Assiut Journal of Agricultural Sciences 56(4) 2025 (279-301)
ISSN: 1110-0486 / EISSN: 2356-9840

Website: http://ajas.journals.ekb.eg/
E-mail: ajas@aun.edu.eg

(Original Article)

Efficiency of Foliar and Seed Treatments of Neonicotinoid Insecticides in Comparison with Sulfoxaflor Against the Faba Bean Leafminer, *Liriomyza trifolii* (Burgess)

Aly A. Abd-Ella*; Dalia S. Bakhet; Samir H. Manaa and Tasneem A. Elghareeb

Plant Protection Department, Faculty of Agriculture, Assiut University, 71526 Assiut, Egypt.

Corresponding author e-mail: aly.abdella@aun.edu.eg
DOI: 10.21608/AJAS.2025.405584.1517

Abstract

Liriomyza trifolii (Burgess) is one of the major insect pests on faba bean in Egypt. The efficacy of seed and foliar treatments of neonicotinoid insecticides in comparison with sulfoxaflor were evaluated for control of leafminer during 2021-2022 and 2022-2023 seasons. Seed treatments of sulfoxaflor, thiamethoxam and imidacloprid reduced leafminer on faba bean variety compared with the control during both seasons. However, acetamiprid and dinotefuran had lower effects as seed treatments. Furthermore, sulfoxaflor exhibited the highest reduction on faba bean leafminer. In addition, the foliar treatments of sulfoxaflor, thiamethoxam, imidacloprid, acetamiprid and dinotefuran significantly reduced the population of leafminer with an average reduction percentage of 82.41, 74.11, 66.13, 56.04 and 49.12%, respectively during the first season. In the second season, the average reduction was significant difference between sulfoxaflor 77.97% and thimathoxam 66.45%, imidacloprid 61.37%, acetamiprid 50.98% and dinotefuran 43.66%. Under faba bean field conditions, sulfoxaflor, thiamethoxam, imidacloprid, acetamiprid and dinotefuran registered a significantly high percent reduction of the faba bean leafminer at 1, 3, 7, 15 and 21 days post treatment. Therefore, sulfoxaflor as foliar and seed treatments could be used in integrated pest management programs for controlling leafminer. Both treatment methods have demonstrated efficacy against *L. trifolii* in faba beans.

Keywords: *Liriomyza trifolii, Management, Neonicotinoids, Sulfoxaflor.*

Introduction

The faba bean leaf miner, *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae), is a major pest that significantly reduces crop yield. Female miners puncture the upper surfaces of faba bean leaves to lay eggs, and the emerging larvae tunnel between the leaf's surfaces, consuming the palisade tissue. This damage impairs photosynthesis, leading to yellowing and drying of the leaflets (Aamer & Hegazi 2014; Eva, 2016, Hassan *et al.,* 2016; Bayoumy *et al.,* 2018; Ali *et al.,* 2020). It was reported as a pest of many plant species belonging to different families including faba bean (Bayoumy *et al.,* 2018), field bean (Aamer & Hegazi 2014), field pea (Hassan *et al.,* 2016) and field tomato (Eva, 2016). Controlling leaf miners solely with chemical insecticides is often challenging (Bayoumy *et al.,* 2018; Ali *et al.,* 2020).

Received: 21 June 2025/ Accepted: 23 September 2025/ Published online: 15 October 2025

Controlling leafminer in crops is very important to increase the quality and quantity of the products. *L. trifolii* is characterized by its high resistance to insecticides (Wei *et al.,* 2015). All insecticides were used in the open fields to control leafminer as abamectin which showed a moderate effect against leafminer (Aly *et al.,* 2023; Hamza *et al.,* 2023). Selective insecticides, such as neonicotinoids, have been introduced in recent years to address the growing resistance of insect pests to traditional insecticides. These newer alternatives are increasingly replacing organophosphates and methylcarbamates, as conventional insecticides have become less effective over time, according to Tomizawa *et al.* (2007). The selective efficacy of neonicotinoids primarily stems from their action at the target site, specifically the agonist binding region of the nicotinic acetylcholine receptor (Nauen *et al.,* 2001; Tomizawa *et al.,* 2007; Casida & Durkin, 2013). Represented by key compounds like imidacloprid, thiamethoxam, acetamiprid, and dinotefuran, neonicotinoids have emerged as one of the most significant classes of insecticides in the last three decades. Neonicotinoids are especially potent against homopteran pests like aphids, as noted by Elbert *et al.* (1991).

Thiamethoxam is recognized as the first commercially available second-generation neonicotinoid insecticide belonging to the thianicotinyl sub-class (Maienfisch *et al.,* 2001). It demonstrates high efficacy in managing numerous economically significant insect pests across various crops, including cotton, wheat, corn and faba bean. Its mode of action encompasses contact, stomach, and systemic activity (Wilde *et al.,* 2001). Sharma and Lal (2002) identified thiamethoxam as an exceptionally effective insecticide against the leaf miner, *Liromiza congesta*. Similarly, Abbas *et al.* (2012) tested three insecticides, including actara (thiamethoxam) 24% WG, and concluded that actara demonstrated remarkable efficacy against both whiteflies and leaf miners. Further supporting these findings, Waly *et al.* (2019) highlighted the significant impact of thiamethoxam in reducing populations of leaf miners (*Liromiza congesta*) and aphids in faba bean plants. Abd-Ella (2014), Yadav *et al.* (2015) and Patil *et al.* (2017) noted that diafenthiuron was found to be next best after thiamethoxam and superior to dimethoate against aphids. Hassan *et al.* (2023) reported that, pelexam (thiamethoxam) had a low effect in reducing the population of *L.trifolii* 30.24%. Singh and Saravanan (2008) stated that imidacloprid recorded a highest percentage reduction (97.16%) of pea leaf miner *Phytomyza horticola* followed by thiamethoxam (93.86%) and acetamiprid (90.77%).

Imidacloprid, introduced by Bayer CropScience in 1991, marked the beginning of the neonicotinoid class of insecticides and has since been sold commercially in numerous countries worldwide (Jeschke *et al.,* 2011). This neurotoxic substance is primarily used for pest control due to its role as an acetylcholine receptor agonist. Classified under neonicotinoids, it is further categorized into subgroups such as N-nitroguanidines (including imidacloprid, thiamethoxam, clothianidin, and dinotefuran), nitromethylenes (nitenpyram), and N-cyanoamidines (acetamiprid and thiacloprid) (Motaung, 2020). Imidacloprid is available in the market under several brand names like Admire, Gaucho, Confidor, Premise, Prothor, and Winner. While it has various applications, the most widely recognized brands are predominantly used in horticulture and agricultural crop production systems (Jeschke *et al.,* 2011). Imidacloprid has traditionally been employed through methods such as foliar spraying, seed dressing, and soil treatment, all of which play an essential role in safeguarding various crop species (Marquini *et al*., 2003; Motaung, 2020). Foliar spraying is particularly effective for managing harmful defoliating pests like butterflies, moths, leaf beetles, grasshoppers, leafminers, and sawflies. Meanwhile, seed coating and soil treatments are applied directly at the targeted site, offering a more precise approach to protecting crops.

Acetamiprid, a novel neurotoxic insecticide from the chloronicotinyl family, is highly suited for orchard and crops protection due to its rapid knockdown effect and prolonged persistence of over three weeks (Lacombe, 1999). It has demonstrated effective control against main pests such as aphids, whiteflies, grasshoppers and leafminers present in pome fruits, stone fruits, citrus, vegetables and crops, it is regularly obtained, equal to or better than standard products (Wilde *et al*., 2004; Wang *et al.,* 2005; Abd-Ella, 2014; 2015; Hassan *et al.,* 2023). Hassan *et al.* (2023) reported that acetamiprid had a low effect in reducing the population of *L. trifolii* 43.81%. Sharma *et al.* (2002) who tested 7 insecticides against pea leafminer, *Phytomyza atricornis* (*Chromatomyia horticola*) on pea plants. Cypermethrin, fenvalerate, dimethoate, dichlorvos, methyl demeton, endosulfan, acetamiprid and phosphamidon. Insecticides significantly reduced the mean number of leaf miner population and increased the green pod yield compared to untreated control. Singh and Saravanan (2008) reported that acetamiprid exhibited the lowest percentage reduction (90.77%) of pea leaf miner *Phytomyza horticola* compared to the other insecticides. Dinotefuran is a relativelynew neonicotinoid insecticide, known for its strong efficacy against various insect pests while maintaining a low level of toxicity to mammals (Mori *et al.,* 2002; Nault *et al.,* 2004; Wilde *et al.,* 2004; Wang *et al*., 2005; Abd-Ella, 2014; 2015). Abbassy *et al.* (2008) reported that the seed dressing of dinotefuran significantly reduced leafminer larvae on common bean.

Sulfoxaflor represents a relatively new class of insecticidal chemistry, specifically designed to combat sap-feeding insect pests (Zhu *et al.,* 2011; Sparks *et al.,* 2013). It stands out as the first crop protection product to feature a sulfoximine moiety, a structural novelty that distinguishes it from other insecticides (Zhu *et al.,* 2011). This unique chemistry introduces significant differences in how sulfoxaflor interacts with metabolic enzymes linked to insecticide resistance and engages with its target site, setting it apart from conventional options (Watson *et al.,* 2011; Sparks *et al.,* 2013; Sparks *et al.,* 2019; Watson *et al.,* 2021). Furthermore, while sulfoxaflor shares a mode of action similar to neonicotinoids such as imidacloprid, thiamethoxam, and acetamiprid acting on insect nicotinic acetylcholine receptors (nAChRs), its mechanism is characterized by a distinct set of attributes (Onozaki *et al.,* 2017; Jeschke *et al.,* 2019). The sulfoximine chemistry also influences sulfoxaflor's interaction with enzymes such as monooxygenases (P450s, CYPs), which are involved in metabolic resistance among pest insects (Sparks *et al.,* 2013). This interplay further impacts the effectiveness and the resistance profile of sulfoxaflor (Sparks *et al.,* 2013; Sparks *et al.,* 2019). Seal *et al.* (2014) evaluated insecticides of various chemical classes to manage leafminer on bean. They reported that all insecticide treatments (foliar and seed dressing) of sulfoxaflor significantly reduced leafminers mines/bean leaf when compared with the nontreated control.

The use of systemic insecticides for seed treatment has become a common method to manage pests across various crops (Taylor *et al.,* 2001). Compared to spray applications, chemical seed treatments typically require lower quantities of insecticide, minimizing environmental contamination and limiting the exposure of non-target organisms (Schemeer *et al.,* 1990; Nault *et al.*, 2004). As a result, seed treatment has gained widespread popularity as part of integrated pest management strategies (Zhang *et al.,* 2011). Neonicotinoid-based insecticidal seed treatments offer farmers an effective means to control insect pests across various field crops globally. These systemic insecticides possess several beneficial chemical properties, such as high-water solubility and lower toxicity to humans and other mammals (Tang *et al.,* 2017). During germination, plant roots absorb these compounds, providing internal protection for growing plants against insect pests (Tomizawa and Casida, 2005) and enhancing their resilience to abiotic stressors while promoting overall vigor (Casida, 2011). Among the neonicotinoids commonly used as seed treatments are carbosulfan (Tang *et al.,* 2006), imidacloprid (Li *et al.,* 1996), thiacloprid (Deng *et al.,* 2011), and thiamethoxam (Tang *et al*., 2017). Therefore, this study aimed to evaluate the efficiency of foliar and seed treatments of four neonicotinoid insecticides acetamiprid, imidacloprid, thiamethoxam and dinotefuran in comparison with sulfoxaflor to control the faba bean leaf miner, *Liriomyza trifolii* under field conditions.

Materials and Methods

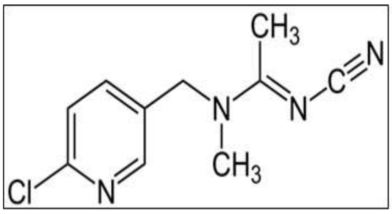
1. Insecticides

Trade names, formulation types, active ingredient percentages, and recommended application rates of the tested neonicotinoid insecticides are outlined in Table 1. The chemical structures of acetamiprid, imidacloprid, thiamethoxam, dinotefuran, and sulfoxaflor, which were applied both as foliar treatments and seed treatments to target faba bean leafminer (*L. trifolii*) under field conditions, are presented in Figure 1. The pesticide doses utilized in the study correspond to the rates suggested on their labels.

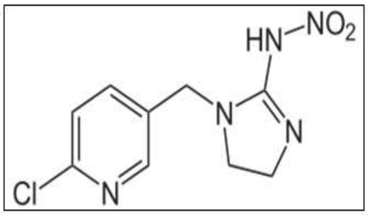
Table 1. Descriptions of the neonicotinoid insecticides used as foliar and seed treatments against the faba bean leafminer, *L. trifolii.*

Active ingredient	Trade name	% (a.i.) and formulation type*	Recommended rates	
			Seed treatment	Foliar spray
Sulfoxaflor	Closer	24% SC	7 cm Kg^{-1}	0.25 cmL^{-1}
Thiamethoxam	Actara	25% WG	7 g Kg^{-1}	0.50 gL^{-1}
Imidacloprid	Ecomide	20% SG	7 cm Kg^{-1}	0.50 cmL^{-1}
Acetamiprid	Aceta	20 % SP	7 g Kg^{-1}	0.25 gL^{-1}
Dinotefuran	Ochin	20% SG	7 g Kg^{-1}	0.50 gL^{-1}

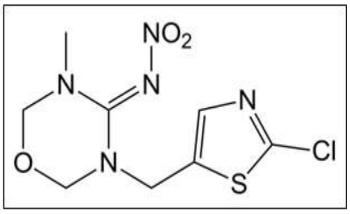
* SC: Suspension concentrate, WG: Wettable granules, SG: Soluble granules, SP: Soluble powder,



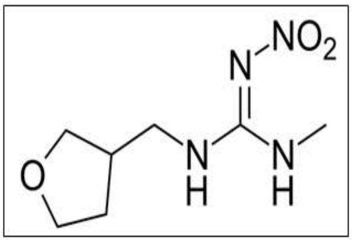
Acetamiprid



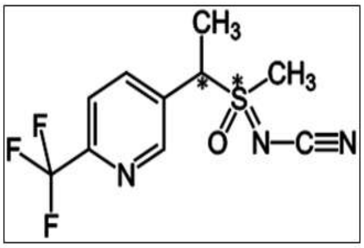
Imidacloprid



Thiamathoxam



Dinotefuran



Sulfoxaflor

Figure 1. Structure of acetamiprid, imidacloprid, thiamethoxam, dinotefuran and sulfoxaflor used as foliar and seed treatments against faba bean leafminer, *L. trifolii* under field conditions.

2. Study site and field Experimental

The field experiments were conducted on faba bean field at Assiut University Experimental Farm, Assiut, Egypt, during 2021/2022 and 2022/2023 seasons. Faba bean seedlings were planted on November 8, following standard agricultural practices. The experimental area, featuring the Balady 156 variety, was sectioned into plots measuring 3.5 meters in length and 3 meters in width, equivalent to 1/400 of a feddan. Insecticide trials were organized using a randomized complete block design (RCBD), with each treatment replicated three times. A total of six treatments, including a control group, were assessed for their effectiveness against the leafminer, *L. trifolii*, on faba bean plants.

- Seed treatment

Faba bean seeds of the Balady-156 variety were placed in a plastic container. Neonicotinoid insecticides were then mixed with the seeds, including sulfoxaflor at a specified rate (7 $cmKg^{-1}$), thiamethoxam (7 gKg^{-1}), imidacloprid (7 $cmKg^{-1}$), acetamiprid (7 gKg^{-1}) and dinotefuran (7 gKg^{-1}) the mixtures were moistened using tap water, thoroughly mixed, and the seeds were then gently spread on a desk to air-dry in the shade. Both the treated and untreated seeds were subjected to germination tests, which revealed no significant differences between the two groups. One week after the faba bean seed treatments, the treated seeds were planted in experimental plots at the Faculty of Agriculture's Experimental Farm, Assiut University, Egypt. Each plot covered an area of 1/400 (10.5 m^2). The experiment followed a complete randomized block design, with three replications for each insecticide treatment. Fifteen days of post-planting, ten plants were randomly selected from each net plot and marked for observations. Researchers recorded the number of mined leaves per plant and the number of mines per ten leaves per plant caused by leafminers. Observations on leaf damage due to leafminers were noted weekly until harvest for both treated groups and the untreated control.

- Foliar treatment

The insecticides under evaluation for their effectiveness were applied after the pest emerged in the field, using a knapsack sprayer. This sprayer, equipped with a single nozzle, was calibrated to apply 200 liters per feddan (where 1 feddan equals 0.42 hectares). Before switching to the next treatment, the sprayer was thoroughly cleaned to prevent cross-contamination. Special attention was given to ensure uniform coverage of the crop with the insecticidal spray solution. The application rates for each pesticide corresponded to the recommended rates provided on their labels (Table 1). For observation purposes, ten plants were randomly selected from each net plot and tagged. These plants were then monitored to record the number of mined leaves per plant as well as the number of mines across ten leaves for assessing the infestation caused by leafminers. The number of damaged leaves of leafminer were recorded 24 hours before spraying and 1, 3, 7, 15 and 21 days after treatment (DAT) from each treatment. The percentages of infestation reduction were calculated according to Henderson and Tilton's equation (1955).

$$\textbf{Reduction}\ \% = \left(\mathbf{1} - \frac{\textbf{N in Co before treatment} \times \textbf{N in T after treatment}}{\textbf{N in Co after treatment} \times \textbf{N in T before treatment}}\right) \times \mathbf{100}$$

where N = insect population, T = treatment and Co = control.

3. Percentage of germination in the field

To study the effects of sulfoxaflor (7 $cmKg^{-1}$), thiamethoxam (7 gKg^{-1}), imidacloprid (7 $cmKg^{-1}$), acetamiprid (7 gKg^{-1}) and dinotefuran (7 gKg^{-1}) insecticides used as seed treatments on the germination of the faba bean seed variety (Balady 156) was evaluated. A total of 100 seeds were planted per plot, with rows dedicated to the treated faba bean variety and a control group within the same plot. Fifteen days after sowing, germination counts were recorded and expressed as a percentage, using the calculation method outlined by Ruan *et al.* (2002):

$$\textbf{Germination}\ \% = \left(\frac{\textbf{No. of germinated seed}}{\boldsymbol{Total\ No. of\ seed\ tested}}\right) \times \mathbf{100}$$

4. Statistical analysis

The data were analyzed using a one-way ANOVA and expressed as mean ± SEM (standard error of the mean). Mean values were differentiated using Duncan's multiple range test (DMRT) at a significant level of 0.05%. Graphics and statistical analyses were performed with GraphPad Prism 5™ software (San Diego, CA).

Results

1. Efficiency of seed treatments of certain neonicotinoid insecticides in comparison with sulfoxaflor against the faba bean leaf miner, *L. trifolii* under field conditions

- Effect of tested insecticide seed treatments on germination (%) of faba bean

As shown in Figure 1, the germination (%) of faba bean seed variety, treated with sulfoxaflor at a rate 7 $cmKg^{-1}$, at a rate of thiamethoxam 7 gKg^{-1}, at a rate of imidacloprid

7 cmKg^{-1}, acetamiprid at a rate of 7 gKg^{-1} and dinotefuran at a rate of 7 gKg^{-1} were ranging from 90.65 to 92.91% and 88.60 to 89.88% during 2021-2022 and 2022-2023 seasons, and there were no significant differences compared to untreated seeds.

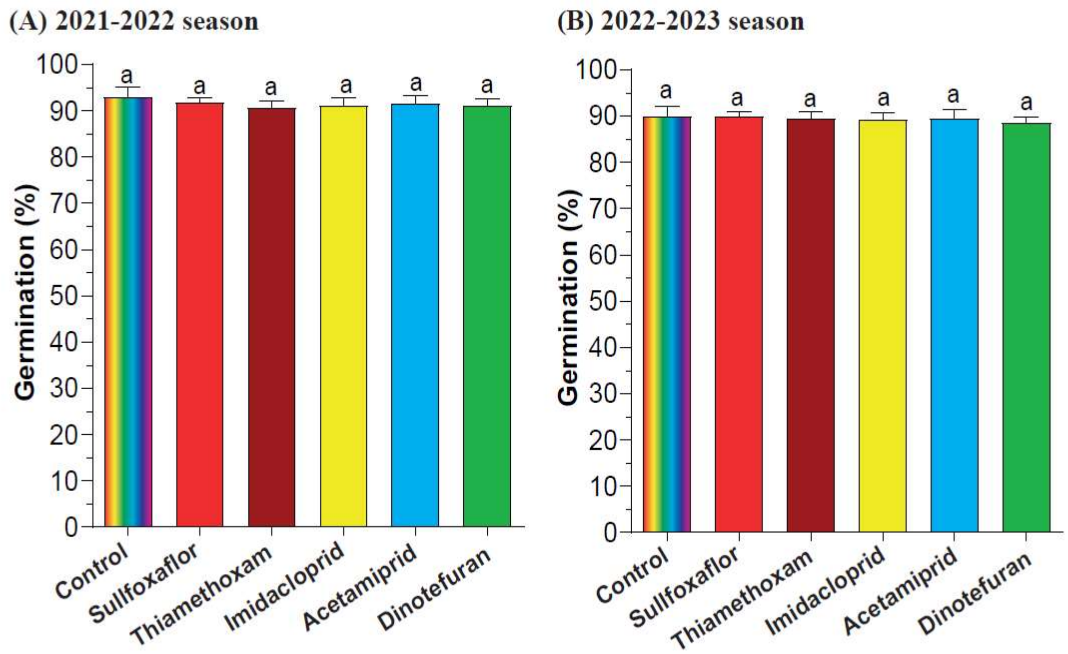


Fig 2. Effect of tested insecticides seed treatment on germination (%) of faba bean in the field during 2021-2022 (A) and 2022-2023 (B) seasons. Columns headed by different letter(s), within the same figure are significantly different (P ≤ 0.05) according to Duncan's Multiple Range Test (DMRT).

- Season 2021-2022

The insecticidal activity of sulfoxaflor (suspension concentrate) at a rate 7 cmKg^{-1}, thiamethoxam (wettable granules) at a rate of 7 gKg^{-1}, imidacloprid (soluble granules) at a rate of 7 cmKg^{-1}, acetamiprid (soluble powder) at a rate of 7 gKg^{-1} and dinotefuran (soluble granules) at a rate of 7 gKg^{-1} applied as seed treatment against faba bean leafminer, *L. trifolii* during 2021-2022 season were evaluated under field conditions. As shown in Table 2 and Figure 3, the faba bean leafminer, *L. trifolii* began to appear on the lower level of faba bean plants on 5 December with an average of 4.43±0.25 leafminers/plant, where the population reached a maximum of 94.90±1.89 leafminers/plant on 13 March. The efficiency of seed treatments of tested insecticides against the faba bean leafminer, *L. trifolii* showed that sulfoxaflor, thiamethoxam, imidacloprid, acetamiprid and dinotefuran reduced the maximum population densities on faba bean variety with the average of 3.27±0.53, 4.39±0.35, 5.62±0.31, 6.51±0.40 and 7.17±0.55 leafminers/plant, respectively, compared with untreated control, (9.91±1.52 leafminers/plant) during December month (Figure 3A). Furthermore, during January month, sulfoxaflor exhibited the highest reduction on faba bean leafminer with an average 13.60±0.85 leafminers/plant followed by thiamethoxam 16.91±0.89, imidacloprid 17.93±0.85, acetamiprid 19.63±0.85 and dinotefuran 21.44±0.85 leafminers/plant compared with untreated plot, (21.51±1.35 leafminers/plant) (Figure

3B). Additionally, during February month, sulfoxaflor recorded the highest reduction on faba bean leafminer with an average 43.81±0.98 leafminers/plant followed by thiamethoxam 46.35±1.12, imidacloprid 48.19±1.23, acetamiprid 49.25±1.19 and dinotefuran 50.55±1.45 leafminers/plant compared with untreated control, (51.56±1.16 leafminers/plant) (Figure 3C). At the harvest time during March, sulfoxaflor had significant efficiency against the faba bean leafminer, *L. trifolii* with an average 59.61±1.48 leafminers/plant followed by thiamethoxam 60.18±1.36 leafminers/plant compared to other tested insecticides. Whereas no significantly different effect showed between imidacloprid 61.04±1.51, acetamiprid 61.92±1.41 and dinotefuran 62.23±1.45 leafminers/plant compared with untreated control 62.31±2.11 leafminers/plant (Figure 3D).

Table 2. Efficiency of neonicotinoid insecticides seed treatment compared to sulfoxaflor against faba bean leaf miner, *L. trifolii* during 2021-2022 season.

Sampling dates		Control	Avg. no. of leaf miners, *L. trifolii*/ plant ± SE				
			Sulf.	Thia.	Imid.	Acet.	Deno.
December	5	4.43±0.25	1.25±0.25	1.53±0.23	2.05±0.20	2.33±0.21	3.12±0.24
	12	8.53±0.36	2.65±0.27	3.67±0.20	4.87±0.28	5.88±0.55	6.54±0.50
	19	10.83±0.77	3.45±0.20	4.69±0.35	6.89±0.45	7.90±0.55	8.77±0.65
	26	15.83±0.48	5.74±0.75	7.65±0.85	8.67±0.76	9.93±0.88	10.23±0.95
Mean		**9.91±1.52a**	**3.27±0.53f**	**4.39±0.35e**	**5.62±0.31d**	**6.51±0.40c**	**7.17±0.55b**
January	2	38.87±1.16	11.25±0.85	14.25±0.75	16.97±0.95	19.07±0.77	22.00±0.98
	9	22.90±1.57	13.75±0.78	17.33±0.97	21.03±0.89	22.90±0.78	24.06±0.95
	16	25.10±1.30	14.26±0.88	19.88±0.90	20.10±0.91	22.60±0.98	26.33±0.86
	23	28.80±1.41	18.75±0.85	22.65±0.98	22.27±0.75	25.13±0.95	27.47±0.85
	30	30.77±1.15	21.25±0.89	24.67±0.95	26.23±0.88	27.53±0.86	29.36±0.75
Mean		**21.51±1.35a**	**13.60±0.85e**	**16.91±0.89d**	**17.93±0.87c**	**19.63±0.91b**	**21.44±0.95a**
February	6	36.27±1.26	28.47±1.05	31.25±0.98	32.97±0.87	33.88±0.95	36.10±0.77
	13	45.87±1.01	37.87±1.05	39.36±1.25	41.77±1.35	42.90±1.05	43.63±1.55
	20	50.17±1.13	43.25±0.78	45.13±1.05	46.45±1.05	47.53±1.33	49.53±1.05
	27	73.92±0.00	65.65±0.89	69.67±1.23	71.56±1.35	72.87±1.30	72.93±1.65
Mean		**51.56±1.16a**	**43.81±0.98d**	**46.35±1.12c**	**48.19±1.23b**	**49.25±1.19a**	**50.55±1.45a**
March	6	94.00±2.52	85.76±1.53	86.07±1.75	88.95±1.98	92.63±1.83	93.33±1.89
	13	94.90±1.89	93.26±1.76	94.60±1.78	94.80±1.15	94.86±1.35	94.90±1.45
	20	50.00±1.76	49.15±1.25	49.75±1.35	49.88±1.35	49.50±1.05	50.12±1.35
	27	10.33±0.76	10.25±0.55	10.27±0.65	10.50±0.55	10.67±0.75	10.50±0.85
Mean		**62.31±2.11a**	**59.61±1.48c**	**60.18±1.36b**	**61.04±1.51a**	**61.92±1.41a**	**62.23±1.45a**

Note: data are expressed as means ± stander error (SE). Sulf.: Sulfoxaflor, Thia: Thiamethoxam, Imid: Imidacloprid, Acet: Acetamiprid and Dino: Dinotefuran. Means followed by the same letter(s), within the same row are non-significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test (DMRT)

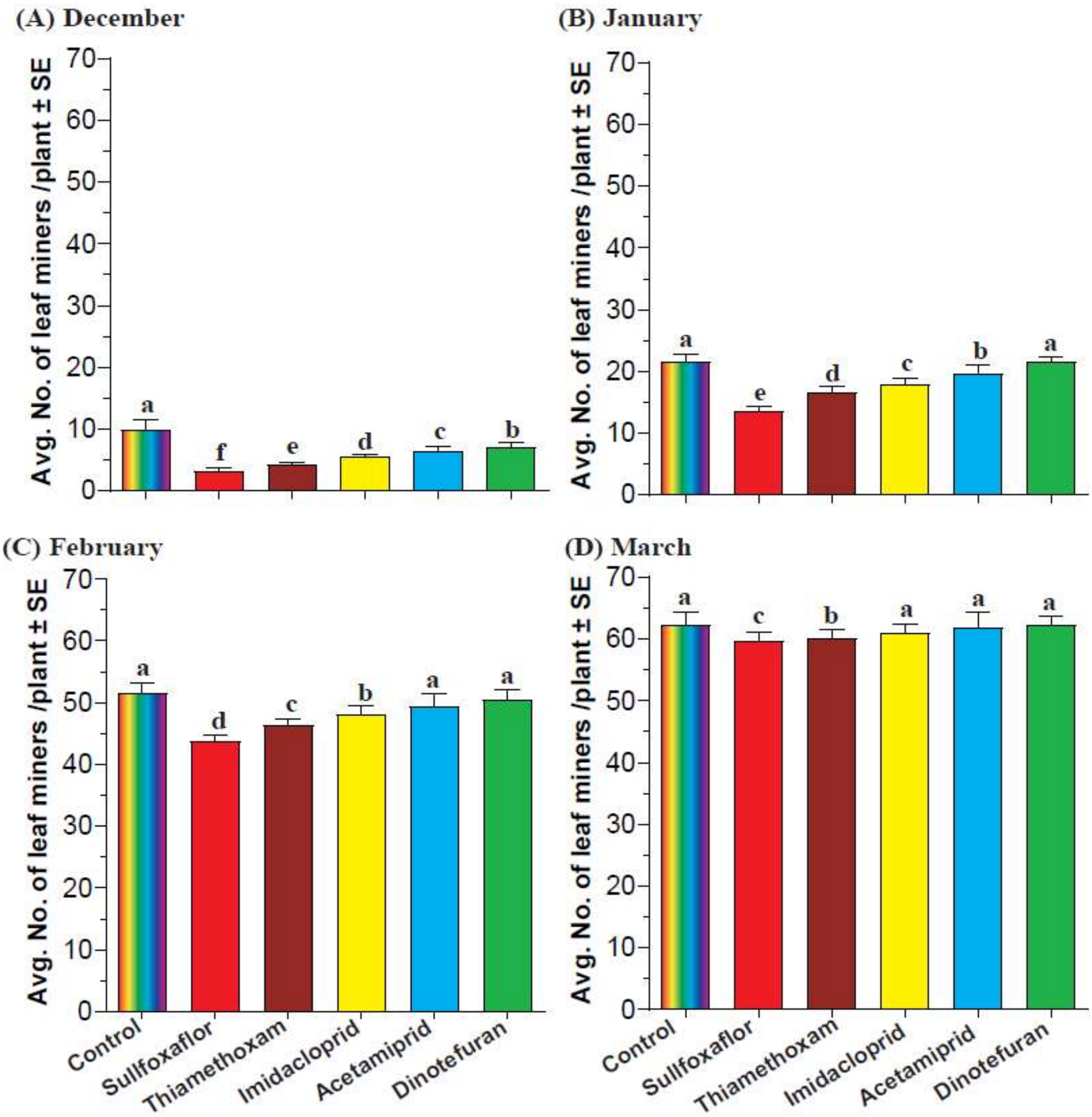


Fig 3. Efficiency of neonicotinoid insecticides seed treatment compared to sulfoxaflor against faba bean leaf miner, *L. trifolii* during December (A), January (B), February (C) and March (D) 2021-2022 season. Columns headed by different letter(s), within the same figure are significantly different (P ≤ 0.05) according to Duncan's Multiple Range Test (DMRT).

- Season 2022-2023

As shown in Table 3 and Figure 4, the faba bean leafminer, *L. trifolii* began to appear on the lower level of faba bean plants on 5 December with an average of 1.93±0.55 leafminers/plant, where the population reached a maximum of 55.70±1.09 leafminers/plant on 27 February. The efficiency of seed treatments of tested insecticides against the faba bean leafminer, *L. trifolii* showed that sulfoxaflor, thiamethoxam, imidacloprid, acetamiprid and dinotefuran reduced the maximum population densities on faba bean variety with the average of 2.64±0.58, 3.28±0.75, 3.31±0.71, 3.41±0.62 and 3.53±0.75 leafminers/plant, respectively, compared with untreated control, (3.78±1.58 leafminers/plant) during December month (Figure 4A). Furthermore, during

January month, sulfoxaflor exhibited the highest reduction on faba bean leafminer with an average 7.14±0.78 leafminers/plant followed by thiamethoxam 9.88±0.99, imidacloprid 11.43±0.97, acetamiprid 12.25±0.93 and dinotefuran 13.50±0.92 leafminers/plant compared with untreated plot, (15.18±1.75 leafminers/plant) (Figure 4B). Additionally, during February month, sulfoxaflor recorded the highest reduction on faba bean leafminer with an average 22.78±0.88 leafminers/plant followed by thiamethoxam 25.66±1.19, imidacloprid 27.95±1.63, acetamiprid 31.39±1.79 and dinotefuran 38.52±1.85 leafminers/plant compared with untreated control, (43.43±1.96 leafminers/plant) (Figure 4C). At the end of season during March, sulfoxaflor had significant efficiency against the faba bean leafminer, *L. trifolii* with an average 16.47±1.52 leafminers/plant followed by thiamethoxam 17.92±1.89 leafminers/plant compared to other tested insecticides. There was no significant difference between imidacloprid 18.27±1.56, acetamiprid 18.55±1.66 and dinotefuran 18.76±1.79 leafminers/plant and untreated control 19.73±1.91 leafminers/plant (Figure 4D).

Table 3. Efficiency of neonicotinoid insecticides seed treatment in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* during 2022-2023 season.

Sampling dates		Control	Avg. no. of leaf miners, *L. trifolii* / plant ± SE				
			Sulf.	Thia.	Imid.	Acet.	Deno.
December	5	1.93±0.55	1.23±0.23	1.63±0.27	1.75±0.29	1.77±0.26	1.82±0.26
	12	3.03±0.76	2.27±0.22	2.87±0.27	2.92±0.38	2.98±0.65	2.99±0.53
	19	4.08±0.97	3.05±0.21	3.97±0.35	3.89±0.75	3.95±0.57	3.97±0.75
	26	6.08±0.88	4.01±0.55	4.65±0.75	4.67±0.79	4.95±0.78	5.33±0.98
Mean		**3.78±1.58a**	**2.64±0.58c**	**3.28±0.75b**	**3.31±0.71a**	**3.41±0.62a**	**3.53±0.75a**
January	2	9.17±1.33	4.22±0.76	5.85±0.77	6.87±0.90	7.77±0.79	8.05±0.91
	9	11.53±1.68	5.75±0.71	7.33±0.91	9.23±0.69	9.93±0.70	10.08±0.90
	16	14.83±1.41	7.63±0.81	8.91±0.92	10.16±0.93	10.68±0.97	12.83±0.89
	23	17.70±1.53	8.56±0.80	12.55±0.98	14.37±0.85	15.13±0.96	16.87±0.87
	30	22.65±1.75	9.53±0.86	14.76±0.96	16.53±0.83	17.73±0.88	19.67±0.79
Mean		**15.18±1.75a**	**7.14±0.78e**	**9.88±0.99d**	**11.43±0.97c**	**12.25±0.93b**	**13.50±0.92b**
February	6	28.53±1.25	14.45±1.01	17.58±0.88	19.67±0.89	23.67±0.91	26.16±0.79
	13	38.50±1.06	17.76±1.00	19.67±1.21	21.79±1.45	26.98±1.15	33.38±1.58
	20	50.97±1.17	23.59±0.76	25.63±1.75	28.56±1.35	30.95±1.37	41.57±1.35
	27	55.70±1.09	35.33±0.80	39.77±1.25	41.76±1.55	43.97±1.39	52.97±1.76
Mean		**43.43±1.96a**	**22.78±0.88f**	**25.66±1.19e**	**27.95±1.63d**	**31.39±1.79c**	**38.52±1.85b**
March	6	41.00±2.02	37.40±1.50	38.07±1.55	38.95±1.58	39.63±1.63	40.33±1.69
	13	26.50±1.79	22.13±1.56	24.63±1.71	24.83±1.10	24.96±1.25	24.99±1.32
	20	8.13±1.75	6.13±1.05	7.59±1.31	7.78±1.15	7.85±1.00	7.93±1.22
	27	1.85±0.56	0.20±0.57	1.37±0.60	1.51±0.58	1.77±0.70	1.79±0.81
Mean		**19.73±1.91a**	**16.47±1.52c**	**17.92±1.89b**	**18.27±1.56a**	**18.55±1.66a**	**18.76±1.79a**

Note: data are expressed as means ± stander error (SE). Means followed by the same letter(s), within the same row are non-significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test (DMRT). Sulf.: Sulfoxaflor, Thia.: Thiamethoxam, Imid.: Imidacloprid, Acet.: Acetamiprid and Dino.: Dinotefuran.

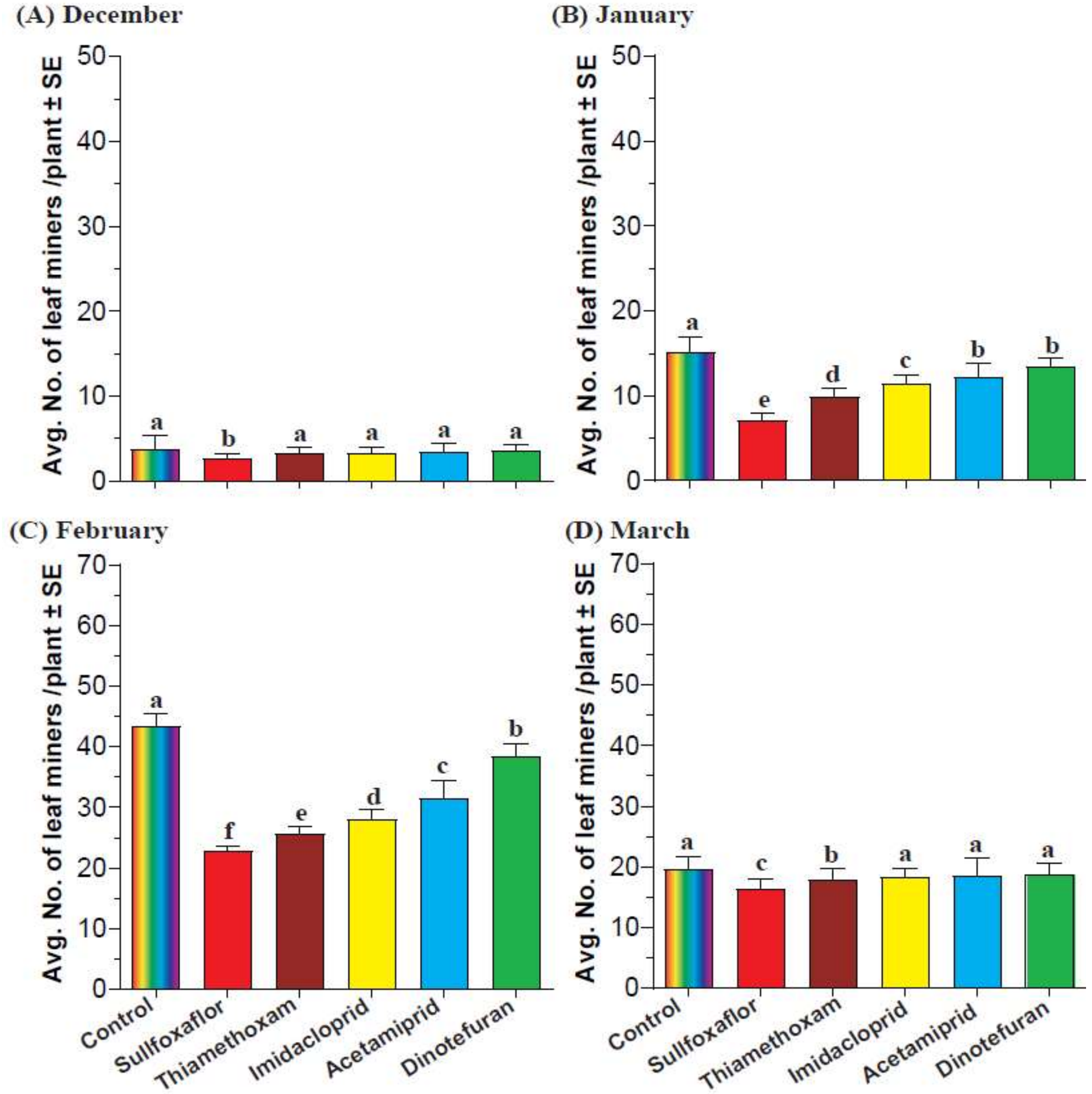


Fig 4. Efficiency of neonicotinoid insecticides seed treatment in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* during December (A), January (B), February (C) and March (D) during 2022-2023 season. Columns headed by different letter(s), within the same figure are significantly different (P ≤ 0.05) according to Duncan's Multiple Range Test (DMRT).

2. Efficiency of foliar treatments of neonicotinoid insecticides in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* under field conditions

- Season 2021-2022

The efficiency of sulfoxaflor (suspension concentrate) at a rate 0.25 cmL^{-1}, thiamethoxam (wettable granules) at a rate of 0.50 gL^{-1}, imidacloprid (soluble granules) at a rate of 0.50 cmL^{-1}, acetamiprid (soluble powder) at a rate of 0.25 gL^{-1} and dinotefuran (soluble granules) at a rate of 0.50 gL^{-1} applied as foliar treatment against faba bean leafminer, *L. trifolii* during 2021-2022 season were evaluated under field conditions. Data analyses for these experiments have been constructed in tables and figures to facilitate comparison between sulfoxaflor and different neonicotinoid insecticides used against the faba bean leafminer, *L. trifolii*, under field conditions. Data represented in Table 4 and Figure 5 showed that all treatments caused a significant reduction in faba bean leafminer population after 1, 3, 7, 15 and 21 DAT compared to control (Fig. 5A, B, C, D, E). Sulfoxaflor, thimathoxam, imidacloprid and acetamiprid, showed a high efficiency against faba bean leafminer under field conditions compared to dinotefuran. Sulfoxaflor recorded a highest significant reduction percent of faba bean leafminer 53.94, 100, 90.77, 86.70, 80.65%, followed by thiamethoxam 42.21, 86.43, 85.67, 80.30 and 75.96%, imidacloprid 41.27, 69.05, 72.11, 75.61 and 72.65%, acetamiprid 37.76, 47.72, 58.17, 66.36 and 70.21% after 1, 3, 7, 15 and 21 DAT, respectively. Whereas dinotefuran registered the lowest significant reduction percent of faba bean leafminer 33.64, 37.38, 54.76, 56.80 and 63.02% at 1, 3, 7, 15 and 21 DAT, respectively. The foliar treatments of sulfoxaflor, thiamethoxam, imidacloprid, acetamiprid and dinotefuran significantly reduced the maximum population densities of faba bean leafminer with an average of reduction percentage of 82.41, 74.11, 66.13, 56.04 and 49.12%, respectively (Fig. 5 F).

Table 4. Efficacy of foliar applications of neonicotinoid insecticides in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* under field conditions at 1, 3, 7, 14 and 21 DAT during 2021-2022 season.

Insecticides	Avg. reduction (%) of leaf miners, *L. trifolii* ± SE					
	1 DAT	3 DAT	7 DAT	15 DAT	21 DAT	Average
Sulfoxaflor 24% SC	53.94 ±2.20a	100.0 ±0.00a	90.77 ±1.99a	86.70 ±2.56a	80.65 ±2.79a	82.41 ±3.08a
Thiamethoxam 25% WP	42.21 ±1.75b	86.43 ±1.20b	85.67 ±2.20b	80.30 ±1.65b	75.96 ±1.67b	74.11 ±3.58b
Imidacloprid 20% SC	41.27 ±2.19b	69.05 ±2.13c	72.11 ±1.27c	75.61 ±1.19c	72.65 ±2.16c	66.13 ±2.35c
Acetamiprid 20% SP	37.76 ±1.53c	47.72 ±1.36d	58.17 ±2.22d	66.36 ±2.41d	70.21 ±1.86c	56.04 ±2.15d
Dinotefuran 20% SC	33.64 ±1.36d	37.38 ±1.70e	54.76 ±1.93e	56.80 ±2.16e	63.02 ±1.73d	49.12 ±2.08e

Notes: Data are expressed as means ± stander error (SE) of three replicates at each insecticide. DAT: Day after treatment. Means followed by the same superscript letter(s), within the same column are non-significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test (DMRT).

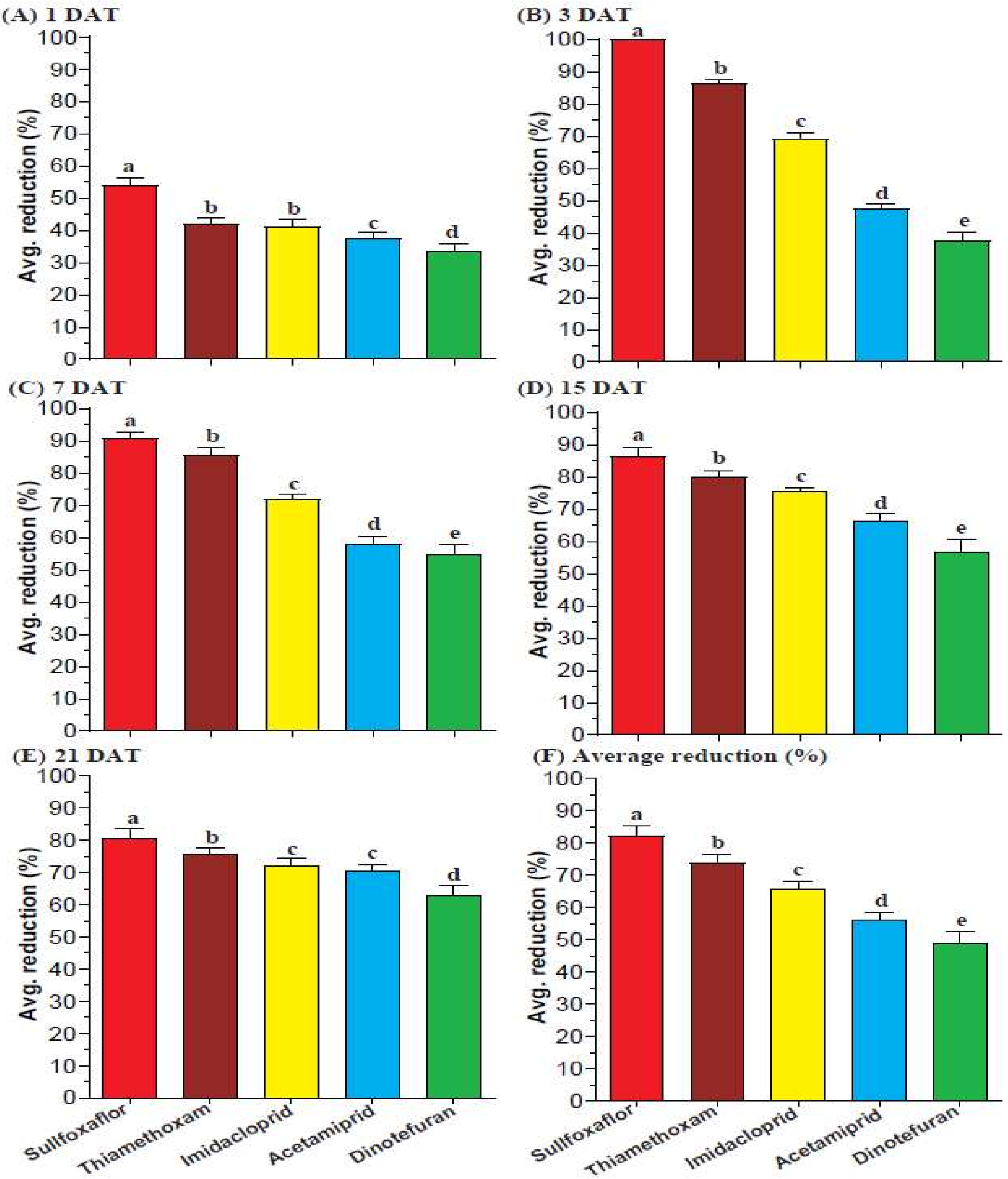


Fig. 5. Efficacy of foliar applications of neonicotinoid insecticides in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* under field conditions at 1 DAT (A), 3 DAT (B), 7 DAT (C), 15 DAT (D), 21 DAT (E) and average reduction percentage (F) during 2021-2022 season. Percentage reduction (mean± SEM) according to Henderson and Tilton's equation. Columns headed by different letter(s), within the same treatment date, are significantly different (P ≤ 0.05) according to Duncan's Multiple Range Test (DMRT).

- Season 2022-2023

Data represented in Table 5 and Figure 6 showed that all treatments caused a significant reduction in faba bean leafminer population after 1, 3, 7, 15 and 21 DAT during 2022-2023 season. Sulfoxaflor, thimathoxam, imidacloprid and acetamiprid, showed a high efficiency against faba bean leafminer under field conditions compared to dinotefuran. Sulfoxaflor registered the highest significant reduction percent of faba bean leafminer 55.89, 72.56, 87.59, 100.0 and 73.80%, followed by thiamethoxam 49.44, 63.81, 75.11, 82.33 and 61.57%, imidacloprid 43.79, 59.56, 67.19, 77.67 and 58.65%, acetamiprid 35.56, 46.89, 55.77, 63.67 and 55.01% after 1, 3, 7, 15 and 21 DAT, respectively. Whereas dinotefuran recorded the lowest significant reduction percent of faba bean leafminer 30.76, 39.78, 49.68, 54.87 and 43.29 % at 1, 3, 7, 15 and 21 DAT, respectively (Fig. 6A, B, C, D, E). The average reduction of all treatments was significant difference between sulfoxaflor 77.97% and neonicotinoid insecticides, thimathoxam 66.45%, imidacloprid 61.37%, acetamiprid 50.98% and dinotefuran 43.66% (Fig. 6 F).

Table 5. Efficacy of foliar applications of neonicotinoid insecticides in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* under field conditions at 1, 3, 7, 14 and 21 DAT during 2022-2023 season.

Insecticides	Avg. reduction (%) of leafminer, *L. trifolii* ± SE					
	1 DAT	3 DAT	7 DAT	15 DAT	21 DAT	Average
Sulfoxaflor 24% SC	55.89 ±2.50a	72.56 ±2.59a	87.59 ±3.77a	100 ±0.00a	73.80 ±3.79a	77.97 ±2.87a
Thiamethoxam 25% WP	49.44 ±1.85b	63.81 ±1.29b	75.11 ±2.07b	82.33 ±1.87b	61.57 ±1.08b	66.45 ±2.08b
Imidacloprid 20% SC	43.79 ±2.33c	59.56 ±2.45c	67.19 ±1.67c	77.67 ±1.33c	58.65 ±1.56c	61.37 ±2.26c
Acetamiprid 20% SP	35.56 ±1.23d	46.89 ±1.67d	55.77 ±2.33d	63.67 ±2.01d	55.01 ±1.68c	50.98 ±2.35d
Dinotefuran 20% SC	30.76 ±1.06e	39.78 ±1.56e	49.68 ±1.87e	54.87 ±2.10e	43.29 ±1.68d	43.66 ±2.18e

Notes: Data are expressed as means ± stander error (SE) of three replicates at each insecticide. DAT: Day after treatment. Means followed by the same superscript letter(s), within the same column are non-significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test (DMRT).

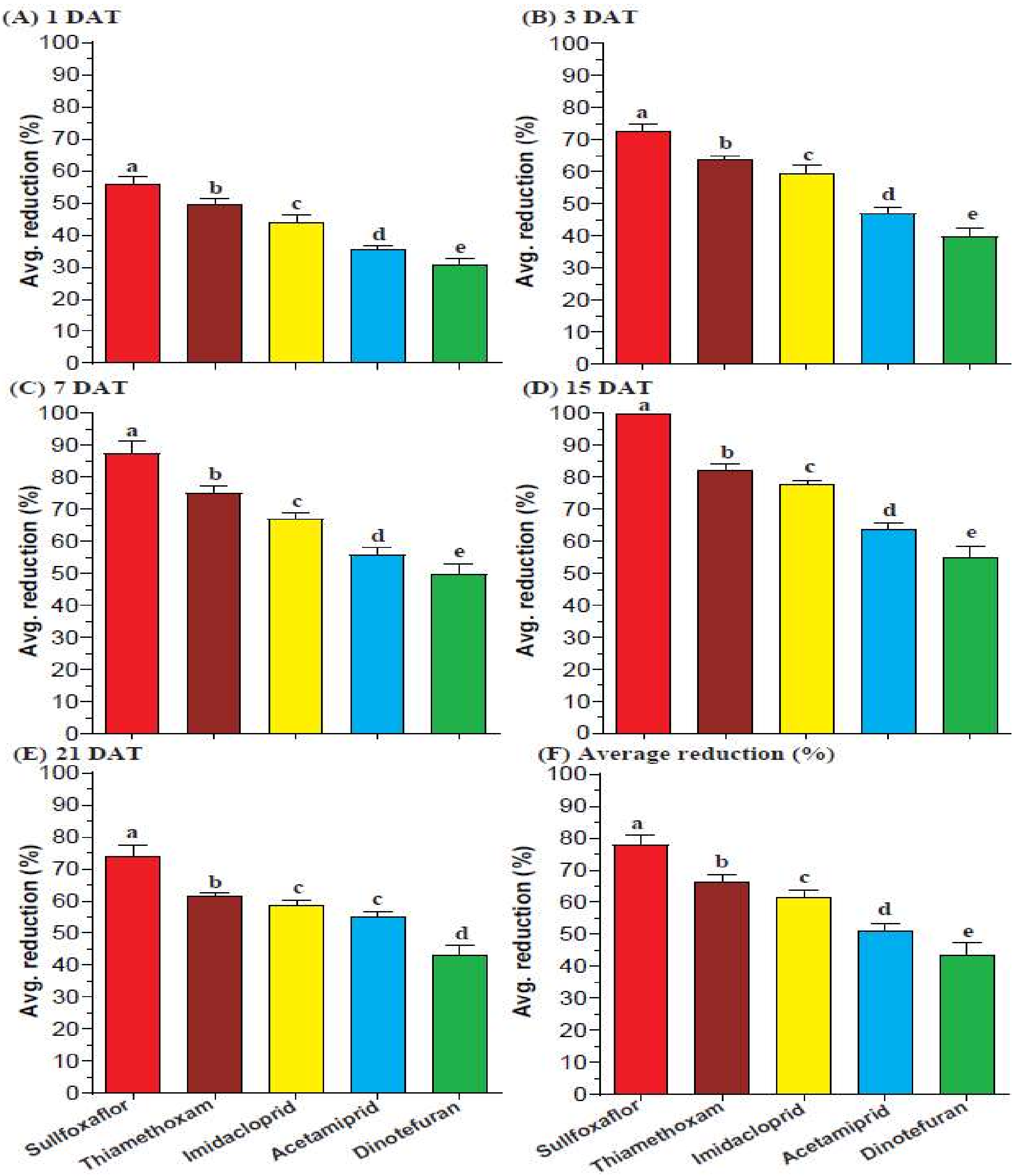


Fig. 6. Efficacy of foliar applications of neonicotinoid insecticides in comparison with sulfoxaflor against faba bean leaf miner, *L. trifolii* under field conditions at 1 DAT (A), 3 DAT (B), 7 DAT (C), 15 DAT (D), 21 DAT (E) and average reduction percentage (F) during 2022-2023 season. Percentage reduction (mean± SEM) according to Henderson and Tilton's equation. Columns headed by different letter(s), within the same treatment date, are significantly different ($P \leq 0.05$) according to Duncan's Multiple Range Test (DMRT).

Discussion

Faba bean leafminer, *L. trifolii* is one of the major pests of faba bean in Egypt, and instituting control measures to prevent the harm they cause will be significant in reducing the associated economic damage (Bayoumy *et al.,* 2018). Effectively managing leafminer infestations in faba bean is crucial for improving both the quality and yield of agricultural produce. Insecticides of various modes of action are most commonly used tool for managing leafminers in commercial agriculture (Sharma *et al.,* 2002; Abbassy *et al*., 2008; Singh & Saravanan, 2008; Jeschke *et al.,* 2011; Seal *et al.,* 2014; Waly *et al.,* 2019; Aly *et al.,* 2023; Hamza *et al.,* 2023; Hassan *et al.,* 2023). This study, conducted during 2021-2022 and 2022-2023 seasons, demonstrated that sulfoxaflor (suspension concentrate) at a rate 7 $cmKg^{-1}$, thiamethoxam (wettable granules) at a rate of 7 gKg^{-1}, imidacloprid (soluble granules) at a rate of 7 $cmKg^{-1}$, acetamiprid (soluble powder) at a rate of 7 gKg^{-1} and dinotefuran (soluble granules) at a rate of 7 gKg^{-1} seed treatments had no effect on the germination percentage of faba bean variety and reducing the faba bean leafminer infestations throughout the faba bean growing seasons (Table 2, 3 and Fig. 3, 4).

The faba bean leafminer, *L. trifolii* began to appear on the lower level of faba bean plants in December where the population reached a maximum in March. During the season, the presence of *L. trifolii* was initially low at the start of the growing period, but the infestation grew significantly more severe toward the end of seasons. The efficiency of seed treatments of tested insecticides against the faba bean leafminer showed that sulfoxaflor, thiamethoxam and imidacloprid reduced the maximum population densities on faba bean variety compared with untreated control during both seasons. However, acetamiprid and dinotefuran had lower effects as seed treatments against faba bean leafminer compared to untreated control. Furthermore, during of all months in both seasons, sulfoxaflor exhibited the highest reduction on faba bean leafminer followed by thiamethoxam, imidacloprid, acetamiprid and dinotefuran compared with untreated plot. These results were in agreement with the work of Seal *et al.* (2014), who found that all insecticide treatments (foliar and seed dressing) of sulfoxaflor significantly reduced leafminers mines/bean leaf when compared with the nontreated control. Waly *et al.* (2019) indicated that thiamethoxam had a large effect in reducing leaf miner (*L. congesta*) in faba bean. In addition, Hassan *et al.* (2023) reported that, thiamethoxam had a low effect in reducing the population of *L. trifolii* 30.24%. Whereas Singh and Saravanan (2008) stated that imidacloprid recorded a highest percentage reduction (97.16%) of pea leaf miner *Phytomyza horticola* followed by thiamethoxam (93.86%) and acetamiprid (90.77%). Imidacloprid has traditionally been employed through methods such as foliar spraying, seed dressing, and soil treatment, all of which play an essential role in safeguarding various crop species (Marquini *et al*., 2003; Motaung, 2020). These results need further research studies in view of the extended period of systemic activity of sulfoxaflor and neonicotinoid insecticides in faba bean leafminer, *L. trifolii*.

The foliar treatments of sulfoxaflor (suspension concentrate) at a rate 0.25 cmL^{-1}, thiamethoxam (wettable granules) at a rate of 0.50 gL^{-1}, imidacloprid (soluble granules) at a rate of 0.50 cmL^{-1}, acetamiprid (soluble powder) at a rate of 0.25 gL^{-1} and dinotefuran (soluble granules) at a rate of 0.50 gL^{-1} applied against faba bean leafminer, *L. trifolii* during 2021-2022 and 2022-2023 seasons were evaluated under field conditions. All treatments caused a significant reduction in faba bean leafminer population after 1, 3, 7, 15 and 21 DAT compared to control. Sulfoxaflor, thimathoxam, imidacloprid and acetamiprid, showed a high efficiency against faba bean leafminer under field conditions compared to dinotefuran. Whereas dinotefuran registered the lowest significant reduction percent of faba bean leafminer. Sulfoxaflor recorded the highest significant reduction percent of faba bean leafminer in both seasons. Foliar spraying is particularly effective for managing harmful defoliating pests like butterflies, moths, leaf beetles, grasshoppers, leafminers, and sawflies. Meanwhile, seed coating and soil treatments are applied directly at the targeted site, offering a more precise approach to protecting crops. It is estimated that roughly 60% of all neonicotinoid applications occur through seed and soil treatments, according to Jeschke *et al.* (2011). Sharma *et al.* (2002) who tested 7 insecticides against pea leafminer, *Phytomyza atricornis* on pea plants. Cypermethrin, fenvalerate, dimethoate, dichlorvos, methyl demeton, endosulfan, acetamiprid and phosphamidon. Insecticides significantly reduced the mean number of leaf miner population and increased the green pod yield compared to untreated control. Our results demonstrated that thiamethoxam exerted a significant impact in reducing populations of the leafminer, *L. trifolii*, in faba beans. These findings align with those of Sharma and Lal (2002), who reported that thiamethoxam was highly effective against leafminers. Similarly, Sreekanth and Reddy (2011) identified thiamethoxam as one of the most effective insecticides against leafminers, aphids, and whiteflies, maintaining its efficacy for up to seven days. Abbas et al. (2012) evaluated three insecticides, including actara (24% WG thiamethoxam) on leafminers and found actara to be exceptionally effective. In contrast, Singh and Saravanan (2008) observed that acetamiprid had the lowest percentage reduction (90.77%) in controlling pea leafminer (*Phytomyza horticola*) compared to other insecticides. Similarly, Hassan *et al.* (2023) reported that acetamiprid showed limited effectiveness in reducing *L. trifolii* populations, achieving only a 43.81% reduction.

Results showed that imidacloprid caused a significant reduction in the faba bean leafminer population after 1, 3, 7, 15 and 21 DAT compared to control. These results are in agreement with the findings of El-Khawas *et al.* (2004) concluded that the chemical insecticide Confidor (imidacloprid) induced the highest percentages of reduction in the population density of *L. trifolii*. Similar results were observed by Abbassy *et al.* (2008) who reported that spraying of common bean plants with bio insecticides significantly reduced the number of leaf miner larvae. Wang *et al.* (2014) emphasized the need for ongoing development of innovative insecticides and compounds to address and mitigate the challenges posed by pesticide resistance. Awad *et al.* (2024) highlight a pressing demand for new active ingredients with desirable toxicological and environmental characteristics to effectively manage insect pests. Sulfoxaflor is the subject of this study, which showed a high efficiency against faba bean leafminer as foliar treatment under field conditions compared to other insecticides and untreated control. Sulfoxaflor belongs to the sulfoximines group and provides control over a wide range of plant sap feeding pests that have developed resistance to other insecticides (Watson *et al.,* 2021). Seal *et al.* (2014) observed comparable outcomes, demonstrating the high efficacy of sulfoxaflor in managing faba bean leafminers. Their study highlighted the insecticide's excellent translaminar transport, enabling movement from the treated upper leaf surface to the lower side. Furthermore, similar findings revealed that neonicotinoid insecticides effectively control various insect pests, significantly reducing their populations in field conditions (El-Khawas *et al.,* 2004; Singh & Saravanan, 2008; Seal *et al*., 2014; Watson *et al.*, 2021).

Conclusion

In conclusion, the results of the present study clearly showed that sulfoxaflor, thimathoxam, imidacloprid, acetamiprid and dinotefuran showed a high efficiency against faba bean leafminer as seed and foliar treatments provided early protection against faba bean leafminer under field conditions. Sulfoxaflor and neonicotinoid insecticides seed treatments are excellent means for the management of faba bean leafminer on faba pean plants. Therefore, sulfoxaflor, thimathoxam and imidacloprid seed treatments could be used in integrated pest management programs for controlling the faba bean leafminer. Furthermore, there is an acute need to determine the susceptibility of faba bean leafminer to sulfoxaflor and the development of resistance to this insecticide as a first step, subsequently; the second step is to study the side effect of this insecticide on the natural enemies under field and laboratory conditions. In addition, for the control of faba bean leafminer, *L. trifolii,* effective insecticides with different modes of actions should be rotated during the growing season of faba beans.

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فعالية معاملة الأوراق والبذور بمبيدات النيونيكوتينويد الحشرية بالمقارنة مع مبيد السلفوكسافلور ضد حشرة صانعة أنفاق أوراق الفول

على أحمد عبد اللاه*، داليا شحاتة بخيت، سمير حسن مناع، تسنيم عبد الرؤوف الغريب

قسم وقاية النبات، كلية الزراعة، جامعة اسيوط، 71526 اسيوط، مصر

الملخص

تعتبر صانعة أنفاق اوراق الفول إحدى الآفات الحشرية الرئيسية التي تصيب الفول البلدي في مصر .تم تقييم فعالية معاملات البذور والأوراق بمبيدات النيونيكوتينويد، مقارنةً بمبيد السلفوكسافلور، في مكافحة صانعة الانفاق خلال موسمي 2022،2021 ،2022،2023 أدت معاملات البذور بسلفوكسافلور وثيامثوكسام وإيميداكلوبريد إلى انخفاض في أعداد صانعة أنفاق الأوراق على صنف الفول البلدي مقارنةً بمعاملة الكنترول خلال كلا الموسمين .مع ذلك، كان للأسيتاميبريد والدينوتيفوران تأثير أقل كمعاملات للبذورعلاوة على ذلك، أظهر السلفوكسافلور أعلى انخفاض في أعداد صانعة أنفاق الأوراق على الفول البلدي .بالإضافة إلى ذلك، أدت المعاملات الورقية بسلفوكسافلور، وثيامثوكسام، وإيميداكلوبريد، وأسيتاميبريد، ودينوتيفوران إلى انخفاض ملحوظ في أعداد صانعة الانفاق، بمتوسط نسبة انخفاض بلغت 82.41%، 74.11%، 66.13%، 56.04%، 49.12% على التوالي خلال الموسم الأول .أما في الموسم الثاني، فقد كان متوسط الانخفاض ملحوظًا بين سلفوكسافلور (77.97%)، وثيامثوكسام (66.45%)، وإيميداكلوبريد (61.37%)، وأسيتاميبريد (50.98%)، ودينوتيفوران (43.66). لذلك، يُمكن استخدام مبيد السلفوكسافلور، سواءً كمعاملة للأوراق أو البذور، في برامج المكافحة المتكاملة للآفات لمكافحة صانعة أنفاق اوراق الفول .وقد أثبتت كلتا طريقتي العلاج فعاليتهما في مكافحة صانعة أنفاق اوراق الفول.

الكلمات المفتاحية: *السلفوكسافلور، الإدارة المتكاملة، صانعة الانفاق، مبيدات النيونيكتينويدز*