Punjab University Journal of Zoology

40(2): 169-180 (2025)
https://dx.doi.org/10.17582/journal.pujz/2025/40.2.169.180

Research Article

Evaluation of Some Insecticides Against *Pieris rapae* (L., 1758) and *Bemisia tabaci* (Genn., 1889): Impacts on Natural Enemies and Biochemical Response

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Article History
Received: March 12, 2025
Revised: June 20, 2025
Accepted: July 01, 2025
Published: October 02, 2025

Authors' Contributions
MASA: Conceptualization, writing review and editing, formal analysis, project administration, methodology, data curation. HMA-E: Investigation, methodology, validation, supervision, writing. FARAG, MFNG and RSS: Conceptualization, writing review and editing, project administration, formal analysis, original draft. MGS: Conceptualization, writing review and editing, project administration, formal analysis. MMA: Conceptualization; writing review and editing, Supervision, formal analysis, project administration, methodology, data curation. All authors have read and agreed to the published version of the manuscript.

Keywords
Pieris rapae, *Bemisia tabaci*, Insecticides, Natural enemies, Biochemical

Abstract | The cabbage white butterfly, *Pieris rapae* (L.) (Lepidoptera: Pieridae), and the whitefly, *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae), are among the most destructive pests of field crops. This study was conducted to assess the effectiveness of four insecticides: methomyl 90% SP, emamectin benzoate 5.7% EC, thiamethoxam 25% WG, and lambda-cyhalothrin 5% EC against *B. tabaci* and *P. rapae* larvae, as well as their natural enemies, *Chrysoperla carnea* and *Coccinella septempunctata*. Additionally, the biochemical response of 4th instar *P. rapae* larvae was assessed, focusing on digestive enzymes (amylase, invertase, trehalase), total soluble proteins, and lipid content. Field experiments were conducted in cauliflower fields in Sharqia Governorate, Egypt, during the 2022–2023 growing seasons. The results indicated that emamectin benzoate showed the highest residual reduction (95.60%) of *P. rapae* in the 2022 season. In 2023, lambda-cyhalothrin was the most effective, achieving a 94.13% reduction. Thiamethoxam was the most effective against *B. tabaci*, causing 91.82% and 90.89% reduction recorded during 2022-2023, respectively. All treatments significantly decreased the populations of *Ch. carnea* and *C. septempunctata*, where emamectin benzoate and lambda-cyhalothrin recorded the highest residual mean reduction in both years, exceeding 90% for both natural enemies. In contrast, thiamethoxam was found to be less harmful. The digestive enzyme activities of *P. rapae* 4th instar larvae varied over time following insecticide exposure. Methomyl caused the highest reduction in amylase and trehalase activity (3.11 and 4.76 µg glucose/min/g body weight, respectively), whereas lambda-cyhalothrin showed the highest significant decrease in invertase activity (3.55 mg glucose/g body weight) after five days. In addition, total protein and lipid contents tended to decrease over time. Thiamethoxam caused the highest protein reduction (24.19 mg/g body weight), and emamectin benzoate caused the highest lipid reduction (6.21 mg/g body weight) after five days. These findings support the development of integrated pest management (IPM) strategies aimed at the sustainable control of *B. tabaci* and *P. rapae* in cauliflower fields.

Novelty Statement | This study presents novel comparative data on the efficacy of four insecticides against *Bemisia tabaci* and *Pieris rapae*, as well as their impact on natural enemies in cauliflower fields during 2022–2023. The findings offered valuable insights for designing safer and sustainable IPM strategies to control *B. tabaci* and *P. rapae* in cauliflower fields.

To cite this article: Ahmed, M.A.S., Abd-Elmonem, H.M., Farag, M.F.N.G., Sakla, R.S., Salama, M.G. and Abdel Hafez, M.M., 2025. Evaluation of some insecticides against *Pieris rapae* (L., 1758) and *Bemisia tabaci* (Genn., 1889): Impacts on natural enemies and biochemical response. *Punjab Univ. J. Zool.*, **40**(2): 169-180. https://dx.doi.org/10.17582/journal.pujz/2025/40.2.169.180

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Introduction

Cauliflower (*Brassica oleracea* L.), belonging to Cruciferae family, is an important cruciferous vegetable with significant production and export potential (Sapkota and Shrestha, 2018). It is highly valued for its rich nutritional content, including vitamins, minerals, dietary fiber and low fat and carbohydrates. Cauliflower is a versatile ingredient that is commonly used in various dishes such as curries, soups, pickles, and salads (Ashraf *et al*., 2017). Remarkably, cauliflower cultivation faces challenges from several insect pests, includingwhiteflies, *B. tabaci* (Genn.) (Hemiptera: Aleyrodidae) and white butterfly, *P. rapae* (L.) (Lepidoptera: Pieridae), which causes considerable damage (El-Sheikh, 2020; Flaih, 2017; Razmi *et al*., 2011).

The whitefly, *B. tabaci*, one of the most destructive pests globally, infests a wide range of crops in tropical and subtropical regions (Oliveira *et al*., 2001). It damages crops by feeding on plant sap, secreting toxic saliva, producing honeydew, facilitating mold growth, attracting ants, and disrupting natural enemies. *B. tabaci* infestation leads to leaf yellowing, curling, reduced plant longevity, and significant yield loss. Moreover, it serves as a vector for viral plant pathogens, causing further economic damage (Van Regenmortel *et al*., 2000).

Similarly, the white butterfly, *P. rapae*, is a serious pest of cruciferous crops (Abdel-Galil *et al*., 2019). Its larvae feed on Brassicaeae plants such as cabbage, cauliflower, and mustard (Hopkins *et al*., 2009). Young larvae graze on the lower leaf epidermis, whereas older larvae cause severe defoliation, often reducing plants to mere stems and veins (Lin LiangBin *et al*., 2001).

Given the significant crop losses associated with these pests, chemical control remains one of the most widely used management strategies. A variety of insecticides, including organophosphates, carbamates, pyrethroids, insect growth regulators (IGRs), and neonicotinoids, have been tested against these pests (Xie *et al*., 2014). However, the widespread use of these chemicals has led to several problems, including pesticide residues on crops, rapid development of resistance in pest populations (Liang *et al*., 2025; Roy *et al*., 2019; Salman *et al*., 2011) and harming beneficial species, including pollinators and natural enemies (Khurana *et al*., 2023). For example, several studies reported that neonicotinoids and pyrethroids effectively suppress pests but harm natural enemies (Cloyd and Bethke, 2011; Regan *et al*., 2017).

In this context, it is essential to reduce reliance on chemical insecticides by integrating alternative approaches, such as cultural and biological control methods, to maintain pest populations below the economic injury level (Mishra and Kanwat, 2017). For example, natural enemies such as the green lacewing, *Ch. carnea* (Stephens, 1836) (Neuroptera: Chrysopidae) and seven-spotted ladybird, *C. septempunctata* (Linnaeus, 1758) (Coleoptera: Coccinellidae) play a significant role in the biological control of pests, including *B. tabaci* and *P. rapae*. Notably, *Ch. carnea* is an effective predator of whiteflies, *P. brassicae*, aphids, and other pests, making it a valuable biocontrol agent (Huang and Enkegaard, 2010; Golmohammadi *et al*., 2021). Correspondingly, *C. septempunctata* is recognized for its predatory behavior against soft-bodied insects, thereby contributing to effective pest management (Mishra and Kanwat, 2017).

Therefore, a major challenge in integrated pest management (IPM) is achieving effective control of *B. tabaci* and *P. rapae*, which allows the conservation of beneficial natural enemies. In this study, we tested the efficacy of four insecticides: Emamectin benzoate, lambda-cyhalothrin, thiamethoxam, and methomyl, against the whitefly *B. tabaci* and white butterfly *P. rapae* larvae. Additionally, the side effects of these insecticides on the natural enemies *Ch. carnea* and *C. septempunctata* were examined. Furthermore, the study examined biochemical changes in *P. rapae* 4th instar larvae, focusing on carbohydrate enzymes (amylase, invertase and trehalase), total soluble proteins, and lipid content.

Materials and Methods

Experimental location

A field experiment was conducted in a cauliflower field in Abn El-Aase, Kafr Saqr region, Sharkia Governorate, Egypt, during two consecutive seasons, September 2022-23. A laboratory experiment was conducted at the Plant Protection Research Institute in the Sharkia Governorate, Egypt.

Insects

The study targeted two pests: *P. rapae* and *B. tabaci*, as well as their natural predators, *Ch. carnea* and *C. septempunctata*. White butterflies (*P. rapae*) were reared in the laboratory for biochemical investigations according to (Su *et al*., 2017) method with slight modifications. Our laboratory colony originated from cultures cultivated on pesticide-free cauliflower. During the experiment, the emergent butterflies were kept at (27±3 °C, 70±10% RH, and 14:10 h L: D) and were fed on a 10% aqueous honey solution daily. The adult butterflies were allowed to mate and lay eggs on the castor bean leaves. Once the leaves with *P. rapae* eggs were collected from the plants, they were transferred to plastic rearing trays measuring 20 × 40 × 15 cm. After the eggs hatched, the larvae were given fresh castor bean leaves as previously described.

Insecticides

Methomyl 90% SP (Lannate, recommended field rate 300g/feddan, Du Pont USA Starchem Industrial chemicals), emamectin benzoate 5.7% EC (Speedo, recommended field rate 60 gm/feddan, AGRES Syngeta), lambda-cyhalothrin 5% EC (Kiranto, recommended field rate 375cm /feddan, Kafr El-Zayt Company for pesticides) and thiamethoxam 25% WG (Actara, recommended field rate 20g/100 litter of water, Agro company Yanbu Street Dokki Giza-Egypt).

Insecticide efficiency bioassays

Field efficacy trials: The experimental area, covering about one feddan, was arranged in a randomized complete block design (RCBD) with five treatments, which included one control group. Each treatment was replicated four times. Each plot measured 1/20 feddan, with a 50 cm buffer zone between them to minimize drift and cross-interference. The environmental conditions were recorded as follows: (24–30 °C, 60–80% RH, and natural lighting conditions), with no rainfall observed throughout the period. It's important to note that, Cauliflower plants were sprayed with the tested compounds at field-recommended rates using a Solo Dorsal Sprayer motor (20 L).

Ingestion toxicity to P. rapae 4th instar larvae

To assess the effectiveness of various insecticides against fourth instar larvae of *P. rapae*, we performed a leaf-dip assay according to the Insecticide Resistance Action Committee (2000). Leaf discs, measuring 2.5 cm in diameter, were cut from castor bean leaves using a cork borer. These discs were then submerged in solutions of emamectin benzoate, lambda-cyhalothrin, thiamethoxam, and methomyl at a concentration of 5 ppm, based on preliminary bioassays and consistent with sublethal dose ranges reported in previous studies (Desneux *et al*., 2007; Göksu *et al*., 2015; Zhang *et al*., 2021), or in control solutions of sterile distilled water. Subsequently, the leaf discs were air-dried for 30 min at room temperature. After drying, the leaf discs were transferred to Petri dishes (9 cm diameter and 1.5 cm depth). In each dish, ten *P. rapae* 4th instar larvae were placed alongside the leaf discs at the centre of the Petri dish. Each treatment was replicated three times, and observations were made on days 1, 3, and 5.

Measurement of the reduction percentages

On a clear morning the infestation levels of *P. rapae* instar larvae and the predators *Ch. carnea* and *C. septempunctata* were visually inspected on 25 randomly selected cauliflower plants from each replication. Additionally, 25 leaves were randomly collected from every replication of cauliflower plants, placed in paper bags, and transported to the laboratory. The numbers of *B. tabaci* nymphs on the upper, middle, and lower leaves were counted using a binocular stereomicroscope. Inspections were conducted one day before treatment (pre-treatment), and subsequently one day (initial kill), seven days, and ten days post-treatment (residual effect). From these data, the reduction percentages of pests were calculated according to Henderson and Tilton (1955) equation as follows:

$$Reduction\ (\%) = 1 - (A/B \times C/D) \times 100$$

Where: A= No. of alive larvae in the treatment after application; B= No. of alive larvae in the treatment before application; C= No. of alive larvae in the control before application; D= No. of alive larvae in the control after application.

Biochemical measurements

To evaluate the effects of methomyl, emamectin benzoate, lambda-cyhalothrin, and thiamethoxam on biochemical parameters (carbohydrate-hydrolyzing enzymes, total lipids, and total soluble protein), *P. rapae* 4th instar larvae were treated with all groups. After one, three and five days of treatment, the larvae were weighed and subsequently frozen. Following 48 h, the frozen larvae were homogenized in 1 mL of distilled water using a homogenizer (MPW-309 Mechanic-Preczyina, Poland). The homogenates were then subjected to centrifugation at 6000 rpm for 10 min at 5 °C, three replicates were conducted for each assay. The resulting supernatant from each group was used to estimate carbohydrate hydrolyzing enzyme activities, total lipids and total soluble protein content (El-Gendy and El-Shafiey, 2018).

The activities of amylase, invertase and trehalose enzymes were estimated according to (Mohammed and Elshewy, 2016). The total soluble protein content was quantified at a wavelength of 546 nm using the method outlined by Goranll *et al*. (1949). Additionally, the total lipid content was estimated according to the method described by Schmit (1964).

Statistical analysis

The statistical analysis was performed by using the Costat statistical software. The data was analyzed by using one-way analysis of variance (ANOVA) to determine significant differences between treatments, followed by post hoc comparisons using Tukey's HSD test, where appropriate significance was at the level of ($P \leq 0.05$).

Results and Discussion

Efficacy of tested insecticides on P. rapae, during 2022-23

The field experiments conducted during the 2022 cauliflower season on managing the white butterfly, *P. rapae*, demonstrated that all pesticide treatments significantly reduced the *P. rapae* population (Table 1). Among these treatments, emamectin benzoate was particularly effective, achieving a maximum reduction over control across all test periods with an impressive residual mean reduction of 95.60% and an annual reduction of 87.77%.

Table 1: Reduction percentage of *Pieris rapae* after applications of different insecticides in the cauliflower field during the 2022 season.

Treatments	2022					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7 d.	10 d.		
Methomyl	0.33	78.64	90.36	93.84	92.10[b]	87.61[ab]
Emamectin benzoate	0.34	72.10	93.75	97.45	95.60[a]	87.77[a]
Thiamethoxam	0.35	78.42	76.68	68.92	72.80[d]	74.67[c]
Lambda-cyhalothrin	0.34	89.14	86.42	86.20	86.31[c]	87.25[b]
Control	0.39	0.44	0.45	0.59		
P					**	**
LSD 0.05					2.12	1.90

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

Table 2: Reduction percentage of *Pieris rapae* after applications of different insecticides in the cauliflower field during the 2023 season.

Treatments	2023					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	0.40	90.14	92.82	89.52	91.17[b]	90.83[b]
Emamectin benzoate	0.53	89.41	92.13	90.53	91.33[b]	90.69[b]
Thiamethoxam	0.23	77.13	72.90	72.00	72.45[d]	74.16[c]
Lambda-cyhalothrin	0.40	94.98	93.27	92.88	94.13[a]	93.71[a]
Control	0.33	0.4	0.45	0.47		
P					**	**
LSD 0.05					1.09	1.18

Means sharing different superscripts in each column are significantly different (Tukey"s HSD, P > 0.05).

In 2023, three pesticides, methomyl, emamectin benzoate, and lambda-cyhalothrin, exhibited the highest efficacy against *P. rapae*. Lambda-cyhalothrin showed superiority with a residual mean reduction of 94.13% over other treatments, followed by emamectin benzoate and methomyl with a residual mean reduction of 91.33 and 91.17%, respectively (Table 2). In contrast, thiamethoxam exhibited the lowest *P. rapae* reduction in 2022 and 2023, with a residual mean reduction percentage of 72.80 and 72.45 %, respectively.

These findings are consistent with the research by Aioub *et al.* (2021), who observed that lambda-cyhalothrin (52 and 2.48 ppm) was the most toxic insecticide against the 4th-instar larvae of the cabbage white butterfly, *P. rapae*, succeeded by emamectin benzoate (2.30 and 4.82 ppm) and indoxacarb (3.12 and 6.31 ppm). The results further corroborate earlier studies that highlighted the efficacy of emamectin benzoate in reducing the larval population of *P. rapae* (Youhua and Hongmei, 2009; Singh *et al.*, 2010; Gautam *et al.*, 2022). Similarly, lambda-cyhalothrin-based insecticides have been reported to exhibit high efficacy in controlling *P. rapae* and *P. xylostella* caterpillars (Vuković *et al.*, 2014).

Efficacy of tested insecticides on B. tabaci, during 2022-23

Thiamethoxam exhibited the most significant reduction against *B. tabaci* larvae throughout the assessed periods, with residual mean reduction values of 91.82% and 89.03% during the 2022 and 2023, respectively. This was followed by lambda-cyhalothrin, then methomyl, then emamectin benzoate (Tables 3, 4).

These findings align with earlier research indicating that thiamethoxam exhibits the highest efficacy against *B. tabaci* (Al-Kherb, 2011; El-Naggar and Zidan, 2013). Furthermore, Das and Islam (2014) reported that both thiamethoxam and emamectin benzoate provided moderate control of *B. tabaci*. Similary, lambda-cyhalothrin has been recognized for its strong efficacy against *B. tabaci*, reinforcing its role as a crucial insecticide in pest management programs (Bughdady *et al.*, 2020; Schuster *et al.*, 2009).

Efficacy of tested insecticides on predators Ch. carnea and C. septempunctata in cauliflower field during 2022-23

The analysis of results indicated that during the 2022, both lambda-cyhalothrin and emamectin benzoate showed the highest significant population reduction of *Ch. carnea*, with residual mean reduction values (90.57 and 90.61%, respectively), followed by methomyl and thiamethoxam with residual mean reduction (88.01 and 51.13%, respectively) (Table 5).

Table 3: Reduction percentage of *Bemisia tabaci* after applications of different insecticides in the cauliflower field during the 2022 season.

Treatments	2022					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual meanreduction
			7d.	10d.		
Methomyl	1.44	70.47	75.24	78.97	77.11[c]	74.89[c]
Emamectin benzoate	1.60	69.73	76.33	66.33	71.33[c]	70.80[d]
Thiamethoxam	1.63	91.54	93.51	91.04	91.82[a]	92.03[a]
Lambda-cyhalothrin	1.63	79.44	87.49	90.41	89.18[b]	85.93[b]
Control	1.79	2.5	2.6	2.8		
P					**	**
LSD 0.05					2.12	1.90

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

Table 4: Reduction percentage of *Bemisia tabaci* after applications of different insecticides in the cauliflower field during the 2023 season.

Treatments	2023					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	1.83	64.99	69.02	73.66	71.34[c]	69.22[cd]
Emamectin benzoate	1.97	72.09	67.39	71.58	69.76[c]	70.53[c]
Thiamethoxam	2.13	85.31	90.78	91.00	90.89[a]	89.03[a]
Lambda-cyhalothrin	1.73	87.02	85.92	85.89	82.91[b]	83.28[b]
Control	1.87	2.17	2.40	2.46		
P					**	**
LSD 0.05					5.06	2.03

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

Table 5: Side effects of pesticides on the associated natural enemies *Chrysoperla carnea* in the cauliflower field during the 2022 season.

Treatments	2022					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	0.67	90.24	89.00	87.02	88.01[b]	88.75[a]
Emamectin benzoate	0.67	70.68	90.24	90.98	90.61[a]	83.97[ab]
Thiamethoxam	0.77	57.89	51.22	51.04	51.13[c]	53.38[b]
Lambda-cyhalothrin	0.80	93.12	90.47	90.67	90.57[a]	91.42[a]
Control	0.81	0.83	0.85	0.86		
P					**	**
LSD 0.05					2.81	2.84

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

In season 2023, the highest significant reduction with a residual reduction of *Ch. carnea* was recorded by emamectin benzoate and lambda-cyhalothrin with an annual mean value (90.57 and 90.10%, respectively), followed by methomyl (87.29%), then thiamethoxam (49.37%) (Table 6). Notably, thiamethoxam exhibited the lowest significant reduction in *Ch. carnea* during seasons 2022-23.

Interestingly, emamectin benzoate and lambda-cyhalothrin exhibited the highest significant reduction of *C. septempunctata* during season 2022, with values (93.35 and 93.15 %). Thiamethoxam and methomyl were recorded at lower reductions of 51.67% and 48.12%, respectively (Table 7). Similarly, lambda-cyhalothrin and emamectin benzoate showed the highest residual mean reduction during season 2023, with values (94.65 and 93.90%, respectively), followed by methomyl (47.10%), then thiamethoxam (43.05%) (Table 8).

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Table 6: Side effects of pesticides on the associated predator *Chrysoperla carnea* in the cauliflower field during the 2023 season.

Treatments	2023					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	0.77	90.43	87.90	86.67	87.29[b]	88.33[b]
Emamectin benzoate	0.78	54.85	90.48	91.42	90.95[a]	78.92[c]
Thiamethoxam	0.81	53.86	52.42	46.32	49.37[c]	50.87[d]
Lambda-cyhalothrin	0.80	92.50	90.17	90.03	90.10[a]	90.90[a]
Control	0.83	0.85	0.87	0.88		
P					**	**
LSD 0.05					1.29	1.18

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

Table 7: Side effects of pesticides on the associated predator *Coccinella septempunctata* in the cauliflower during the 2022 season.

Treatments	2022					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	1.20	46.67	49.57	52.57	48.12[c]	49.60[d]
Emamectin benzoate	1.40	93.90	92.79	85.35	93.35[a]	90.68[b]
Thiamethoxam	1.20	45.47	57.86	59.28	51.67[b]	54.20[c]
Lambda-cyhalothrin	1.30	92.83	93.47	92.71	93.15[a]	93.00[a]
Control	1.40	1.48	1.46	1.44		
P					**	**
LSD 0.05					2.40	1.82

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

Table 8: Side effects of pesticides on the associated predator *Coccinella septempunctata* in the cauliflower during the 2023 season.

Treatments	2023					
	Pre-count number	Initial kill 1d.	Residual effect		Residual mean reduction	Annual mean reduction
			7d.	10d.		
Methomyl	1.00	45.20	49.00	55.30	47.10[b]	49.83[c]
Emamectin benzoate	1.20	93.50	94.30	80.50	93.90[a]	89.43[b]
Thiamethoxam	1.10	40.50	45.60	50.70	43.05[c]	45.60[d]
Lambda-cyhalothrin	1.25	94.00	95.30	94.50	94.65[s]	94.60[a]
Control	1.30	1.40	1.36	1.33		
P					**	**
LSD 0.05					1.97	1.27

Means sharing different superscripts in each column are significantly different (Tukey's HSD, P > 0.05).

These results were supported by the findings of Nasreen *et al.* (2007), who observed that methomyl resulted in approximately 95% mortality in the first instar, 92% in the 2nd instar, and 60–70% in the 3rd instar of *Ch. carnea*. Similary, the combination of lambda-cyhalothrin and thiamethoxam significantly decreased natural enemies in cotton fields (Zambrano *et al.*, 2021). In addition, El-Arnaouty *et al.* (2010) showed that emamectin benzoate had the highest reduction percentage for the predator insect *Coccinella* spp. Meanwhile, Sechser *et al.* (2003) reported that emamectin benzoate had the lowest impact on *Ch. carnea* populations. Additionally, insecticides belonging to various chemical groups have been shown to increase the mortality rate of *C. undecimpunctata* (L.) (Coleoptera: Coccinellidae) and *Ch. carnea* (Stephens) (Neuroptera: Chrysopidae) (El-Heneidy *et al.*, 2015; Eldesouky, 2019).

Biochemical responses of the tested insecticides on P. rapae

Digestive enzyme activities: To assess the impact of the tested insecticides on the biochemical parameters of *P. rapae* 4th instar larvae, carbohydrate hydrolyzing enzymes such as amylase, invertase, and trehalase were estimated after one, three , and five days. After one d, all treatments showed a significant increase in amylase enzyme activity of 4th instar larvae of *P. rapae* compared with control (Table 9), where the lambda-cyhalothrin treatment exhibited the most increase, reaching 6.79 µg glucose/min/g. bwt., followed by methomyl,emamectin benzoate and thiamethoxam, respectively. It is important to note that, amylase activity in all treated groups declined over time, whereas methomyl exhibited the lowest significant activity at the fifth day with a value of 3.11 µg glucose/min/g. body weight) compared to control with a value of 5.12 µg glucose/min/g. body weight.

Table 9: Effect of tested insecticides on amylase enzyme activity in the 4th instar larvae of *Pieris rapae.*

Tested insecticides		Amylase enzyme activity (mg glucose/g body weight/days		
		1 d	3d	5d
Methomyl	SA	6.56[b]	0.02[e]	3.11[e]
	RA%	35.56	-99.84	-39.25
Emamectin benzoate	SA	5.88[c]	4.745[c]	4.64[c]
	RA%	31.86	-65.01	-9.21
Thiamethoxam	SA	5.62[d]	2.04[d]	3.83[d]
	RA%	30.45	-84.60	-25.13
Lambda cy-halothrin	SA	6.79[a]	4.87[b]	4.77[b]
	RA%	36.84	-63.29	-6.84
Control		0.018[e]	13.28[a]	5.12[a]
P		0.000 ***	0.000 ***	0.000 ***
$LSD_{0.05}$		0.049	0.075	0.084

SA, Specific activity (mg glucose/g. b. wt./min.) and RA% – (Relative activity %) – ((Treatment - Control)/Control) × 100.

Table 10: Effect of tested insecticides on invertase enzyme activity in the 4th instar larvae of *Pieris rapae.*

Tested insecticides		Invertase enzyme activity (mg glucose/g body weight)/days		
		1 d	3d	5d
Methomyl	SA	9.827[d]	14.39[c]	5.36[d]
	RA%	466.95	- 0.019	- 0.337
Emamectin benzoate	SA	11.70[c]	16.04[a]	8.96[a]
	RA%	556.3	2.094	0.10
Thiamethox-am	SA	13.47[b]	3.142[e]	8.30[b]
	RA%	640.67	- 0.78	0.02
Lambda cy-halothrin	SA	16.16[a]	13.14 [d]	3.55[e]
	RA%	768.90	- 0.10	- 0.56
Control		0.021[e]	14.67[b]	8.09[c]
P		0.000***	0.000***	0.000***
$LSD_{0.05}$		0.048	0.073	0.078

SA, Specific activity (mg glucose/g. b. wt./min.) and RA% – (Relative activity %) – ((Treatment - Control)/Control) × 100.

The data revealed a significant increase in invertase enzyme activity of 4th instar larvae of *P. rapae* in all treatments after 1 day. Lambda-cyhalothrin showed the highest increase with a value of 16.168 (mg glucose/g. body weight). While after 3 days, emamectin benzoate exhibited a greater increase (16.049 mg glucose /g. body weight). in contrast, after five days, there was a decrease in invertase enzyme activity compared to that at one and three days, whereas lambda-cyhalothrin showed the lowest enzyme activity (3.552 mg glucose /g. body weight) (Table 10).

Regarding trehalase activity after one d, all treatments showed an increase, and lambda-cyhalothrin showed the highest increase (7.529 mg glucose/g. body weight) (Table 11). After three days, lambda-cyhalothrin, thiamethoxam and methomyl showed a decrease in trehalase activity (4.2615, 5.75 and 6.200, respectively) compared to the control. Emamectin benzoate showed the highest increase in enzyme activity after three and five days. Methomyl and thiamethoxam showed the lowest enzyme activity after five days compared to the control group. Briefly, amylase, invertase and trehalase showed an increase after one day of treatment, followed by a decrease after three and five days across most tested insecticides.

Table 11: Effect of tested insecticides on trehalase enzyme activity in the 4th instar larvae of *Pieris rapae.*

Tested insecticides		Trehalase enzyme activity (mg glucose/g body weight)/days		
		1d	3d	5d
Methomyl	SA	2.95[d]	6.20[c]	4.76[c]
	RA%	5.94	-4.09	-24.01
Emamectin benzoate	SA	4.51[c]	7.44[a]	10.17[a]
	RA%	9.14	15.10	62.22
Thiamethoxam	SA	5.36[b]	5.75[d]	5.55[d]
	RA%	10.87	-11.04	-11.34
Lambda-cy-halothrin	SA	7.52[a]	4.26[e]	8.04[b]
	RA%	15.29	-34.07	- 0.56
Control		0.04[e]	6.46[b]	6.27[c]
P		0.000 ***	0.000 ***	0.000 ***
$LSD_{0.05}$		0.10	0.17	0.08

SA, Specific activity (mg glucose/g. b. wt./min.) and RA% – (Relative activity %) – ((Treatment - Control)/Control) × 100.

Enzyme bioassays serve as diagnostic tools for assessing physiological changes or damage in organisms exposed to pollutants. Amylase and invertase are key digestive enzymes in various insect species, playing essential roles in digestion, growth, and development (Zeng *et al*., 2019), while trehalase is important for carbohydrate absorption (Chen and Gibney, 2023).

These results are consistent with the findings of

Assar *et al*. (2016) who reported that emamectin benzoate reduced invertase activity while increasing amylase and trehalose levels in 4th instar *Spodoptera littoralis* larvae. In contrast, a slight decrease in trehalase and amylase activity, and a minor increase in invertase activity were observed in tomato leaf miner larvae, *Tuta absoluta* larvae treated with emamectin benzoate (Al-Ghnam and Abd El Naby, 2020; El-Tokhy *et al*., 2020).

Measurement of total soluble protein content

The obtained results (Figure 1) showed that after one day, the total soluble protein content was reduced for all the treatments compared to the control group. After three days, lambda-cyhalothrin showed the highest significant increase with values (61.27 mg/g. body weight), followed by emamectin benzoate (39.31 mg/g. body weight). While, after five days, emamectin benzoate pesticide showed the highest significant increase (47.158 mg/g. body weight) compared to the control. In contrast, thiamethoxam and methomyl experienced a decline in total soluble protein content throughout the treatment periods compared to the control group.

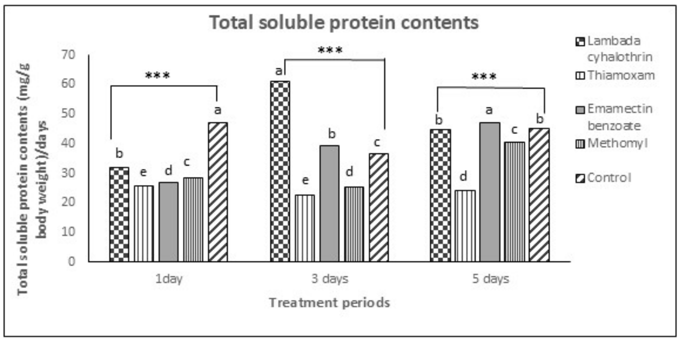

Figure 1: Comparative analysis of total soluble protein concentration (mg/g. body weight) in *P. rapae* larvae treated with lambda-cyhalothrin, thiamethoxam, emamectin benzoate, methomyl and control group. Protein content significantly varied across treatments and time points, with lambda-cyhalothrin consistently inducing the highest protein levels, especially at day three, while thiamethoxam and methomyl resulted in the lowest protein levels. Different letters between bars indicate a significant difference (*p*-value < 0.05). The stars on the top of each treatment group indicate the significance level between their means *(* = P < 0.001).***

These results are in agreement with those of Taleh *et al*. (2021), who reported that combinations of emamectin benzoate with either azadirachtin or indoxacarb significantly reduced the total protein content of tomato leaf miner larvae, *T. absoluta*. This reduction in protein content may be due to the dissociation of protein, resulting in the insect's reduced energy storage (Nath *et al*., 1997).

Measurement of total lipid content

The total lipid content (mg/g body weight) was decreased across all treatments, with the exception oflambda-cyhalothrin pesticides, which had a value of 8.763 (mg/g body weight) compared to the control's 7.624 (mg/g body weight) after one day of treatment. It is important to note that all treatments demonstrated a trend of decreasing total lipids after three and five days (Figure 2).

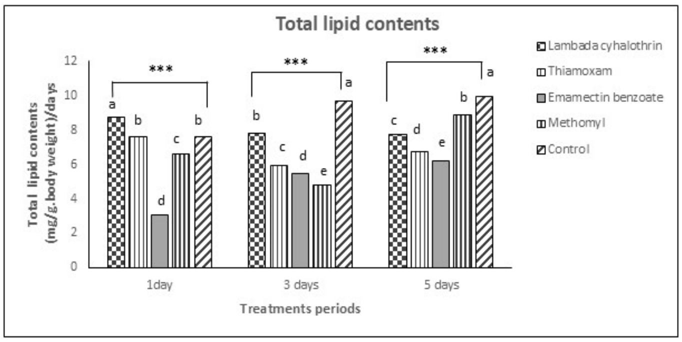

Figure 2: Comparative analysis of total lipid contents (mg/g body weight) in *P. rapae* larvae treated with lambda-cyhalothrin, thiamethoxam, emamectin benzoate, methomyl and the control group. Lipid levels varied significantly across treatments and generally decreased over time. Emamectin benzoate and thiamethoxam treatments led to the greatest reductions after five days. Different letters between bars indicate a significant difference (*p*-value < 0.05). The stars on the top of each treatment group indicate the significance level between their means *(* = P < 0.001).***

These results align with the findings of Assar *et al*. (2016) who reported a significant reduction in total protein and lipid content in the 4th instar *S. littoralis* larvae following emamectin benzoate treatment. Similarly, Xu *et al*. (2016) observed that sublethal concentrations of insecticides, such as cyantraniliprole, led to a decrease in the nutrient content, including lipids, proteins, and carbohydrates, in the black cutworm *Agrotis ipsilon* (Lepidoptera: Noctuidae).

Overall, extensive reliance on chemical insecticides has raised global concerns due to health risks, the development of insecticide resistance, and ecological disruption affecting non-target organisms, including beneficial predators and pollinators (Serrão *et al*., 2022). In our study, the insecticides showed efficacy against *P. rapae* and *B. tabaci*, but they also negatively impacted natural enemies like *Ch. carnea* and *C. septempunctata*, revealing a key limitation. To address this, future research should explore integrating advanced technologies into pest management strategies such as using biopesticides, gene-editing tools like gene drives (Legros *et al*., 2021), CRISPR/Cas9 systems (Doudna and Charpentier, 2014), and genetically modified crops (Kumar *et al*., 2020). Additional methods such as pheromone traps (Levi-Zada, 2023), nanotechnology-based formulations (Malik *et al*., 2023), and DNA insecticides (Oberemok *et al*., 2019). These innovations will be essential for developing safer, more sustainable pest management in cropping systems.

Conclusion

Our study presents encouraging findings on the effectiveness of methomyl, emamectin benzoate, thiamethoxam and lambda-cyhalothrin against two target pests, *P. rapae and B. tabaci*, in cauliflower crops during the 2022 and 2023 seasons. Notably, emamectin benzoate emerged as the most effective option for controlling *P. rapae* in 2022, whereas lambda-cyhalothrin achieved the highest reduction in 2023. Additionally, thiamethoxam consistently showed the greatest reduction in *B. tabaci* populations across both seasons. It is important to note that, all insecticide treatments had varying impacts on the populations of the natural enemies *Ch. carnea* and *C. septempunctata*. Lambda-cyhalothrin was the most harmful to both beneficial species during both years. In contrast, thiamethoxam was found to be less harmful to *Ch. carnea* in 2022 and 2023, whereas methomyl and thiamethoxam appeared to have a lesser impact on *C. septempunctata* populations. Overall, these findings indicate that thiamethoxam could be an optimal choice for inclusion in an Integrated Pest Management (IPM) strategy for cauliflower, given its high effectiveness against both *B. tabaci* and *P. rapae* alongside its relatively mild effects on vital natural enemies. Future studies should focus on long-term monitoring of insecticide resistance and assess non-target impacts through risk assessments. Additionally, integrating biopesticides, resistant cultivars, habitat manipulation, and cultural practices that enhance natural enemy populations for more sustainable pest management in cauliflower fields.

Declarations

Acknowledgement

The authors extend their appreciation to Prof. Al-Shannaf, H.M.H., for his help and support in designing the field experiment

Funding

No funding was received for this study.

IRB approval

This study did not involve human participants or vertebrate animals and therefore did not require Institutional Review Board (IRB) approval.

Ethical approval

This study does not involve any research activities that require ethical approval.

Declaration of generative AI and AI-assisted technologies in the writing process

No Generative AI and AI-assisted technologies wer used in the writing process.

Conflict of interest

The authors have declared no conflict of interest.

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