1925). The corrected mortality percentages were statistically computed according to Finney (1971). Moreover, the toxicity index was determined according to Sun (1950), in order to compare the efficiency of the tested compounds. All

tested biological parameters were statistically analyzed by SAS statistics (Cary 1998).

## **Results**

### *Toxicity of insecticides against adult B. zonata*

Toxicity of malathion (malatox 57% EC), lambda-cyhalothrin (super lambda 10% EC), and spinosad (Conserve 0.024% EC) against males and females of *B. zonata* is shown in Table 1. Lambda surpassed the other two tested insecticides against both males and females of *B. zonata* at LC<sub>25</sub> and LC<sub>50</sub> recording the lowest values of 0.017, 0.04, and 0.65, 1.008 ppm, respectively.

In addition, data in Table 1 indicate that the toxicity lines of spinosad were the steepest for both males and females of the peach fruit fly (1.94 and 1.56, respectively), whereas lambda showed the flattest lines (0.42 and 0.47, respectively). In light of the toxicity index, lambda was the most effective compound against males and females of *B. zonata* (the standard). The efficiency of the other two tested insecticides was 0.62, 25.39, and 0.85, 28.56% of the standard (lambda) against males and females of *B. zonata*, respectively.

### *Toxicity of natural oils against adults of B. zonata*

Results in Table 2 indicate that lemon-grass oil was more efficient against males of *B. zonata* than sesame oil. The first recorded LC<sub>50</sub> values of 0.31%, whereas the second recorded 0.38%. However, the opposite occurred at LC<sub>25</sub>, since sesame oil was nearly more effective than lemon grass oil, showing an LC<sub>25</sub> value of 0.06% compared to 0.08% for lemon-grass oil. On the other hand, lemon-grass was the most potent against females of *B. zonata*, showing LC<sub>25</sub> and LC<sub>50</sub> values of 0.05 and 0.26%, respectively. The

Table 1: Toxicity of malathion, lambda-cyhalothrin and spinosad against males and females of *B. zonata* after 24 h post treatment.

Compound	Stage	LC <sub>25</sub> [Ppm]	LC <sub>50</sub> [Ppm]	Confidence limits(s)				Slope ± SD	Chi Square	Toxicity index % at LC <sub>50</sub>
				LC <sub>25</sub>		LC <sub>50</sub>				
				Lower	Upper	Lower	Upper			
Malathion	Male	18.53	104.15	4.10	28.70	46.26	172.26	0.89±0.08	14.14	0.62
	Female	12.24	118.15	4.5251	23.1709	78.0756	164.9503	0.68±0.08	1.79	0.85
Lambda-cyhalothrin	Male	0.017	0.65	0.0003	0.08	0.21	1.15	0.42±0.10	1.48	100
	Female	0.04	1.008	0.0019	0.1228	0.4818	1.6671	0.47±0.10	2.68	100
Spinosad	Male	1.15	2.56	0.84	1.46	1.99	3.27	1.94±0.11	12.75	25.39
	Female	1.29	3.53	0.6318	1.9689	2.0758	6.2091	1.56±0.09	41.06	28.56

Table 2: Toxicity of lemon grass and sesame oils against males and females of *B. zonata* after 24 h post treatment.

Compound	Stage	LC <sub>25</sub> [%]	LC <sub>50</sub> [%]	Confidence limits(s)				Slope ± SD	Chi Square	Toxicity index % at LC <sub>50</sub>
				LC <sub>25</sub>		LC <sub>50</sub>				
				Lower	upper	Lower	upper			
Lemon grass oil	Male	0.08	0.31	0.05	0.11	0.24	0.38	1.11±0.09	8.54	100
	Female	0.05	0.26	0.03	0.08	0.19	0.33	0.94±0.087	6.25	100
Sesame oil	Male	0.06	0.38	0.03	0.09	0.28	0.51	0.79±0.07	1.68	80.45
	Female	0.07	0.64	0.04	0.12	0.47	0.85	0.72±0.06	4.50	40.25

corresponding values of sesame oil were 0.07 and 0.64%, respectively. As shown in Table 2, the toxicity line of lemon-grass was the steepest for both males and females of *B. zonata* (slope=1.11 and 0.94) when compared to that of sesame oil (slope=0.79 and 0.72, respectively). Considering that lemon-grass oil was the standard at LC<sub>50</sub> (the most efficient), the potency of sesame oil was 80.45 and 40.25 of the standard, for male and female *B. zonata*, respectively.

### Biological studies

#### Effect of sub-lethal concentrations of the tested insecticides on parent progeny of adult fly

Data in Table 3 show that the pre-oviposition period was slightly prolonged when the parent progeny was treated with both malathion and spinosad (17.70 and 18.3 days, respectively). Nonetheless, lambda-cyhalothrin shortened the pre-oviposition period insignificantly (13.7 days), compared to the untreated individuals that recorded 15.0 days. The three tested insecticides slightly reduced the oviposition period to 34.3, 27.7, and 25.0 days for malathion, spinosad, and

lambda-cyhalothrin, respectively. The difference between spinosad and lambda-cyhalothrin was statistically insignificant. The untreated individuals showed the highest period of oviposition (86.0 days). The post-oviposition period of females treated with malathion and spinosad, as well as that of the untreated ones varied faintly (6–7, 4–3, and 5–3 days, respectively), whereas the post-oviposition period of females treated with lambda-cyhalothrin increased significantly to reach the highest period, recording 31–33 days. The three tested insecticides reduced the fecundity considerably to 40.7, 42, and 27.1 eggs for malathion, spinosad, and lambda-cyhalothrin, respectively, when compared to the untreated individuals that recorded 410.9 eggs. The longevity of male and female *B. zonata* adults were noticeably shortened at the three tested insecticides ranging between 37.3–77.7 days for males, and 51.3–70.0 days for females, compared to 88.0 and 107.7 days, respectively.

The highest percent of hatchability was recorded in the untreated individuals at 99.7%, while the lowest hatchability rate for individuals

Table 3: Effect of sub-lethal concentrations [LC<sub>50</sub>] of tested pesticides on some biological aspects of parent's progeny of adult peach fruit fly.

Biological aspect / Compound	Preoviposition Period ±SE [day]	Oviposition Period ±SE [day]	Postoviposition Period ±SE [day]	Fecundity ±SE	Longevity ±SE [day]		Hatchability ±SE %	Pupation ±SE %	Emergence ±SE %
					Males	Females			
Malathion	17.7± 2.2a	34.3± 0.9b	4.3± 1.5b	40.7± 3.3c	77.7±1.5b	51.7± 0.7c	51± 1c	42± 1.2c	42.3±1.5c
Spinosad	18.3± 2.4a	27.7± 2.6c	5.3± 0.7b	42± 1.5b	46.3±1.9c	51.3± 0.3c	60± 0.0b	53.7± 1.2b	51.7± 1.7b
Lambda	13.7± 0.3a	25± 2.1c	31.3± 1.3a	27.1± 0.3d	37.3±1.5d	70± 1.2b	38.7± 1.9d	31.3± 1.2d	28.3±1.7d
Control	15± 0.0a	86± 0.6a	6.7± 0.9b	410.9± 0.9a	88±1.5a	107.7± 1.5a	99.7± 0.3a	97± 1.2a	95.7± 0.7a

Table 4: Effect of sub-lethal concentrations (LC<sub>50</sub>) of tested oils on some biological aspects of parent's progeny of adult peach fruit fly.

Biological aspect / Compounds	Preoviposition Period ±SE [day]	Oviposition Period ±SE [day]	Postoviposition Period ±SE [day]	Fecundity ±SE	Longevity ±SE [day]		Hatchability ±SE %	Pupation ±SE %	Emergence ±SE %
					Males	Females			
Lemon grass	15.3± 0.9a	28.7± 3c	20.7± 0.7a	24± 0c	41±2.3b	66± 0.7c	95± 0b	91.7± 0.9b	91.7±0.9b
Sesame	15± 1.2a	54± 1.7b	4.3± 0.7b	26.2± 0.6b	40±2.6b	74± 0.3b	83.3± 0.9c	82± 0.6c	76.7± 0.9c
Control	15± 0.0a	86± 0.6a	6.7± 0.9b	410.9± 0.9a	88±1.5a	107.7± 1.5a	99.7± 0.3a	97± 1.2a	95.7± 0.7a

treated with lambda-cyhalothrin was 38.7%. Similarly, with regards to the pupation rate and emergence rate, the untreated individuals recorded the highest percentages (97.0 and 95.7), whereas the individuals treated with lambda-cyhalothrin showed the lowest ones (31.3 and 28.3%, respectively).

#### Effect of sub-lethal concentrations of the tested oils on parent progeny of adult fly

The biological activity of the tested essential oils (lemon-grass and sesame) against adult *B. zonata* was estimated. Data in Table 4 clarify that there was no remarkable effect on the pre-oviposition period for both lemon-grass and sesame oils, compared to the control. The two tested natural oils significantly reduced the oviposition period to 28.7 days (for lemon-grass oil) and 54.0 days (for sesame oil), compared to 86.0 days for the untreated individuals.

Lemon-grass significantly increased the post-oviposition period (20.7 days), compared to the control group (6.7 days). On the other hand, sesame oil shortened the period to 4.3 days, which did not significantly differ from that of the control group.

The two tested natural oils significantly reduced the fecundity to 24 and 26.2 for lemon-grass and sesame oils, respectively, compared the untreated individuals at 410.9.

Statistical analysis of the variance proved that the longevity of males and females treated with the two tested natural oils notably dropped to 41.0, 66.0 days (for lemon-grass oil), and 40.0, 74.0 days (for sesame oil) compared to 88.0 and 107.7 days for the untreated individuals, respectively. Besides, the percentages of egg hatchability, pupation, and emergence of treated individuals with lemon-grass and sesame oils, significantly decreased to 83.3–95.0, 82.0–91.7 and 76.7–91.7, compared to 99.7, 97.0, and 95.7 for the untreated individuals, respectively.

Table 5: Effect of sub-lethal concentrations (LC<sub>50</sub>) of tested pesticides on some biological aspects of F1 progeny of adult peach fruit fly.

Biological aspect Compound	Preoviposition Period ±SE [day]	Oviposition Period ±SE [day]	Postoviposition Period ±SE [day]	Fecundity ±SE	Longevity ±SE [day]		Hatchability ±SE %	Pupation ±SE %	Emergence ±SE %
					Males	Females			
Malathion	14± 0.6a	62± 0.9b	10.7± 2.2b	169.2± 0.6c	82.3±1.5ba	86.7 ± 1.2b	88.3± 1.2b	86.7± 1.7b	74.7±0.3b
Spinosad	14± 0.6a	57.3± 1.3c	8.7± 0.9b	176.3± 1.5b	83.3±0.6ba	80± 0.9c	73.3± 1.5c	72.3± 1.5c	69± 1c
Lambda	13.3± 0.3a	48.3± 0.9d	21.3± 1.9a	140.3± 0.9d	80.7±1.2b	82.9± 1.7cb	64± 1d	62.3± 1.5d	60.7±1.5 d
Control	15± 0.0a	85± 0.6a	7.3± 0.9b	447.3± 0.7a	84.7±1.5a	107.3± 1.5a	99.3± 0.3a	96.7± 0.9a	95.7± 0.7a

Table 6: Effect of sub-lethal concentrations (LC<sub>50</sub>) of tested oils on some biological aspects of F1 progeny of adult peach fruit fly.

Biological aspect Compound	Preoviposition Period ±SE [day]	Oviposition Period ±SE [day]	Postoviposition Period ±SE [day]	Fecundity ±SE	Longevity ±SE [day]		Hatchability ±SE %	Pupation ±SE %	Emergence ±SE %
					Males	Females			
Lemon grass	14± 0.6a	51.7± 1.7c	19± 0.6a	110± 1.2c	74.3±0.7b	84.7± 1.7c	95± 1.2b	94.3± 1.8ba	92.3±1.5a
Sesame	14.3± 0.3a	57.7± 1.9b	8.7± 0.9b	176.7± 1.2b	81.7±1.7b	80.7± 0.9b	90 ± 0.6c	90± 1.8b	87.7± 1.2b
Control	15± 0.0a	85± 0.6a	7.3± 0.9b	447.3± 0.7a	84.7±1.5a	107.3± 1.5a	99.3± 0.3a	96.7± 0.9a	95.7± 0.7a

### Biological activity of F1 progeny after treatment with tested pesticides

All tested biological aspects of F1 progeny of *B. zonata* in Table 5 show the same trend as the parent progeny. The untreated individuals recorded the highest values, except for the post-oviposition period, which recorded the highest period of 21.3 days with individuals treated with lambda-cyhalothrin. The differences in pre-oviposition periods between treatments were statistically insignificant, and ranged between 13.3 and 15.0 days. The oviposition period of the treated individuals ranged between 48.2 and 62.0 days, compared to 85.0 days for untreated ones. The three tested insecticides significantly reduced the fecundity to 169.2, 176.3, and 140.3 for malathion, spinosad, and lambda-cyhalothrin, respectively, compared to the control group at 447.3. Male longevity ranged between 80.7 and 84.7 days, whereas the longevity of the untreated female individuals showed the highest period at 107.3 days, which was significantly higher than that observed with the treated

individuals ranging between 80.0 and 86.7 days. The percentages of egg hatchability, pupation, and the emergence of the treated individuals ranged at 64–88.3, 62.3–86.7, and 60.7–74.7, in contrast with 99.3, 96.7, and 95.7 for the untreated individuals, respectively. In general, lambda-cyhalothrin was the most potent compound.

### Biological activity of F1 progeny after treatment with tested oils

Results in Table 6 show the biological effects of the two tested oils (lemon-grass and sesame oils) on F1 progeny of *B. zonata* adults.

Data reveal that the tested natural oils did not have a strong effect on the pre-oviposition periods of *B. zonata* which ranged between 14.0 and 15.0 days. Yet, on another hand, the oviposition and post-oviposition periods were significantly influenced, as the two tested natural oils shortened the period of oviposition to 51.7 and 57.7 days for lemon-grass and sesame oils, respectively, whereas lemon grass prolonged the post-

oviposition period to 19.0 days. The two tested natural oils noticeably reduced the fecundity to 110 and 176.7 eggs for lemon-grass and sesame oils, respectively, when compared to the untreated ones (447.3).

Contrastingly with untreated individuals, the two tested natural oils significantly reduced the longevity of both males and females to 74.3–81.7 and 80.7–84.7 days, respectively. In addition, the two tested oils decreased the hatchability rate considerably to 95.0 (for lemon-grass oil) and 90.0 (for sesame oil), compared to 99.3 for the untreated group. There were slight differences in pupation rate and emergence between individuals treated with lemon-grass oil, and untreated ones, yet varied significantly with those treated with sesame oil.

## Discussion

In the nineteenth century, the peach fruit fly of *B. zonata* was officially identified and recorded for the first time in Egypt, where it attacked some of the main fruit varieties, and caused severe damage to several hosts in the Near East (e.g. mangoes, peach, and others) (Al-Eryan 2008). The control of fruit flies has mainly been dependent on the use of an organophosphorus insecticide, such as malathion (Hasanuzzaman & Idris 2019). Spinosad is a novel insect control agent derived by the fermentation of the *Actinomyces bacterium*, *Saccharopolyspora spinosa* (Thompson *et al.* 1997). Chemical insecticides that are relatively safe or have low mammalian toxicity, such as pyrethroid (lambda-cyhalothrin) have also been used. Another solution has been to use insecticides of natural origin, which are more eco-friendly and safer than traditional options (Ileke *et al.* 2014).

In the present study, the laboratory experiments were carried out to evaluate the lethal effects of three insecticides (malathion, lambda-cyhalothrin, and spinosad) and two

plant oils (lemon-grass and sesame) against *B. zonata*.

The present study shows that lambda-cyhalothrin (pyrethroid) is the most potent between spinosad and malathion on adults. These results are in harmony with those obtained by Oke (2008) who reported that lambda-cyhalothrin was better than deltamethrin in reducing the number of melon fruit flies' pupae. These results also agree with El-Moursy *et al.* (2000) who stated that the chemical insecticide pyrethroid (baythroid) was significantly more potent than the bio-insecticide Delfin against *Spodoptera littoralis* (Boisduval, 1874). Hamza & Hamza (2018) indicated that the examined insecticides (malathion, alpha-cypermethrin, lambda-cyhalothrin) could achieve considerable levels of mortality of *Rhyzopertha dominica* (Fabricius, 1745) adults in stored wheat.

Results show that spinosad was more effective than malathion on adults. These findings correspond to those of Xin-Geng & Russell (2006), confirming that a fruit fly bait based on spinosad recently became a primary instrument for wide-area suppression or eradication of tephritid fruit fly pests. These findings agree with El-Aw *et al.* (2008), and Bakret *et al.* (2016) who stated that spinosad was more effective than malathion in regulating and controlling *Ceratitis capitata* (Wiedemann, 1824), and *B. zonata*. The same result was obtained by Mahmoudv *et al.* (2011) who reported that spinosad caused more than 85% mortality against *Plutella xylostella* (Linnaeus, 1758). Aydien & Gurkan (2006) suggested that spinosad was potentially important in the control of *S. littoralis*.

Results illustrate that the effects of LC<sub>50</sub> values, for all the examined compounds, were higher in the case of adult females than in males. The obtained results concur with the outcomes of Bakr *et al.* (2016) concluding that females of *B. zonata* were less sensitive than males to malathion and spinosad.

The present study focuses on the effect of the biological aspects on the adults of *B. zonata*, showing that all tested compounds significantly decreased fecundity, hatchability, longevity of males and females, pupation rate, and emergence rate of adults, when compared with untreated individuals. El-Sheikh (2012) reported that longevity, fecundity, and fertility drastically decreased for female *S. littoralis* treated with spinosad in comparison to the control. Jemaa (2015) noted that spinosad confirmed promising ovicidal activity against *Ectomyelois ceratoniae* (Zeller, 1839) eggs.

Furthermore, the present study shows that all tested essential oils significantly decreased fecundity, hatchability, the longevity of males and females, pupation, and emergence of adults, when compared with the untreated control group. Seada *et al.* (2016) stated that with the application of essential oils, the numbers of laid eggs and emerging offspring decreased in *Sitophilus oryzae* (Linnaeus, 1763), and *Callosobruchus maculatus* (Fabricius, 1775). Idoko & Adesina (2012) illustrated that Piper guineense decreased the oviposition, hatchability, and emergence of *C. maculatus*. El-Nagar *et al.* (2012) noted that peppermint oil had an impact on the mating and oviposition of *C. maculatus*. Mating, fecundity, and emergence of the next generation progenies were significantly reduced by oil treatment. Adel *et al.* (2015) showed that the highest mortality rates for parents of *C. maculatus* were caused by fennel oil, followed by geranium and basil oils, whereas Mohamed *et al.* (2020) studied the percentage of adult emergence, and noted that not all viable pupae succeeded to continue their development, and produce viable adults. The volatile oil *Mentha piperita* significantly decreased the percentage of adult emergence, while the volatile oil *Origanum majorana* decreased the number of larvae of *Galleria mellonella* (Linnaeus, 1758). The highest percentage of adult emergence was 100 in the untreated control group.

Oviedo *et al.* (2020) noted that the exposure of sexually mature adults of *C. capitata* and *Anastrepha fraterculus* (Schiner, 1868) to both *Baccharis dracunculifolia* and *Pinus elliottii* essential oils resulted in lower longevity and female fecundity than in the untreated group.

## Conclusion

According to the obtained results, the three insecticides were effective in controlling the adults of *B. zonata*. However, Lambda-cyhalothrin was found to be better than malathion and spinosad. This study attempted to control *B. zonata* with certain plant oils which seemed to be safer and less contaminating. The tested essential oils (lemon-grass and sesame) had significant toxicity towards *B. zonata*, making them a promising sustainable tool for pest management. Nevertheless, lemon-grass was more effective than sesame oil. More importantly, all the tested insecticides and essential oils were either more or equally effective in deterring oviposition, ovicidal, fecundity, and the emergence of adult *B. zonata*.

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