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RESEARCH

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Field evaluation of whorl application of sand mixed or spray insecticides against *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on yield of maize

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Abstract

Background *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), the fall armyworm (FAW), has recently invaded Egypt and poses serious threats to maize farmers as it causes huge economic costs and yield losses. Selection of efficient insecticides and appropriate methods of application can be a problem to control this pest.

Methods Two-year field studies to effectiveness of whorl application (sand mixed or spray) of seven insecticides comprising new insecticides generations with conventional insecticides from different groups at maximum recommended dosage field rate against FAW on yield of maize was evaluated in maize fields at El-Qualubia Governorate, Egypt.

Results In plots treated with insecticide mixed in sand, all tested insecticides recorded a significant decrease in FAW larvae with significantly higher yields than those treated with spraying or untreated plots. However, among tested insecticides in both applications, chlorantraniliprole was found to be the most effective followed by emamectin benzoate and spinosad and these insecticides gave better control FAW with higher yield than conventional insecticides tested. In this context, the highest decrease in FAW density was recorded in plots treated with chlorantraniliprole mixed in sand or sprayed (93.69% for 2021; 91.59% for 2022) and (84.74% for 2021; 85.78% for 2022), respectively, as well as a significantly high yield. However, lambda-cyhalothrin recorded the highest density of FAW (33.86% for 2021; 32.72% for 2022) in the treated plots with spraying with lowest significant yield during the 2021 and 2022 seasons in the treated plots with spraying by 8.98 and 8.00%, respectively, increase over control plots.

Conclusions These results indicate that insecticides mixed in sand application are more efficacious against FAW larvae along with yield increase than spraying.

Keywords Application methods, Chemical control, Fall armyworm, Maize yield, Sand, Whorl application

Background

Maize (*Zea mays* L.) also called "Queen of cereals" is one of the important cereals which ranks third among world food crops with a total production of 1148 million tons from a total harvested area of 197 M ha in 2019 (FAOStat, 2021). More than 200 m people in Africa depend on maize for food security, as it is used as food for humans, fodder for livestock and poultry, as well as raw material for industrial products such as oil

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and starch (FAOStat, 2021). However, fall armyworm (FAW) has caused 8–20 m tons per annum of maize yield losses in Africa, affecting maize production and becoming a threat to food security (CABI 2017). In Egypt, maize is planted in almost all governorates, and its production is declining due to infection with several pest species, the most dangerous of which is FAW which has become a major threat to maize production in Egypt; thus, avoiding yield losses is critical.

Spodoptera frugiperda (J.E. Smith), often known as the FAW and the whorl worm, is a Noctuidae moth species; it is a prevalent pest in more than 100 countries worldwide (Goergen et al. 2016). The larvae of FAW feed on a wide range of crops, but have mainly been registered as a maize pest (CABI 2020). The damage caused by the larvae's feeding can lead to substantial economic losses for growers. The severity of yield loss produced by FAW can vary based on a number of variables, including the stage of plant development, the crop species and the population density of the pest (Cruz 1983). In severe situations, yield loss might be as high as 75% or more, causing farmers severe financial damage (Cruz 1999).

Hence, several control measures have been implemented in order to mitigate and manage the infestations caused by FAW. However, the use of chemical insecticides is still the main control strategy (Roy and Biswas 2020). Because there are so many insecticides, selection of highly efficient insecticides and appropriate methods of application is an important problem in developing Integrated Pest Management (IPM) strategies for FAW control. It is known that the effectiveness of insecticides can vary depending on several factors, such as the method of application, dose, timing and the species of pest targeted, and to achieve the desired result, it is necessary to take them into account (Abhilash and Singh 2009). The method of application plays a crucial role in determining the efficacy of insecticides, as different methods can lead to varying levels of exposure to the targeted pests (Roy and Biswas 2020).

FAW is also difficult to control, due to the cryptic feeding of larvae deep inside maize whorls. Even insecticide spray applications do not always effectively reach larvae inside maize whorls Roy and Biswas 2020), and as a result, strategies are essential to make the insecticides reach the leaf whorl. The whorl application of sand, soil and ash against FAW is a traditional management practice adopted by farmers in Africa (Abate et al. 2000) and America (Wyckhuys and Oneil 2007), but their efficacy has not been documented in Egypt. As a result, to achieve the desired outcome, it is necessary to take into account the method of application, rate and timing of insecticides and to incorporate them into an IPM strategy that aligns with the overall objectives of pest control and management. In this context, the aim of this study was to compare efficiency of whorl application of insecticides either mixed in sand or sprayed by direct effect on FAW and indirect effect of leaf damage on maize yield. Consequently, this work may contribute to improving the efficacy of insecticides through the use of optimal application methods to achieve maximum control of FAW, along with protecting and increasing maize yield.

Methods

Insecticides

In two years, evaluated seven insecticides comprising new insecticides generations with conventional insecticides from different groups at maximum dosage are registered by Egyptian Ministry of Agriculture for controlling insect pests in maize fields (Table 1).

Study site and experimental design

Field experiments were carried out at maize fields in El-Qualubia Governorate (30°19′45.12″N, 31°13′0.48″E), Egypt, for two consecutive seasons. The season field trial was conducted 15th and 21st of May 2021 and 2022, respectively, with the maize variety "SHY-162" (selected as the most used by farmers as a high yielding) in a randomized complete block design (RCBD) of fourteen treatments plus untreated control in three replicated plots

Table 1 Insecticides used at maximum recommended field rate in maize and tested against *Spodoptera frugiperda*

Trade name, formulation	Active ingredient	Field rate	Suppliers
Karate, EC	Lambda-cyhalothrin	375 mL	Syngenta, Switzerland
Coragen, SC	Chlorantraniliprole	0.4 mL	DuPont
Proclaim, SG	Emamectin benzoate	60 g	Syngenta, Switzerland
SC Tracer,	Spinosad	30 cm3	Dow Agro-Sciences, UK
Adwuprof, EC	Profenofos	1000 mL	Syngenta, Switzerland
Commando, SC	Buprofezin	5 mL	Dow AgroSciences, USA
Match, EC	Lufenuron	160 mL	Syngenta, Switzerland

(Table 1). Maize was grown in area divided into plots size 30 m × 20 m and were isolated from each other by 2 m by following recommended agronomic. The insecticides were used using whorl application, mixed in sand and spray. Both applications also used the same maximum recommended field rate of insecticide. The tested insecticides were applied directly to the plant whorl 20 and 35 days after sowing, either mixed in sand (250 mL of each insecticide + 100 kg slightly moist sand) or as a spray (at the same rate by motorized backpack sprayer).

Sampling collection

Ten plants were randomly selected from each experimental plot. The observations on the number of fall armyworm (FAW) larvae/plant in each experimental plot 7 and 14 d after treatment (DAT) were recorded. The weight of overall yield/fed. (kg) was also calculated and compared between the treated and untreated plots.

Statistical analysis

One-way ANOVA followed by Tukey's test was used to compare the larval population densities of FAW and overall yield among the experimental field plots and control plots during the two study years.

Results

The results indicate that the density of fall armyworm (FAW) larvae in the insecticide-treated plots mixed in sand was found to be lower than that in the spray treatment during two years; also the difference among all treated plots was statistically significant. There were highly significant differences in FAW densities between all treatments 20 and 35 days after sowing ($p = 0.003$), while there were slight significant differences after 7 and 14 days after treatment ($p = 0.396$) (Tables 2 and 3). In both applications, chlorantraniliprole was the most effective showing the lowest density of FAW larvae followed by emamectin benzoate and spinosad, while lambda-cyhalothrin was the least effective. However, the highest decrease of FAW density was recorded in plots treated of chlorantraniliprole mixed in sand (93.69% for 2021; and 91.59% for 2022), followed by emamectin benzoate (84.74% for 2021; and 85.78% for 2022) and spinosad (78.59% for 2021; and 79.86% for 2022), while the plots treated with lambda-cyhalothrin had the highest density of FAW (49.22% for 2021; 48.02% for 2022) followed by profenofos (55.09% for 2021; and 53.99% for 2022) (Table 2). Regarding treatments with buprofezin and lufenuron recorded reduction of FAW density from 68 to 65%, statistical analysis reveals no significant difference over two seasons. Similar trends were observed in the treated plots by insecticides sprays over two years (Table 3).

Yield

Maize yield was significantly higher in plots treated with insecticides either mixed in sand or spray, compared to untreated plots (Table 4). However, treated plots with insecticides mixed in sand gave higher maize yield than those treated with spraying. Results showed that the yield among different treatments was statistically significant but within two years not statistically significant. In the treated plots with insecticides mixed in sand, the highest yield (60.37% for 2021; and 61.54% for 2022) was recorded in the treatment chlorantraniliprole followed by emamectin benzoate (54.06% for 2021; and 56.05% for 2022) and spinosad (46.22% for 2021; and 49.19% for 2022). On the contrary, lambda-cyhalothrin recorded the lowest significant yield during the 2021 and 2022 seasons in the treated plots with spraying by 8.95 and 8.00%, respectively, increase over control plots.

Discussion

Fall armyworm (FAW) is now spread all over Egypt; spraying insecticides is the primary method of control. Several insecticide applications are required to kill the FAW larvae feeding inside the plant whorl. In the present study, field evaluations were conducted using whorl application of some insecticides (mixed in sand or spray) in two cropping seasons against FAW.

The current study showed that exposure to insecticides, using whorl application of some insecticides (mixed in sand or spray), had a significant effect on of FAW larvae and consequently on maize yield during two seasons of the study. However, all insecticide treatments mixed in sand significantly reduced the larval population and leaf damage compared to the sprayed plots. Thus, it can be inferred that the insecticides mixed in sand provide higher yield and quality of maize, which may be due to lower infestation. In both applications, there were high significant differences between tested insecticides at 20 and 35 days after sowing, while at 7 and 14 days there were slight significant differences between all insecticides tested. In both applications, the most effective time observed was 20 days after planting with 7 days after treatment; it can be attributed that compared to the later instars, the early instars of FAW larvae are more susceptible to insecticides (Hardke et al. 2011). The method and time of application play a role in determining the efficacy of insecticides, as they can lead to different levels of exposure to target pests, and thus, these findings have critical implications for effective control of FAW (Abhilash and Singh 2009). Previous studies have shown that that insecticides mixed in sand are more effective than spraying them, as they directly target the FAW larvae by abrasion

Table 2 Evaluation of whorl application of sand mixed insecticides against *Spodoptera frugiperda*- 2021–2022

Treatment	% Reduction no. of larvae/thirty plants				% General mean reduction
	[a] T1		[b] T2		
	[c] 7 DAT	[d] 14 DAT	[c] 7 DAT	[d] 14 DAT	
Season 2021					
Spinosad	82.68 (2.37)bc	84.80 (2.44)c	72.38 (1.54)c	74.51 (3.06)b	78.59
Lufenuron	67.77 (2.57)d	73.87 (2.90)de	60.81 (2.53)d	61.86 (3.97)c	66.08
Buprofezin	69.19 (4.14)d	76.54 (3.13)d	61.56 (2.15)d	65.60 (4.64)c	68.22
Profenofos	63.00 (2.48)de	56.17 (2.88)f	51.97 (1.95)e	49.23 (2.30)d	55.09
Chlorantraniliprole	100.0 (0.57)a	100.0 (0.54)a	90.00 (2.48)a	84.77 (2.71)a	93.69
Lambda-cyhalothrin	50.62 (2.70)f	53.86 (3.29)fg	44.94 (3.56)f	47.45 (2.12)d	49.22
Emamectin benzoate	85.18 (3.00)b	90.27 (2.40)b	81.11 (2.10)b	82.39 (4.17)a	84.74
Season 2022					
Spinosad	83.71 (2.04)b	86.25 (2.97)c	73.94 (1.63)b	75.55 (2.04)b	79.86
Lufenuron	66.97 (2.18)c	73.06 (3.34)de	59.83 (3.53)cd	60.81 (2.79)c	65.17
Buprofezin	68.91 (2.34)c	75.88 (3.51)d	60.88 (2.04)c	64.94 (4.23)c	67.65
Profenofos	62.04 (2.75)cd	55.63 (4.16)f	50.66 (1.65)de	47.64 (2.53)d	53.99
Chlorantraniliprole	100.0 (0.57)a	100.0 (0.54)a	83.37 (2.44)a	83.00 (1.91)a	91.59
Lambda-cyhalothrin	49.44 (2.18)e	52.57 (3.93)fg	43.65 (2.44)f	46.42 (2.05)d	48.02
Emamectin benzoate	86.08 (3.76)b	91.57 (2.09)b	82.50 (1.57)a	82.97 (3.26)a	85.78

[a] Treatment 20 days after sowing

[b] Treatment 35 days after sowing

[c] 7 days after treatment

[d] 14 days after treatment. Values in a column followed by different lowercase letters are statistically different at the 5% level (Tukey test)

to the cuticle (Divya et al. 2022; Kalleshwaraswamy et al. 2022; Nboyine et al. 2022).

The present study revealed that there was a significant difference between densities of FAW between treated plots by insecticides either mixed in sand or spray and untreated plots. All tested insecticides were effective; however, newer insecticides (chlorantraniliprole, emamectin benzoate and spinosad) either mixed in sand or spray were highly effective against populations of FAW than conventional insecticides. The superiority of unconventional insecticides over traditional insecticides may be due to their different modes of action, in addition to the extensive use of traditional insecticides, which has led to the emergence of resistance to them. Cook et al. (2004) studied the effectiveness of indoxacarb, spinosad, and emamectin benzoate against FAW and discovered that these insecticides significantly reduced FAW populations. Mallapur et al. (2019) reported that pinoteram, emamectin benzoate and spinosad were the most effective in controlling FAW infestation. Deshmukh et al. (2020) reported that emamectin benzoate, chlorantraniliprole and spinetoram were most effective in controlling FAW infestation from lambda-cyhalothrin. Kalleshwaraswamy et al. (2022) found that soil mixed chlorantraniliprole provided excellent control of FAW populations.

The current study showed that maize yield and quality were significantly higher in the insecticide-treated plots mixed with sand followed by spraying compared to the

Table 3 Evaluation of whorl application of spray insecticides against *Spodoptera frugiperda*- 2021–2022

Treatment	% Reduction no. of larvae/thirty plants				% General mean reduction
	[a] T1		[b] T2		
	[c] 7 DAT	[d] 14 DAT	[c] 7 DAT	[d] 14 DAT	
Season 2021					
Spinosad	70.75 (2.09)b	77.00 (1.48)b	65.40 (2.90)b	68.19 (2.39)c	70.34
Lufenuron	63.54 (2.22)c	70.45 (3.77)bc	54.04 (2.19)c	57.11 (4.80)d	61.29
Buprofezin	63.61 (4.01)c	71.58 (2.00)c	55.12 (4.77)c	58.16 (4.63)d	62.12
Profenofos	48.85 (1.93)d	46.41 (2.75)d	44.65 (1.97)d	41.53 (2.66)e	45.36
Chlorantraniliprole	92.47 (2.49)a	84.71 (2.73)a	81.00 (1.08)a	79.27 (2.26)a	84.38
Lambda-cyhalothrin	34.87 (3.48)e	37.15 (2.56)e	30.65 (1.67)e	32.75 (2.71)f	33.86
Emamectin benzoate	71.40 (3.52)b	77.57 (2.99)b	68.42 (2.55)b	74.61 (3.70)ab	73.00
Season 2022					
Spinosad	73.16 (2.49)bc	77.77 (2.55)b	66.00 (2.50)c	68.71 (1.90)c	71.41
Lufenuron	62.61 (2.02)d	69.00 (1.96)c	53.12 (2.74)d	55.28 (1.69)d	60.00
Buprofezin	62.86 (2.60)d	70.74 (2.06)bc	54.49 (4.06)d	57.86 (2.21)d	61.49
Profenofos	47.57 (3.14)e	45.74 (1.67)d	43.23 (3.81)e	40.18 (2.23)e	44.18
Chlorantraniliprole	91.50 (3.20)a	83.13 (4.10)a	80.23 (1.54)a	78.44 (2.15)a	83.33
Lambda-cyhalothrin	33.40 (3.47)f	36.00 (3.39)e	29.77 (1.44)f	31.72 (2.00)f	32.72
Emamectin benzoate	74.46 (2.84)b	78.66 (2.49)b	70.44 (2.05)b	73.78 (4.25)ab	74.34

[a] Treatment 20 days after sowing

[b] Treatment 35 days after sowing

[c] 7 days after treatment

[d] 14 days after treatment. Values in a column followed by different lowercase letters are statistically different at the 5% level (Tukey test)

control plots during both study years which may be due to the lower FAW infestation. It was found that population density of FAW is strongly negatively correlated with the yield/plot. Field experiments conducted by Mallapur et al. (2019); Deshmukh et al. (2020); Wale and Hole (2020) had reported that reduction in pest population because applications of insecticides mixed in sand can enhance the crop production more than spray.

Based on these results to improve the efficacy of these methods, applications should be made as soon as damage symptoms are observed in maize whorls. Regular inspection of fields and early detection of infestation means that larvae are still small and susceptible to treatment. In practice, farmers usually apply treatment only into the whorls of damaged plants. Since larvae do migrate between plants, it is further recommended that treatment be applied into the whorls of the neighboring plants as well. Therefore, in order to suppress the pest, these methods can be included in IPM programs.

Conclusions

To keep fall armyworm (FAW) populations under control, the use of insecticides mixed in sand by whorl application at early times during the maize growing season is of great importance. At the same time, successful control for FAW population along with higher yields of maize was obtained using novel insecticides could be an alternative to conventional insecticides.

Table 4 Evaluation of whorl application of sand mixed insecticides or spray against *Spodoptera frugiperda* on yield of maize 2021–2022

Treatment	Yield/fed. (kg)			
	[a] A1	% of control	[b] A2	% of control
Season 2021				
Untreated check	24.12 ± 4.68 fg		23.00 ± 4.68de	
Spinosad	44.85 ± 2.86c	46.22	34.00 ± 1.02bc	32.35
Lufenuron	35.91 ± 2.35d	32.83	29.38 ± 3.62d	21.72
Buprofezin	38.50 ± 6.61d	37.35	31.95 ± 2.68bc	28.01
Profenofos	32.19 ± 5.38de	25.07	27.13 ± 4.45d	15.22
Chlorantraniliprole	60.87 ± 7.99a	60.37	44.24 ± 4.31a	48.01
Lambda-cyhalothrin	29.66 ± 4.28ef	18.68	25.26 ± 3.66d	8.95
Emamectin benzoate	52.50 ± 2.54b	54.06	38.93 ± 2.54b	40.92
Season 2022				
Untreated check	23.55 ± 5.22 fg		22.64 ± 4.68de	
Spinosad	46.35 ± 1.46c	49.19	33.92 ± 3.95bc	33.25
Lufenuron	35.00 ± 3.14d	32.71	28.54 ± 3.39d	20.67
Buprofezin	37.44 ± 4.59d	37.10	31.11 ± 2.72bc	27.23
Profenofos	31.23 ± 3.72de	24.59	26.36 ± 3.30d	14.11
Chlorantraniliprole	61.23 ± 3.57a	61.54	43.98 ± 3.45a	48.52
Lambda-cyhalothrin	28.82 ± 4.23ef	18.29	24.61 ± 2.05de	8.00
Emamectin benzoate	53.58 ± 4.06b	56.05	38.58 ± 3.20b	41.32

[a] Insecticides mixed in sand

[b] Insecticides spray

These data will enable maize growers to choose the most effective insecticides through using whorl application to protect against FAW infestation. Side effects on natural enemies must also be taken into account.

Abbreviation

FAW Fall armyworm

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Author contributions

SMI contributed to subject selection, study design, the experiments, paper writing, collecting, interpretation of the data, and performing statistical analysis. The author read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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