Sequential Application of Various Insecticides for the Management of Cotton Bollworm (Hubner) *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Cotton Production

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Abstract

Background: Cotton bollworm (Hubner) (*Helicoverpa armigera*) (Lepidoptera: Noctuidae) is a major constraint to cotton production and productivity in Ethiopia.
Objective: To determine the best spray sequence of various insecticides as a strategy of resistance management of the pest.
Materials and Methods: Field experiments were conducted during the 2017 and 2018 main cropping season at Werer Agricultural Research Center. Eight different insecticides (chlorantraniliprole, deltamethrin, chlorfenapyr, lufenuron+profenofos, chlorpyriphos, lambda-cyhalothrin, profenofos, and alphacypermethrin) belonging to five major insecticide classes were systematically arranged in six treatments and three spraying sequences along with a control treatment. The experiment was laid out as a Randomized Complete Block Design and replicated four times per treatment. Data were collected on bollworm population, damaged squares, flowers, and bolls at pre and post insecticide application, boll number per plant, and seed cotton yield. Using the modified Abbott's formula, the percent efficacy was computed.
Results: Significant differences ($P<0.05$) were observed among the treatments for post spray larvae count, damaged squares, and boll counts in the 2017 and 2018 cropping seasons. Sequential and rotational application of a cocktail of the insecticides, namely, chlorantraniliprole, chlorfenapyr, profenofos, and chlorfenapyr, chlorantraniliprole, lufenuron+profenofos resulted in the best control with 81.8% and 76.4% of *H. armigera* larvae controlling efficacy. The lowest average cotton boll number (9.69/plant) and cotton yields (2.24 ton/ha) were obtained from the unsprayed treatment.
Conclusion: Applying the insecticides in sequence increased seed cotton yield by 36.2% and 33.9% compared to the yields obtained from the unsprayed plots. The results imply that rotational use of insecticides with different modes of action is the best strategy to control the pest.

Keywords: Bolls; Bollworm; Flowers; Mode of action; Pyrethroids; Squares; Yield

1. Introduction

In Ethiopia, cotton is one of the most widely cultivated crops both by small and large-scale cotton producers. Presently, production of the cotton crop has become an attractive trade for foreign and local investors which could help the country in terms of providing job opportunities and as a source of foreign exchange earnings (Belay, 2012 cited by EIAR, 2016). However, the pest spectrum of cotton is quite complex among which insect pest problem has become the major one. A total of seventy species of insects and mites have been known to attack cotton at different growth stages in Ethiopia (Ermias *et al.*, 2009) out of which bollworm complex (*Helicoverpa armigera*, *Pectinophora gossypiella*, *Diparopsis watersi,* and *Earias* spp) is a great menace.

Cotton bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) is a polyphagous insect damaging diverse crops, such as beans, chickpea, peas, sorghum, cotton, tomato, pepper, sunflower, safflower, flax, and niger seed (Tsedeke Abate, 1982; Waktole Sori, 1996). In Ethiopia, bollworm complexes cause 36–60% yield losses among which *H. armigera* is a major culprit (Tsedeke Abate, 1982; Waktole Sori, 1996; Geremew Terefe and Ermias Shonga, 2006). All parts of the cotton plant are vulnerable to attack by the pest. The larva feeds on cotton young leaves, squares, flower buds, flowers, and bolls (Geremew and Ermias, 2006; Deguine *et al.*, 2008). In China, cotton bollworms caused about 50–60% yield reduction each year from 1980–1990 on cotton (Xiao *et al.*, 2002).

Cotton pest management is the most important task in the total production cost of cotton in most years. Cotton farms can lose the whole production when correct pest managements are not taken. Among production control costs, 43 % is spent on pesticide purchase, and 33 % on weed control efforts (EIAR, 2016).

In Ethiopia, for decades, a wide range of insecticides have been used for the control of cotton insect and mite pests, particularly Cotton bollworm (Ermias Shonga *et al.,* 2009). Control of pests with insecticides from a single chemistry group is

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common in most cotton farms and such a practice for an extended period results in the development of resistance as in the case of lambda-cyhalothrin for Cotton bollworm species at Dubti (Germew Terefe, 2004), dimethoate for aphid species at the Middle Awash (IAR, 1990), and carbamate group (carbosulfan, furathiocarb and pirimicarb) for aphid species resistance at Arbaminch, Dubti and Werer (Ermias Shonga, 2006). Additionally, studies on the screening of different insecticides for Cotton bollworm control showed a declining efficacy of endosulfan at Werer Agricultural Research Center (WARC) (WARC, 1998) and commercial farms in Ethiopia (Geremew Terefe and Surachate, 2005). Application of different insecticides sequentially resulted in significant reductions in larval population as compared with repeated applications of the same insecticide (Salama *et al.*, 2013). *Helicoverpa armigera* is a multi-resistant insect species; it can express more than one resistance mechanism to a particular insecticide group (Muhammad, 2007).

Accordingly, designing an insecticide resistance management strategy for *H. armigera* is very crucial. The use of insecticide mixtures or mode of action rotation and sequential application is an important approach for managing insecticide resistance, which could delay or mitigate the onset of resistance development in arthropod pest populations (Cloyd, 2010).

Pyrethroid insecticides are important in relation to other management options due to low tendency to accumulate in organism and short biodegradation period, and economic value led to overuse of pyrethriods with unavoidable consequences (Bhardwaj *et al.*, 2020). Therefore, the present study was conducted to study the effectiveness of selected insecticide application sequences against *H. armigera* on cotton under field conditions.

2. Materials and Methods

The experiment was conducted at Werer Agricultural Research Center (WARC), Amibara District, Gebresu zone of Afar National Regional State during the 2017 and 2018 cropping seasons under field conditions using irrigation. WARC is located at an altitude of 750 meter above sea level, at the latitude of 9^{o} 20' 31"N, and longitude of 40^{o}10' 11" E. The study areas is characterized by a mean annual rainfall of 540 mm which is erratic and mean maximum and minimum temperatures of 34.4 ^{o}C and 19.6 ^{o}C, respectively. The soil is vertisol with porosity and bulk density (0–25cm depth) of 49.06% and 1.35 g cm^{-2}, respectively (Wendmagen Chekole and Abere Mnalku, 2012).

2.1. Description of the Materials used for the research

2.1.1. Planting material

The popular cotton variety used for the study was Deltpine-90, which was obtained from Werer Agricultural Research Center (WARC).

2.1.1. Insecticides

Eight different insecticides were used for the experiment. These insecticides are recommended for the control of Cotton bollworm on cotton by WARC (Table 1).

Table 1. Description of insecticides used in the experiment.

Common name	Trade name	Chemical group	Rate/ha
Chlororfenapyr	Tutan 36 SC	Pyrole	225 ml
Chlorantraniliprole	Coragen 200 SC	Diamide	125 ml
Deltamethrin	Decis 2.5 EC	Pyrethroid	600 ml
Lambda-cyhalothrin	Karate 5 % EC	Pyrethroid	400 ml
Alpha-cypermethrin	Fastac 100 g/lt	Pyrethroid	300 ml
Chlorpyriphos	Pyriban 48 % EC	Organophosphate	2000 ml
Profenofos	Proof 720 g/lt	Organophosphate	900 ml
Lufenuron+Profenofos	Curador 55 EC	IGR+Organophosphate	650 ml

Note*: EC = Emulsifiable concentrate, SC = Soluble concentrate, IGR = Insect Growth Regulators.*

2.2. Treatments and Experimental Design

The eight insecticides were systematically arranged in to six treatments (including one untreated check) and three spraying sequences (Table 2). The experiment was laid out as a Randomized Complete Block Design (RCBD) with four replications per treatment. An individual total plot size was 63 m^2. The distance between the row to row and plant to plant was 90 cm and 20 cm, respectively.

2.3. Experimental Procedures

2.3.1. Planting date and methods

The land was prepared by a tractor operated machine. Planting was done on 26 May 2017 and 21st May 2018 by hand. The plots were irrigated eight times by giving a 10-day interval after first irrigation and then watering every at the interval of 15 days up to the time of 65% boll opening period. Plots were weeded twice by hoeing and hand-weeded two times. All other recommended agronomic practices were applied to the plots. On each plot inspecting *H. armigera* infestation was started three weeks after germination and continued until the cotton plants matured. Ten plants per plot were randomly taken and tagged for the assessment of *H. armigera* infestation by checking leaves, squares, flowers, and bolls. From the tagged plants data were recorded on *H. armigera* eggs and larvae, square, flower, and boll damage of *H. armigera*.

On an experimental plot, a total of three rounds of spray were applied using a hand-operated knapsack sprayer based on natural infestation when the economic threshold level was 10 larvae per 100 plants (WARC, 2015). The evaluated insecticide sprays were prepared according to the company's recommended doses in a water application volume of 200 liters/hectare.

2.3.2. Dates of spraying

The first round spray application was made on July 6th, 2017, and June 28th, 2018 coinciding with the period of formation of the squares and flowers of the plant, and the subsequent two sprays were applied at a 15-day interval. The second round spray application coincided with the pick square and flower formation period and the third round application coincided with the boll formation and boll opening period of the cotton plant. Ten plants were tagged in each plot and young shoot leaves, squares, flowers, and bolls were examined for data collection. Cotton bollworm egg and larvae, damaged squares, flowers, and bolls; non-target and beneficial insects on pre and post-spray count of 3, 5, 7, and 10 days were recorded. Data were collected on the number of days after treatment. At crop maturity and just before cotton-picking, healthy bolls per plant were counted from the ten predetermined plants including on plants from the control plots. Finally, seed cotton was harvested and weighed.

2.2. Data Analysis

All data were analyzed using PROC GLM (SAS Version 9.0, SAS Institute, 1999). PROC UNIVARIATE was used to test data for normality and homogeneity of variance based on the Shapiro-Wilk statistic. To satisfy the assumptions of ANOVA, the pre and post-spray count mean data were square root transformed ($\sqrt{x+0.5}$). When F-values were significant ($P < 0.05$), means were compared by Fisher's Least Significant Difference (LSD) test. Percent efficacy for each treatment was computed based on the modified Abbotte's formula by Fleming and Retenkarna, (1985).

$$\%\ \text{Efficacy} = [1 - (\text{Ta} * \text{Cb}) / (\text{Tb} * \text{Ca})]$$

Where, Ta = Post-treatment population in treatment, Cb = Pre-treatment population in check, Tb = Pre-treatment population in treatment, Ca = Post-treatment population in check.

Table 2. Insecticide treatments for spray sequence in field experiments during the 2017 and 2018 cropping seasons at Werer Agricultural Research Centre, Middle Awash Valley, Ethiopia.

Treatment name	Sequence of treatment		
	1st spray	2nd spray	3rd spray
T1	chlorantraniliprole 200 SC @ 150 ml/ha	chlorfenapyr 36 SC @ 225 ml/ha	profenofos 720 G/L @ 900 ml/ha
T2	deltamethrin 2.5 EC @ 600 ml/ha	lufenuron + Profenofos 55 EC @ 650 ml/ha	chlorfenapyr 36 SC @ 225 ml/ha
T3	chlorfenapyr 36 SC @ 225 ml/ha	chlorantraniliprole 200 SC @ 150 ml/ha	lufenuron+profenofos 55 EC @ 650 ml/ha
T4	lufenuron+profenofos 55 EC @ 650 ml/ha	chlorfenapyr 36 SC @ 225 ml/ha	alphacypermethrin 100 G/L @ 300ml/ha
T5	chlorpyriphos 48 % EC @ 2l/ha	lufenuron+profenofos 55 EC@650 ml/ha	lambda-cyhalothrin 5% EC @ 480ml/ha
T6	lambda-cyhalothrin 5 % EC @ 480ml/ha	lambda-cyhalothrin 5 % EC @ 480 ml/ha	lambda-cyhalothrin 5% EC @ 480ml/ha
T7	Unsprayed	Unsprayed	Unsprayed

3. Results

The results of the first round spray revealed that, the post spray larval and damaged square counts were significantly ($P < 0.05$) different among the treatments both in 2017 and 2018 cropping seasons (Tables 3). In both cropping seasons, the highest larval count, square numbers, and numbers of damaged flowers were recorded from control treatment and the lowest were recorded from chlorfenapyr treated plots (Tables 3).

The results of the second round spray in the 2017 and 2018 cropping seasons revealed that the post-spray mean larvae count, damaged squares, flowers, and bolls revealed significant ($P < 0.05$) variations among the different insecticides applied (Tables 4). In both cropping years, among the tested insecticides, the highest larval controlling efficacy was obtained from spraying chlorfenapyr, while the lowest was from spraying lambda-cyhalothrin (Tables 4). The third round spray showed a significant ($P < 0.05$) difference for the post-spray larvae counts and damaged boll counts among the treatments in the 2017 cropping season (Table 5). In the 2018 cropping season, the post spray larval count, damaged squares, and boll count per plant revealed significant ($P < 0.05$) differences among the treatments (Table 5).

There was a significant difference ($P < 0.05$) in the number of boll per plant among the treatments in both cropping years (Table 6). The highest numbers of boll per plant and seed cotton yield were obtained from the treatment with the rotation of chlorantraniliprole, Chlorfenapyr, Profenofos. However, the lowest numbers of boll per plant and seed cotton yield were obtained from the control treatment in both seasons (Table 6). The rotation of chlorantraniliprole, chlorfenapyr resulted in cotton yield advantages of 0.72 and 0.75 ton/ha in the 2017 and 2018 seasons compared to the commonly and repeatedly used lambda-cyhalothrin (Table 6).

Table 3. Means of pre and post-spray larva counts, damage square and damage flower, and efficacy of different insecticide tested at the 1st round spray application in a field experiment, Werer, during the 2017 and 2018 cropping seasons.

Treatment name	2017 cropping season						
	No. of larvae count/plant		No. of damage squares/plant		No. of damage flowers/plant		% Efficacy
	Pre-spray	Post-spray	Pre-spray	Post-spray	Pre-spray	Post-spray	
T1:chlorantraniliprole 200 SC	0.15(0.81)	0.03(0.73)c	0.28(0.87)	0.06(0.75)c	0.03(0.72)	0.02(0.72)	79.89
T2:deltamethrin 2.5% EC	0.18(0.82)	0.13(0.79)ab	0.30(0.89)	0.14(0.80)b	0.08(0.75)	0.03(0.72)	31.04
T3:chlorfenapyr 36SC	0.20(0.83)	0.04(0.73)c	0.50(0.10)	0.04(0.74)c	0.08(0.76)	0.04(0.73)	81.90
T4:lufenuron+profenofos 55% EC	0.15(0.81)	0.04(0.74)c	0.28(0.88)	0.09(0.77)bc	0.03(0.72)	0.01(0.71)	71.84
T5:chlorpyriphos 48 % EC	0.20(0.84)	0.09(0.77)bc	0.30(0.89)	0.11(0.78)bc	0.08(0.75)	0.04(0.74)	54.74
T6:lambda-cyhalothrin 5 % EC	0.18(0.82)	0.08 (0.76)bc	0.28(0.87)	0.11(0.78)bc	0.10(0.77)	0.04(0.73)	55.17
T7:Unsprayed	0.18(0.82)	0.18(0.82)a	0.15(0.81)	0.34(0.92)a	0.03(0.72)	0.06(0.74)	-
LSD (0.05)	Ns	0.050	Ns	0.051	Ns	Ns	
CV (%)	8.15	4.44	12.47	4.34	10.43	4.96	
	2018 cropping season						
	No. of larvae counts/plant		No. of damage squares/plant		No. of damage flowers/plant		% Efficacy
Treatment Name	Pre-spray	Post-spray	Pre-spray	Post-spray	Pre-spray	Post -spray	
T1:chlorantraniliprole 200 SC	0.58(1.03)	0.06(0.77)c	0.85(1.12)	0.02(0.72)c	0.0(0.71)	0.03(0.73)	80.43
T2:deltamethrin 2.5% EC	0.33(0.90)	0.12(0.78)b	0.38(0.92)	0.68(1.07)ba	0.0(0.71)	0.08(0.76)	26.92
T3:chlorfenapyr 36SC	0.75(1.09)	0.09(0.77)b	0.95(1.18)	0.18(0.82)bc	0.05(0.74)	0.08(0.76)	75.00
T4:lufenuron+profenofos 55% EC	0.33(0.91)	0.04(0.73)b	0.30(0.89)	0.03(0.72)c	0.0(0.71)	0.02(0.72)	76.92
T5:chlorpyriphos 48 % EC	0.50(0.99)	0.02(0.81)b	0.50(0.96)	0.48(0.98)bac	0.05(0.74)	0.04(0.73)	40.00
T6:lambda-cyhalothrin 5 % EC	0.30(0.89)	0.09(0.77)b	0.18(0.81)	0.30(0.89)cb	0.0(0.71)	0.01(0.71)	41.67
T7:Unsprayed	0.58(1.03)	0.29(0.88)a	0.78(1.08)	1.16(1.23)a	0.0(0.71)	0.09(0.77)	-
LSD (0.05)	Ns	0.07	Ns	0.29	Ns	Ns	
CV (%)	11.9	6.34	20.5	21.7	2.9	4.1	

Note: *Means followed by the same letter(s) within a column are not significantly different from each other at a 5% level of significance. Values in parentheses pre- and post-spray mean data were square-root-transformed. % Efficacy = Percent efficacy.*

Table 4. Means of pre and post-spray counts of larvae counts, damage square, flower, bolls, and efficacy of different insecticides tested at the 2nd round rotation spray application, Werer, during the 2017 and 2018 cropping seasons.

2017 cropping season

Treatment Name	No. of larvae count/ plant		No. of damage square/ plant		% efficacy	No. damage flowers/ plant		No. damage bolls/plant	
	Pre-spray	Post-spray mean	Pre-spray	Post-spray mean		Pre-spray	Post-spray mean	Pre-spray	Post-spray mean
T1:Chlorfenapyr 36 SC	0.40(0.95)	0.07(0.75)d	0.55(1.02)	0.13(0.79)d	85.61	0.23(0.85)	0.07(0.75)	0.08(0.76)	0.06(0.75)
T2:Lufenuron+profeno 55 EC	0.45(0.97)	0.15(0.81)bcd	0.73(1.11)	0.31(0.90)bcd	68.82	0.20(0.83)	0.12(0.79)	0.15(0.81)	0.12(0.79)
T3:Chlorantraniliprole 200 SC	0.38(0.93)	0.09(0.77)cd	0.50(0.99)	0.16(0.81)cd	76.61	0.15(0.80)	0.13(0.79)	0.18(0.82)	0.13(0.79)
T4:Chlorfenapyr 36 SC	0.40(0.95)	0.11(0.78)cd	0.95(1.16)	0.38(0.93)bcd	75.15	0.33(0.91)	0.14(0.80)	0.18(0.82)	0.11(0.78)
T5:Lufenuron+profeno 55 EC	0.50(0.10)	0.18(0.83)bc	1.23(1.30)	0.43(0.96)bc	66.09	0.23(0.85)	0.17(0.81)	0.23(0.84)	0.15(0.81)
T6:Lambdacyhalothrin 5%EC	0.48(0.99)	0.23(0.85)b	1.18(1.28)	0.58(1.03)b	55.69	0.33(0.91)	0.13(0.79)	0.28(0.88)	0.18(0.82)
T7:Unsprayed	0.55(1.02)	0.78(1.13)a	0.98(1.21)	1.13(1.27)a	-	0.25(0.86)	0.24(0.86)	0.05(0.74)	0.19(0.83)
LSD (0.05)	Ns	0.06	Ns	0.15		Ns	Ns	Ns	Ns
CV (%)	8.32	4.96	16.74	10.68		9.83	8.12	9.51	5.14

2018 cropping season

Treatment Name	No. of larvae count/plant		No. of damage square/plant		% efficacy	No. damage flowers/plant		No. damage bolls/plant	
	Pre-spray	Post-spray	Pre-spray	Post-spray		Pre-spray	Post-spray	Pre-spray	Post-spray
T1:Chlorfenapyr 36 SC	0.23(0.84)	0.05(0.74)b	0.28(0.88)	0.13(0.794)c	80.85	0.0(0.71)	0.03(0.73)c	0.03(0.72)	0.06(0.75)c
T2:Lufenuron+profeno 55 EC	0.55(1.61)	0.213(0.84)ba	0.98(1.19)	0.49(0.99)ba	66.71	0.10(0.77)	0.13(0.79)ba	0.30(0.89)	0.19(0.83)ba
T3:Chlorantraniliprole200SC	0.33(0.91)	0.113(0.78)b	0.60(1.03)	0.36(0.92)bac	70.18	0.15(0.80)	0.06(0.75)bc	0.23(0.85)	0.15(0.81)bac
T4:Chlorfenapyr 36 SC	0.20(0.84)	0.063(0.75)b	0.33(0.89)	0.27(0.87)bc	73.08	0.03(0.72)	0.07(0.75)bc	0.13(0.79)	0.09(0.77)bc
T5:Lufenuron+profeno 55 EC	0.50(0.99)	0.213(0.84)ba	0.83(1.13)	0.34(0.92)bac	63.38	0.03(0.72)	0.10(0.77)ba	0.30(0.89)	0.23(0.85)a
T6:Lambdacyhalothrin5%EC	0.43(0.96)	0.231(0.85)ba	0.73(1.10)	0.53(1.00)ba	53.12	0.10(0.77)	0.07(0.75)bc	0.28(0.88)	0.21(0.84)a
T7:Unsprayed	0.35(0.92)	0.406(0.95)a	0.50(0.99)	0.56(1.02)a	-	0.08(0.76)	0.16(0.81)a	0.20(0.84)	0.23(0.85)a
LSD (0.05)	Ns	0.12	Ns	0.14		Ns	0.05	Ns	0.06
CV (%)	9.22	9.50	15.41	10.14		8.64	3.94	7.47	5.29

Note: *Means followed by the same letter(s) within a column are not significantly different from each other at a 5% level of significance. % Efficacy = Percent efficacy. Values in parentheses of pre and post spray means data were square-root-transformed.*

Table 5. Means of pre and post-spray larva counts, damage square, flower, bolls, and efficacy of different insecticides tested at the 3rd round rotation spray application, Werer, 2017 and 2018 cropping seasons.

Treatment Name	No. of larvae count/plant		No. damage squares/plant		% Efficacy	No. damage flowers/plant		No. damage bolls/plant	
2017 cropping season									
	Pre-spray	Post-spray	Pre-spray	Post-spray		Pre-spray	Post-spray	Pre-spray	Post-spray
T1:Profenofos 72%EC	0.15(0.80)	0.03(0.73)[b]	0.28(0.87)	0.04(0.74)	79.89	0.13(0.79)	0.03(0.72)	0.18(0.82)	0.11(0.78)[b]
T2:Chlorfenapyr 36SC	0.25(0.86)	0.04(0.74)[b]	0.38(0.93)	0.03(0.73)	83.10	0.15(0.80)	0.03(0.73)	0.15(0.81)	0.09(0.77)[b]
T3:Lufenuron+profenofos	0.30(0.89)	0.08(0.76)[b]	0.33(0.90)	0.05(0.74)	76.86	0.15(0.81)	0.03(0.73)	0.25(0.86)	0.10(0.77)[b]
T4:Alphacypermethrin 100%EC	0.20(0.84)	0.04(0.73)[b]	0.25(0.86)	0.08(0.76)	81.90	0.10(0.77)	0.02(0.72)	0.28(0.87)	0.12(0.79)[b]
T5:Lambda-cyhalothrin 5%EC	0.18(0.82)	0.07(0.75)[b]	0.25(0.87)	0.07(0.75)	62.07	0.08(0.75)	0.03(0.72)	0.13(0.79)	0.10(0.77)[b]
T6:Lambda-cyhalothrin 5%EC	0.23(0.85)	0.10(0.77)[b]	0.30(0.894)	0.11(0.78)	57.09	0.28(0.88)	0.05(0.74)	0.23(0.85)	0.21(0.84)[a]
T7:Unsprayed	0.18(0.82)	0.18(0.86)[a]	0.25(0.86)	0.26(0.86)	-	0.25(0.86)	0.09(0.77)	0.25(0.86)	0.24(0.86)[a]
LSD (0.05)	Ns	0.06	Ns	Ns		Ns	Ns	Ns	0.048
CV (%)	7.98	5.28	8.71	8.98		8.71	4.11	12.18	4.00
2018 cropping season									
	Pre-spray	Post-spray	Pre-spray	Post-spray		Pre-spray	Post-spray	Pre-spray	Post-spray
T1:Profenofos 72%EC	0.30(0.89)	0.06(0.75)[b]	0.38(0.93)	0.03(0.72)[b]	84.27	0.10(0.77)	0.03(0.72)	0.20(0.84)	0.07(0.75)[b]
T2:Chlorfenapyr 36SC	0.33(0.91)	0.07(0.75)[b]	0.38(0.92)	0.04(0.74)[b]	82.26	0.15(0.80)	0.03(0.73)	0.18(0.82)	0.13(0.79)[b]
T3:Lufenuron+profenofos	0.28(0.88)	0.07(0.75)[b]	0.26(0.87)	0.08(0.76)[b]	79.03	0.15(0.80)	0.02(0.73)	0.28(0.88)	0.14(0.79)[b]
T4:Alphacypermethrin100%EC	0.33(0.91)	0.09(0.77)[b]	0.33(0.89)	0.08(0.76)[b]	75.82	0.08(0.76)	0.03(0.72)	0.25(0.87)	0.21(0.84)[b]
T5:Lambda-cyhalothrin 5%EC	0.30(0.89)	0.14(0.79)[b]	0.50(0.99)	0.13(0.79)[b]	61.56	0.08 (0.76)	0.04(0.74)	0.10(0.77)	0.16(0.81)[b]
T6:Lambda-cyhalothrin 5%EC	0.33(0.90)	0.16(0.81)[b]	0.38(0.93)	0.16(0.81)[b]	59.68	0.15(0.81)	0.03(0.72)	0.25(0.86)	0.19(0.82)[b]
T7:Unsprayed	0.33(0.91)	0.39(0.93)[a]	0.30(0.89)	0.36(0.92)[a]	-	0.08(0.76)	0.11(0.78)	0.25(0.87)	0.43(0.96)[a]
LSD (0.05)	Ns	0.06	Ns	Ns		Ns	Ns	Ns	0.05
CV (%)	7.98	5.28	8.71	8.98		8.71	4.11	12.18	4.00

Note*: Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance. % Efficacy = Percent efficacy. Values in parentheses of pre and post spray mean data were square-root-transformed.*

Table 6. Means of bolls number per plant and seed cotton yield in a field experiment, Werer, during the 2017 and 2018 cropping seasons.

Treatment no.	Spray sequence of treatment			2017 cropping season		2018 cropping season	
	1st spray	2nd spray	3rd spray	Healthy boll/plant	Seed cotton yield (t ha^{-1})	Healthy boll/plant	Seed cotton yield (t ha^{-1})
1	chlorantraniliprole 200 SC @150ml/ha	chlorfenapyr 36 SC @225ml/ha	profenofos 720 G/L @900ml/ha	16.53^{a}	3.84^{a}	20.85^{a}	3.17^{a}
2	deltamethrin 2.5EC @600ml/ha	lufenuron + Profenofos 55EC @650ml/ha	chlorfenapyr 36 SC @225ml/ha	12.85^{b}	3.35^{bc}	12.68^{b}	2.48^{b}
3	chlorfenapyr 36 SC @225ml/ha	chlorantraniliprole 200 SC @150ml/ha	lufenuron+profenofos 55EC @ 650ml/ha	14.08^{b}	3.68^{ab}	15.53^{ab}	3.08^{a}
4	lufenuron+profenofos 55EC @650ml/ha	chlorfenapyr 36 SC @225ml/ha	alphacypermethrin 100G/L @300ml/ha	14.15^{b}	3.51^{abc}	14.05^{b}	2.42^{b}
5	chlorpyriphos 48% EC @2l/ha	lufenuron+profenofos 55EC @650ml/ha	lambda-cyhalothrin 5% EC @480ml/ha	12.63^{b}	3.39^{bc}	10.5^{b}	2.31^{bc}
6	lambda-cyhalothrin 5% EC @480ml/ha	lambda-cyhalothrin 5% EC @480ml/ha	lambda-cyhalothrin 5% EC @480ml/ha	12.40^{bc}	3.12^{c}	10.13^{b}	2.26^{bc}
7	Unsprayed	Unsprayed	Unsprayed	10.38^{c}	2.56^{d}	9.0^{b}	1.91^{c}
LSD (0.05)				2.05	0.44	6.78	5.08
CV (%)				10.39	8.87	15.37	13.57
SE				0.69	0.15	2.28	0.15

Note*: Means followed by the same letter (s) within a column are not significantly different from each other at 5% level of significance.*

4. Discussion

The present study indicated application of chlorantraniliprole 200SC and chlorfenapyr 36 SC resulted in a better control of *H. armigera* larva on cotton. The results is consistent with the findings of Cordova *et al.* (2006) and Bheemanna *et al.* (2008) who found that chlorantraniliprole 20 SC @40 g a.i. ha^{-1} effectively controlled *H. armigera* on cotton by causing impaired regulation, paralysis, and ultimately death of sensitive species. Similarly, Aslam *et al.* (2004) and Perini *et al.* (2016) also reported that due to knockdown chemical nature, chlorfenapyr effectively controlled *H. armigera*. For the long time, year to year and repeated application within a season of lambda-cyhalothrin and deltamethrin had resulted effective for controlling of *H. armigera* in cotton. That lufenuron insect growth regulator insecticide also resulted in an effective control of the pest by forming abnormal new cuticle and death of the insect was earlier reported by Gopal and Tarikui (2014) and Tarikul *et al.* (2015). Confirming the results of this study, Vittozzi *et al.* (2001) reported that Profenophos insecticide toxicity can occur in two ways: inhibition of acetylcholine esterase, and cytotoxic effects on immune cells.

Sequential application of chlorantraniliprole, chlorfenapyr, profenofos insecticides resulted in the lowest *H. armigera* larvae population due to high controlling efficacy. However, the lowest controlling efficacy was from conventional insecticides lambda-cyhalothrin applied in three sequences. The results this study revealed that sequential application of a mixture of insect growth regulator and organophosphate insecticides provided a good control of the *H. armigera* larva pest. The results confirmed that in both cropping seasons during the experiment, inclusion of deltamethrin in the rotation reduced the insecticide efficacy in controlling cotton bollworm.

The results of this study agrees with the findings of Salama *et al.* (2013) who reported that the sequential application of conventional insecticides in rotation with biocides, IGRs, and anti-molting compounds provided a good average reduction in the larval population of cotton bollworms. Similarly, Rabia *et al.* (2016) suggested a rotational scheme of application of insecticides with different modes of action to reduce the onset of development insecticide resistance in *H. armigera*. Many studies have evaluated the effects of insecticide mixtures in suppressing populations and damage of *H. armigera* insect pests (Martin *et al.*, 2003; Hamed *et al.,* 2006; Nayak and Daglish, 2007; Borude *et al.,* 2018). Pesticide mixture has been recommended for use as a resistance management strategy based on the assumption that insects will not develop resistance to multiple modes of action simultaneously (Warnock and Cloyd, 2005).

5. Conclusion

The results of this study have revealed that application of deltamethrin and lambda-cyhalothrine reduced their efficacy for controlling *Helicoverpa armigera*; thus, there is a need to replace them with the new insecticides chlorfenapyr for providing good control against *H. armigera* on cotton. Application of insecticide with a different mode of action in rotations resulted in a significantly higher cotton yield than the convectional way of spraying lambda-cyhalothrin repeatedly. Future studies are needed to monitor the level of insecticide resistance and design insecticide resistance management strategies.

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