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Efficacy of Insecticides against Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) in Maize Field in Chitwan, Nepal

Ghana Shyam Bhandari[1@], Priyanka Bhandari[2] and Lalit Sah[3]

[1]National Maize Research Program, Rampur, Chitwan; @: ghanashyam.bhandari1978@gmail.com
https://orcid.org/0000-0001-7648-5823
[2]Nepal Polytechnic Institute, Bharatpur, Chitwan; PB: piru.bhandari@gmail.com
[3]IDE Nepal, Maharajgunj, Kathmandu; PB: lalitsah1@gmail.com

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ABSTRACT

A field experiments were conducted to determine the comparative efficacy of different chemical insecticides against the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), in maize under natural field conditions during winter seasons of 2020 and 2021. The experiments were laid out in a randomized complete block design with four replications and seven treatments, namely: chlorantraniliprole 18.5% SC @ 0.4 ml/liter of water; azadirachtin 1500 ppm @ 5 ml/liter of water; spinosad 45% SC @ 0.3 ml/liter of water; spinetoram 11.7% SC @ 0.4 ml/liter of water; novaluron 10% EC @ 2 ml/liter of water; emamectin benzoate 5% SG @ 0.4 g/liter of water; and an untreated control at National Maize Research Program (NMRP), Chitwan, Nepal. The efficacy study revealed that all the treatments significantly reduced plant damage and increased grain yield compared to the untreated control ($p < 0.05$). Spinosad proved to be the most effective, with a minimum infestation rate of 9.3% followed by chlorantraniliprole (12.4%) and spinetoram (16.5%), compared to the untreated control (79.6%). Spinosad treated plot also yielded the highest grain 4885 kg/ha, followed by spinetoram (4647 kg/ha), chlorantraniliprole (4470 kg/ha) and emamectin benzoate (4335 kg/ha) as compared to the untreated control (1758 kg/ha) in the combined analysis. Although azadirachtin 1500 ppm was the least effective among the treatments, it was still significantly superior to the untreated control. Furthermore, plant height, ear height, cob length, cob diameter, thousand grain weight and grain yield of maize were negatively correlated with foliar damage done by fall armyworm.

Keywords: Maize, fall armyworm, damage, spinosad, chlorantraniliprole

साराँश

अमेरिकन फौजी कीराको ब्यवस्थापनको लागि बजारमा उपलब्ध भएका तुलनात्मक रुपमा सुरक्षित मानिएका बिषादीहरुको परिक्षण राष्ट्रिय मकैबाली अनुसन्धान कार्यक्रम, रामपुर, चितवनको प्राकृतिक फिल्ड अबस्थामा सन २०२० र २०२१ सालको जाडो महिनामा गरिएको थियो । उक्त परिक्षणमा जम्मा ७ वटा उपचार विधिहरु समावेश गरिएको थियो जसमा क्लोरान्ट्रानिलिप्रोल १८.५% एस.सी. ०.४ एम.एल. प्रति लिटर, एजाडेरिक्टिन १५०० पिपिएम ५ एम.एल. प्रति लिटर, स्पीनोस्याड ४५% एस.सी. ०.३ एम.एल./लिटर, स्पीनोटोराम ११.७% एस.सी. ०.४ एम.एल./लिटर, नुभालुरोन १०% ई.सी. २ एम.एल./लिटर, इमामेक्टिन बेन्जोएट ५ % एस.जी. ०.४ ग्राम/लिटर र बिना उपचार विधिलाई रेन्डोमाइज कम्पील्ट डिजाइनमा ४ पटक दोहोर्याएर गरिएको थियो । उक्त परिक्षणमा छरेका सबै विषादीहरुले विषादी नछरेको प्लटका तुलनामा फौजीकीराको क्षति कम गरेको पाइनुको साथै उत्पादनमा बृद्धि गरेको पाइयो । यस परिक्षणमा फौजीकीराको क्षति सबैभन्दा कम (९.३%) स्पीनोस्याड ४५% एस.सी. विषादी छरेका प्लटमा पाइयो, त्यसपछि क्रमशः क्लोरान्ट्रानिलिप्रोलले (१२.४%) र स्पीनोटोरामले (१६.५%) मा पाइएको थियो जुन बिना उपचार बिधिको क्षति (७९.६%) को तुलनामा ज्यादै कम हो । त्यसैगरी सबैभन्दा बढि उत्पादन (४८८५ किलो प्रति हेक्टर) स्पीनोस्याड छरेको प्लटमा नै पाइयो त्यसपछि क्रमशः स्पीनोटोराम (४६४७ किलो प्रति हेक्टर) क्लोरान्ट्रानिलिप्रोल (४४७० किलो प्रति हेक्टर), इमामेक्टिन बेन्जोएट (४३३५ किलो प्रति हेक्टर) उपचारित प्लटमा पाइयो जहाँ बिना उपचारितको प्लटमा (१७५८ किलो प्रति हेक्टर) पाइयो । एजाडेरिक्टिनबाट उपचारित प्लटले अन्य उपचार बिधि भन्दा कम उत्पादन दिएको

पाइए तापनि बिना उपचार बिधि भन्दा बढि थियो । त्यसैगरी फौजी कीराले पारेको क्षतिसँग मकैको बिरुवाको उचाई, घोगाको उचाई, घोगाको लम्बाई, घोगाको मोटाई, हजार दानको तौल र उत्पादकत्वसँग तुलना गर्दा श्रणात्मक सम्बन्ध पाइयो ।

INTRODUCTION

Maize (*Zea mays*) is the second most important staple crop in Nepal after rice. Maize stands second (28.83%) in terms of area and production in Nepal contributing the area of 985565 ha with production of 3106397 mt. and yield 3.15 mt/ha (MoAD 2021/22). Out of total cereal production, maize crop alone contributes about 25.02% in Agriculture Gross Domestic Product (AGDP) and 6.88% in Gross Domestic Product (Pandey and Basnet 2018). The productivity of maize in Nepal is lower as compared to other developed country; for limiting maize yield, both biotic and abiotic factors have played a major role in Nepal (Achhami et al 2015). Among the insect pests, fall armyworm threats the maize cultivation in recent year. The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is an invasive insect species native to the tropical and subtropical regions of the American continent (Capinera 2020), but has already invaded Africa, Asia, and Oceania (Overton et al 2021). In North America, this pest appears in late summer or fall months, so this sporadic pest is called fall armyworm (FAW) (Prasanna et al 2018). In Nepal, this pest has been noticed for the first time in Gaidakot, Nawalpur district (N 27^{o} 42'16.67", E 84^{o} 22'50.61") on 9th May 2019 (Bajracharya et al 2019). Farm-level estimation from Ghana and Zambia suggested a yield loss of 22-67 percent (Day et al 2017), 47 percent in Kenya (Kumela et al 2018) and 9.4 percent in Zimbabwe (Baudron et al 2019) due to FAW infestation. The larval stage is the most damaging stage of the insect (FAO, 2019), feeding more than 350 species of host plants (Montezano et al 2018) belonging to 42 plant crop families (Early et al 2018). The damage could lead to 39% to over 70% yield losses (Bhusal and Bhattarai 2019), with the highest economic damage of 72% reported in Argentina (Murua et al 2006). It causes massive damage in several parts of the country, resulting in huge economic losses (FAO 2017; GC 2019). Bashir et al (2019) reported that fall armyworm can cause 100% loss of maize crops in Nepal when lacked proper management.

Pesticide management is the common practice for managing FAW in Nepal and other developing countries in South Asia. Neem-based pesticides (1500 ppm) @ 5 ml/liter, spinetoram 11.7SC @ 1 ml/2 liters of water, emamectin benzoate 5% SC @ 1 g/2.5 liters, chlorantraniliprole 18.5 SC @ 1 g/2.5 liters, and spinosad 45% SC @ 1 ml/liter of water are the common recommended pesticides to control FAW in Nepal (GC et al 2019). Several synthetic chemicals have been used for pest control, such as chlorantraniliprole 18.5% SC, emamectin benzoate 5% SG, methomyl, cyfluthrin, and methyl Parathion (Bhusal and Bhattarai 2019; Rijal 2019). Research conducted to find the field efficacy of several commercial insecticides to control FAW in India revealed that the chlorantraniliprole 18.5 SC was the most effective followed by emamectin benzoate 5 SG, spinetoram 11.7 SC, flubendiamide 480 SC, indoxacarb 14.5 SC, lambda-cyhalothrin 5 EC, and novaluron 10 EC (Deshmukh et al 2020). Seed treatment with cyantraniliprole 19.8%+ thiamethoxan 19.8% @ 4ml per kg seed is reported to be effective for about 2 to 3 weeks after germination of maize seed (Firake 2019). Farmers apply chemical pesticides at high dose and frequency, cocktail spray (Aryal 2014) because of lack of awareness regarding the harmful effects such as cancer (Basil et al 2007) and many maize growers could not use effective chemicals to manage fall armyworm because agro-vet suppliers had provided them with insecticides haphazardly. Therefore, this study aims to identify the effective chemicals for the management of fall armyworm in our local context.

MATERIALS AND METHODS

Experimental site and design: This research was carried-out at the Maize Research Farm of the National Maize Research Program, Rampur, Chitwan, Nepal. The geography of the experimental site is latitude 27^{0} 40'N, longitude 84^{0} 19' E, and 228 m mean sea level. Field experiments were conducted for two consecutive years of 2020 and 2021 to evaluate different chemicals (**Table** 1) for the fall armyworm management in maize crop and their impact on maize yield during the crop season (winter season). Planting was done in eight rows of five meter length with a cropping geometry of 60 cm×25 cm. The experiment was laid out in randomized complete block design with four replications. All the agronomic practices, such as fertilizer application, weeding, side-dressing, and other necessary management practices were done as per the recommendation to maintain good crop. Fertilizer was applied in recommended does as 120:60:40 kg $N:P_2O_5:K_2O$/ha for the tested open pollinated variety (Manakamana-3).

Table 1. Treatments details

Treatment	Chemical name	Trade name	Formulation	WHO Class	Dose
1	Chlorantraniliprole 18.5%	Allcora	SC	U	0.4ml/liter of water
2	Azadirachtin1500	Neemax	ppm	U	5 ml/ liter of water
3	Spinosad 45%	Tracer	SC	III	0.3ml/liter of water
4	Spinetoram 11.7%	Delegate	SC	II	0.4 ml/liter of water
5	Novaluron 10%	Rimon	EC	U	2 ml/liter of water
6	Emamectin benzoate 5%	Crop-star	WDG	II	0.4 g/liter of water

SC=suspension concentrate, ppm=part per million, EC=emulsifiable concentrate, WDG=water dispersible granule, U=Unlikely to present acute hazard, II=moderately hazardous, III=slightly hazardous

Sample plants: In each treatment, middle four rows were evaluated for recording plant damage data. From each treatment, twenty plants were collected for measurement of ear damage done by fall armyworm. Similarly, five cobs were taken to measure cob diameter and cob length.

Plant damage parameters: Plant damage percentage was observed visually during the vegetative (V8 leaf stage) and just before tasseling (V12 leaf stage) by counting healthy and damaged plants of all treatments. However, ear damaged by fall armyworm from the sampled plants were counted visually after harvesting. Foliar damage was scored by visual observation using the scoring scale of 1-9 reported by Davis and Williams (1992) described it in **Table** 2.

Table 2. Fall armyworm damage scoring scale (1-9)

Scale	Description	Host reaction
1	No visible leaf feeding damage	Highly resistant (RH)
2	Few pin holes on older leaves	Resistant (R)
3	Several shot-holes injury on a few leaves	Resistant (R)
4	Several shot-hole injuries common on several leaves or small lesions	Moderately resistant (MR)
5	Elongated lesions (> 2 cm long) on a few leaves	Moderately resistant (MR)
6	Elongated lesions on several leaves	Susceptible (S)
7	Several leaves with elongated lesions or tattering	Susceptible (S)
8	Most leaves with elongated lesions or severe tattering	Highly susceptible (HS)
9	Plant dying as a result of foliar damage	Highly susceptible (HS)

Pest incidence percentage was calculated by dividing the number of infested plants by the total number of plants and multiplying the result by 100.

Yield attributes: Cob diameter, cob length, 1000 grain weight were measured after harvesting of five sample cobs from each treatment. Cob diameter was measured by using Vernier caliper. In case of grain yield estimation, all harvested cobs were converted into mt/hectare by using the formula:

Grain yield measurement: Grain yield (kg per plots) at 15 percent moisture was converted into mt/ha and calculated with the help of following formula given by NMRP:

$$\text{Grain yield (ton/ha)} = \frac{\text{Grain yield}\left(\frac{\text{kg}}{\text{plot}}\right) \times \text{selling \%} \times 10\,(100 - \text{moisture \%})}{\text{Net plot area } (\text{m}^2) \times 85}$$

Data analysis: All the collected data were analyzed in two way ANOVA and GenStat software and subjected to correlation analysis with the weather parameters.

Weather parameters

Climate and weathers can significantly influence the growth and development and distribution of insects. Weather parameters were recorded during the experimental period from the weather station established at National Maize Research Program, presented as below in **Figure** 1.

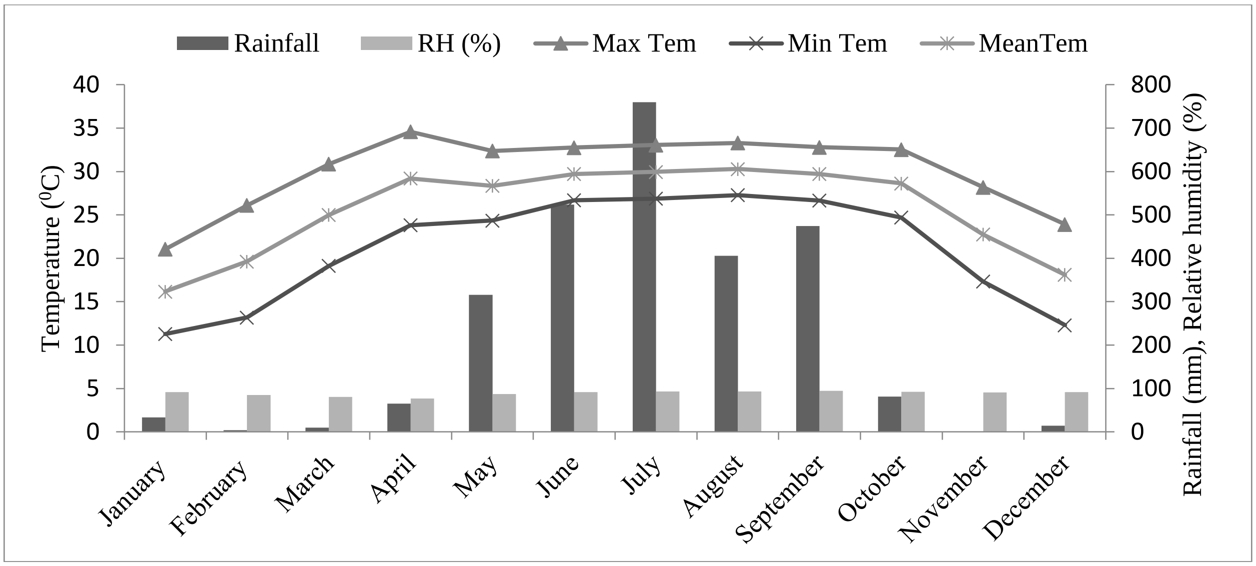

Figure 1: Meteorological data during experimental period (2020 and 2021) at Rampur, Chitwan, Nepal

RESULTS

Foliar damage

The incidence of leaf injury and foliar damage due to natural infestation by fall armyworm was recorded at the knee-high stage (25 DAS) and before the tasseling stage (45 DAS) after the application of treatments during 2020 and 2021. Statistical analysis showed that all treatments significantly reduced plant damage compared to the untreated control ($p < 0.05$) at all stages of plant growth observed (**Table 3, 4, and 5**). The lowest plant infestation (13.3%) was observed in the spinosad 45% SC treated plot, followed by chlorantraniliprole 18.5% SC (19.4%) and spinetoram 11.7% SC (22.2%), compared to the untreated control (87.1%) during 2020 (**Table 3**). Similarly, in the second-year experiment, both spinosad and chlorantraniliprole treated plots showed the same level of infestations (5.4%) followed by spinatoram (10.7%), compared to the untreated plot (76.7%) (**Table 4**). In the pooled analysis for 2020 and 2021, the spinosad treated plot showed the lowest infestation (9.3%), followed by chlorantraniliprole (12.4%) and spinetoram (16.5%) as compared to the untreated control (79.6%). These three superior treatments protected maize crops by 88.3%, 84.4%, and 79.3%, respectively, compared to the untreated control (**Table 5**).

Results showed that other insecticides, namely azadirechtin 1500 ppm and novaluron 10% EC were found least effective among the treatments but was significantly superior to untreated control.

Table 3. Effect of treatments on reduction of plant damage by fall armyworm in maize at NMRP, Rampur during winter, 2020

Treatments	FAW damage at different crop stage (%)			Reduction of plant damage over untreated control (%)
	Knee high stage (25DAS)	Before tasseling stage (45DAS)	Mean damage (%)	
Chlorantraniliprole 18.5% SC	22.9[a]	15.9[a]	19.4[a]	77.7
Azadirechtin 1500 ppm	87.0[c]	57.8[c]	72.4[d]	16.9
Spinosad 45% SC	20.4[a]	6.2[a]	13.3[a]	84.7
Spinetoram 11.7% SC	35.9[ab]	8.6[a]	22.2[ab]	74.5
Novaluron 10% EC	56.4[b]	18.4[a]	37.4[bc]	57.1
Emamectin benzoate 5% SC	38.8[ab]	40.1[b]	39.5[c]	54.6
Untreated control	85.8[c]	88.4[c]	87.1[d]	
GM	49.6	33.6	41.6	
CV, %	37.3	31.8	25.5	
P value	**	**	**	
LSD	27.53	15.88	15.77	

*DAS=days after seed sowing, CV=coefficient of variance, LSD=least standard deviation, **=highly significant, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Table 4. Effect of insecticides on reduction of plant damage by fall armyworm in maize at NMRP, Rampur during winter, 2021

Treatments	Plant damage at different leaf stage (%)			Reduction of plant damage over untreated control (%)
	Knee high stage (25 DAS)	Before tasselling stage (45 DAS)	Mean damage (%)	
Chlorantraniliprole 18.5% SC	5.9[a]	4.5[a]	5.4[a]	85.3
Azadirechtin 1500 ppm	18.0[b]	36.4[b]	27.2[c]	38.6
Spinosad 45% SC	5.4[a]	5.2[a]	5.3[a]	86.4
Spinetoram 11.7% SC	6.3[a]	15.1[ab]	10.7[ab]	75.1
Novaluron 10% EC	51.1[c]	6.8[a]	28.9[c]	50.3
Emamectin benzoate 5% SC	19.1[b]	19.7[ab]	19.4[bc]	66.2
Untreated control	75.0[d]	69.2[c]	72.1[d]	
Grand mean	25.8	22.5	24.1	
CV, %	26.5	64.0	34.9	
P value	**	**	**	
LSD	10.14	21.36	12.52	

*DAS=days after seed sowing, CV=coefficient of variance, LSD=least standard deviation, **=highly significant, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Table 5. Effect of chemical insecticides on reduction of plant damage by fall armyworm in maize at NMRP, Rampur in combined analysis, during 2020 and 2021

Treatments	Plant damage at different leaf stage (%)			Reduction of plant damage over untreated control (%)
	Knee high stage (25 DAS)	Before tasselling stage (45 DAS)	Mean damage (%)	
Chlorantraniliprole 18.5% SC	14.4[a]	10.4[a]	12.4[a]	84.4
Azadirechtin 1500 ppm	52.5[b]	47.1[c]	49.8[c]	37.4
Spinosad 45% SC	12.9[a]	5.7[a]	9.3[a]	88.3
Spinetoram 11.7% SC	21.1[a]	11.9[a]	16.5[a]	79.3
Novaluron 10% EC	53.7[b]	12.6[a]	33.2[b]	58.3
Emamectin benzoate 5% SG	28.9[a]	29.9[b]	29.4[b]	63.1
Untreated control	80.4[c]	78.8[d]	79.6[d]	
Grand mean	37.7	28.0	32.9	
CV, %	28.7	40.8	24.3	
P value	**	**	**	
LSD	16.07	17.00	11.85	

*DAS=days after seed sowing, CV=coefficient of variance, LSD=least standard deviation, **=highly significant, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Yield and yield attributes

Statistical analysis showed that all treatments were significantly different from the untreated control ($p<0.05$) in terms of thousand grain weight ($p=0.012$) and grain yield ($p=<.001$). However, non significant differences were found in plant height, ear height, cob length, or cob diameter (**Tables 6, 7, and 8**). The highest cob length (14.4 cm) and cob diameter (4.6 cm) were recorded in the spinosad-treated plot, followed by chlorantraniliprole and spinetoram, as compared to the untreated control (12.9 cm and 4.2 cm) in the combined analysis (**Table 8**). In the thousand grain weight analysis, the spinosad treatment again showed the highest grain weight (340 grams), followed by chlorantraniliprole (331 grams), compared to the untreated control (255 grams).

The highest grain yield in 2020 (4572 kg/ha) was found in the Spinosad treated plot, followed by spinetoram (4488 kg/ha) and chlorantraniliprole (4305 kg/ha), compared to the untreated control (2509 kg/ha) (**Table 6**). Similarly, in the second-year experiment, the spinosad-treated plot produced the highest yield (5198 kg/ha), followed by spinetoram (4807 kg/ha) and chlorantraniliprole (4636 kg/ha), compared to the untreated control (1007 kg/ha) (**Table 7**). In the pooled analysis for 2020 and 2021, the highest grain yield (4885 kg/ha) was observed in the Spinosad-treated plot, followed by spinetoram (4758 kg/ha) and chlorantraniliprole (4470 kg/ha) (**Table 8**).

Table 6. Efficacy of different insecticides on maize grain yield and yield attributing traits during winter, 2020

Treatment	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Thousand grain weight (gm)	Grain yield (Kg/ha)	Increase in yield over untreated check (%)
Chlorantraniliprole 18.5% SC	218	120	14.3	4.4	301	4305[a]	41.7
Azadirachtin 1500 ppm	211	112	13.3	4.5	256	3446[B]	27.2
Spinosad 45% SC	199	110	14.7	4.6	297	4572[a]	45.1
Spinetoram 11.7% SC	233	107	13.7	4.5	302	4488[a]	44.1
Novaluron 10% EC	206	96	14.0	4.4	283	3857[ab]	34.9
Emamectin benzoate 5% SC	231	110	14.0	4.5	279	4150[ab]	29.5
Untreated control	219	104	13.6	4.4	253	2509[C]	
Grand mean	217	108	13.9	4.5	281	3904	
CV,%	12	14	6.8	3.8	15.1	13.3	
P value	ns	ns	ns	ns	ns	*	
LSD	-	-	-	-	-	0.769	

*cm=centimeter, ha=hectare, LSD=least significant difference, ns=non significant, *=significant, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Table 7. Effect of commercial insecticides on maize grain yield and yield attributing traits during winter, 2021

Treatments	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Thousand grain weight (gm)	Grain yield (kg/ha)	Increase in yield over untreated check (%)
Chlorantraniliprole 18.5% SC	196.9	87.5[cd]	14.4	4.4[bc]	360[a]	4635[ab]	78.3
Azadirechtin 1500 ppm	181.6	67.0[ab]	12.7	4.3[a]	354[a]	1769[c]	43.1
Spinosad 45% SC	209.4	103.0[d]	14.1	4.6[c]	382[a]	5198[a]	80.6
Spinetoram 11.7% SC	193.5	88.0[cd]	13.5	4.5[bc]	360[a]	4807[ab]	79.1
Novaluron 10% EC	210.1	87.5[cd]	13.8	4.4[bc]	340[a]	4298[b]	76.6
Emamectin benzoate 5% SC	190.8	83.0[bc]	13.8	4.5[bc]	325[a]	4521[ab]	77.7
Untreated control	161.0	59.5[a]	12.1	3.9a	257[b]	1007[c]	
Grand mean	191.9	82.2	13.47	4.4	340	3748	
CV, %	13.3	14.5	11	4.7	12	13.9	
P value	ns	*	ns	*	*	**	
LSD	-	17.68	-	0.305	61.00	0.775	

*cm=centimeter, ha=hectare, ns=non significant, *=significant, LSD=least significant difference, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Table 8. Effect of chemical insecticides on grain yield and yield attributing traits of maize in pooled analysis during winter 2020 and 2021

Treatments	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Thousand grain weight (gm)	Grain yield (kg/ha)	Increase in yield over untreated check (%)
Chlorantraniliprole 18.5% SC	209.1	104[ab]	14.34	4.5	331[ab]	4470[ab]	58.5
Azadirechtin 1500 ppm	201.4	90[bc]	12.99	4.4	305[b]	2608[c]	31.6
Spinosad 45% SC	211.4	107[a]	14.37	4.6	340[a]	4885[a]	55.6
Spinetoram 11.7% SC	210.8	97[abc]	13.62	4.4	331[ab]	4647[a]	57.6
Novaluron 10% EC	208.6	92[abc]	13.91	4.4	312[b]	4078[b]	53.0
Emamectin benzoate 5% SC	208.2	97[abc]	13.88	4.5	302[b]	4335[ab]	
Untreated control	190.8	82[c]	12.82	4.2	255[c]	1758[d]	
Grand mean	205.8	95	13.71	4.4	311	3826	
CV, %	7.5	11	7.6	3.2	11.3	9.0	
P value	ns	*	ns	ns	*	**	
LSD	-	14.91	-	-	52.11	0.512	

*cm=centimeter, ha=hectare, ns=non significant, *=significant, **=highly significant, LSD=least significant difference, Mean in a column followed by the same letters are not significantly different at P=0.05.*

Correlation among the parameters

The correlation coefficient of various growth and yield parameters, namely: plant height, ear height, cob length, cob diameter, thousand grain weight and grain yield with foliar damage that was done by fall armyworm in presented in **Table 9**. Plant height, ear height, cob length, cob diameter and thousand grain weight and grain yield were negatively correlated with foliar damage. Conversely, positively correlations were found between plant height, ear height, cob length, cob diameter and thousand grain weights with grain yield.

Table 9. Correlation coefficient of growth and yield parameters with foliar damage

	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	1000 grain weight (gm)	Mean Damage (%)	Grain yield (kg/ha)
Plant height (cm)	-						
Ear height (cm)	0.85*						
Cob length (cm)	0.85*	0.91**					
Cob diameter (cm)	0.88*	0.83	0.70				
Thousand grain weight (gm)	0.93**	0.90**	0.79	0.84			
Mean Damage (%)	-0.97	-0.94	-0.89	-0.86	-0.96		
Grain yield (kg/ha)	0.97**	0.89	0.91**	0.86*	0.89	-0.97**	-

*cm=centimeter, gm=gram, kg=kilo gram, ha=hectare, *=significant, **= highly significant*

DISCUSSION

In the present study, all commercially available insecticides tested were found to be toxic to fall armyworm, effectively reducing infestation and significantly enhancing grain yield compared to the untreated control. A significant difference was observed among the various treatments in terms of percentage damage and grain yield in treated plots. The minimum plant and cob damage, along with higher yields, was recorded for spinosad 45 SC and spinetoram 11.7 SC, followed by chlorantraniliprole 18 SC, Emamectin benzoate 5 SG and novaluron 10 EC. Spinosad and spinetoram act on nicotinic acetylcholine receptors (nAChRs), chlorantraniliprole modulates ryanodine receptors (Adom and Adams 2020), and novaluron is a growth regulator that inhibits chitin biosynthesis (IRAC 2024). Due to their unique modes of action, these insecticides may delay insect resistance, have a longer-lasting effect, and fit well into integrated pest management (IPM) strategies. The effectiveness of spinosad, spinetoram, chlorantraniliprole, and emamectin benzoate against fall armyworm observed in this study has also been supported by other researchers. Gebreziher (2020) reported that spinosad (45 SC, 0.3 ml/lit.), chlorantraniliprole (18.5 SC, 0.4 ml/lit.), and Emamectin benzoate (5 SG, 0.4 g/lit.) were the most effective when applied at early larval stages, with spinosad causing >90% larval mortality, as noted by Cruz et al (2012). Similarly, Deshmukh et al (2020) found that emamectin benzoate 5 SG, followed by chlorantraniliprole 18.5 SC and spinetoram 11.7 SC exhibited the highest acute toxicity against fall armyworm in maize. Mallapur et al (2019) reported minimal infestation with treatments of spinetoram and emamectin benzoate, effectively reducing FAW infestation and crop damage. In laboratory studies, Hardke et al (2014) found that newer insecticides, such as chlorantraniliprole, flubendiamide, and Spinetoram, caused higher FAW mortality compared to traditional insecticides like lambda-cyhalothrin and novaluron. Similarly, Wang et al (2023) demonstrated that chlorantraniliprole significantly reduced FAW populations in maize fields. Dileep Kumar et al (2020) reported that the poison baits prepared with spinetoram (5 ml/kg of rice bran mixed with 10% jaggery) resulted in maximum larval mortality and minimized leaf damage caused by fall armyworm. In this experiment, nuvaluron was found to be less effective than others but superior than azaderichtin. The present results align with the findings of Deshmukh et al (2020), who found novaluron 10 EC to be less effective compared to chlorantraniliprole 18.5 SC, emamectin benzoate 5 SG, and spinetoram 11.7 SC. Similarly, Kumar and Mohan (2019) observed a reduced larval population in plots treated with spinetoram (97.32%) in both their Rabi and Kharif season studies in India, followed by Novaluron (93.09%) and chlorantraniliprole (90.43%).

Lower infestation levels and higher yields were observed in plots treated with spinosad, spinetoram, chlorantraniliprole, and emamectin benzoate compared to untreated control plots. The reduction in fall armyworm infestation through the application of effective insecticides resulted in increased maize grain yield, aligning with the findings of Srujana et al (2021), who reported higher yields in spinosad- and spinetoram-treated maize fields. Similarly, Nonci et al (2021) found higher maize yields in fields treated with spinosad and spinetoram, followed by chlorantraniliprole and emamectin benzoate. These results are consistent with those of Patidar et al (2022), who recorded a grain yield of 5063 kg/ha in protected plots, compared to 3394 kg/ha in unprotected plots. Among the treatments, azadirachtin 1500 ppm-treated plots recorded the lowest grain yield (2608 kg/ha) but were still significantly higher than the untreated control (1758 kg/ha). Additionally, these findings are supported by Bajracharya et al (2020), who reported that neem-based pesticides and imidacloprid were less effective against fall armyworm, resulting in greater maize plant damage and lower yields.

In this experiment, a negative correlation was found between foliar damage and plant height, ear height, cob length, cob diameter, thousand grain weight, and grain yield. These results are in line with the findings of Bakry and Abdel-Baky (2023), who reported a highly significant negative relationship between foliar damage caused by fall armyworm and all the measured parameters.

CONCLUSION

The study identified specific insecticides that demonstrated high efficacy in reducing fall armyworm populations and minimizing damage to maize crops. Among the tested insecticides, those containing active ingredients such as spinosad 45% SC at 0.3 ml/liter, chlorantraniliprole 18.5% SC at 0.4 ml/liter, spinetoram 11.7% SC at 0.4 ml/liter, and emamectin benzoate 5% SG at 0.4 g/liter of water showed significant effectiveness in managing fall armyworm. The use of these effective green and blue-labeled chemical insecticides, when integrated with Integrated Pest Management (IPM) practices, offers a viable solution for managing fall armyworm in maize fields. Continued research and field trials are essential to optimize these insecticides and ensure their long-term sustainability and environmental safety. The findings of this study provide a foundation for developing robust pest management protocols and highlight the critical role of chemical insecticides in protecting maize crops from fall armyworm damage.

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