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ORIGINAL RESEARCH ARTICLE

Insecticidal activity of diverse chemicals for managing the destructive alien pest fall armyworm *Spodoptera frugiperda* (J.E. Smith) on Maize crop in India

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Abstract
In an endeavor to ascertain the efficacy of insecticides with a varied mode of action to combat the invasive alien pest fall armyworm *Spodoptera frugiperda* in Maize an experiment was conducted at Regional Agricultural Research Station, Nandyal, Acharya N G Ranga Agricultural University, Andhra Pradesh, India for a period of three years (2019/20/21) in *rabi* season. The present findings revealed that poison bait with Thiodicarb 75 SP (50 kg rice bran + 5 kg Jaggery + 500 g Thiodicarb 75 SP @ 50 kg/ha) was effective in the management of fall armyworm. Least cob damage of 8.5 percent and higher yield of 7344 kg/ha was observed in the "poison bait" treatment. Spinosad 45SC@ 175 ml/ha and Spinetoram 11.7SC @ 250 ml/ha treatments showed on par resuilts with poison bait treatment. In the case of Spinosad 45SC@ 175 ml/ha, 11.57 percent of cob damage and 6852 kg/ha yield was recorded, whereas Spinetoram 11.7SC@250 ml/ha treated plots showed 14.3 percent of cob damage with 6813 kg/ha yield. Our field experiment concluded that poison bait followed by Spinosad 45SC and Spinetoram 11.7SC were effective in management of fall armyworm in Maize.

Keywords *Spodoptera frugiperda* · Efficacy of insecticides · Thiodicarb · Spinosad · Spinetoram · Percent cob damage

Introduction

In India, maize is the vital cereal crop grown extensively and it ranks 4th globally in terms of area and 7th in production. India contributes to 4% of the total world's maize area and 2% in production. The area of the crop extended to about 9.2 million hectares in 2018–19 (DACNET 2021). Maize is widely grown in Andhra Pradesh for livestock and poultry feed, industrial purposes, seed production, starch industry, food and table purpose. This crop has occupied an area of 3.01 lakh hectares in 2019–20 with a productivity of 7055 kg/ha (Agricultural Statistics at a Glance, 2020). The Andhra Pradesh (A.P.) state has higher state productivity compared to other states of India. Krishna and Godavari districts in A.P. recorded 12 t/ha yield (https://iimr.icar.gov.in/).

Corn is challenged with many pests (stem borer, armyworms, earworms) and diseases (turcicum and maydis leaf blights, downy mildew, charcoal rot) that reflect in yields of the crop. One of the crucial pests for research in present days is the fall armyworm (FAW) *Spodoptera frugiperda*an exotic pest introduced recently in the year 2018 into the Indian country and caused an outbreak with severe economic losses to the farmers. It was confined to America initially where it was observed in Mexico, Brazil, Argentina, and the USA and from there it was spread to the African countries in December 2015, where it challenged the survival of native species causing huge damage (Prowell et al. 2004; Clark et al. 2007). Invasion of fall armyworm in India was reported initially in the Karnataka state (Sharanabasappa et al. 2018) and later on it was spread to other parts of the country. This alien pest has a genetic similarity with the one that exists in South Africa and origin in the Western hemisphere (Nagoshi et al. 2019).

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Congenial ecological conditions for pest multiplication and climate in India have caused a drastic multiplication rate with a major threat to the farming community. Reports in recent studies reveal that *S. frugiperda* has over 353 larval host plants from about 76 families which include Poaceae (106), Asteraceae (31), and Fabaceae (31) (Montezano et al. 2018). In Andhra Pradesh (A.P.) it was observed toattack major crops such as Maize, Soyabean, Jowar and Fingermillet. Being polyphagous in nature it has attacked many crops and caused huge losses leading to the question of native species sustainability.

This pest has a short life cycle (30 days) (Sparks 1979), high fecundity (about 1000 eggs per female adult moth), wide host range, remarkable dispersible ability as pest makes use of air-currents for their migration (Johnson 1987), and highly versatile to various environmental conditions (ACMAD 2018). These were the major reasons for its spread and devastation in various agro-climatic regions. Females lay the eggs in patches on the leaf surface on the Maize crop. These eggs hatch in 4–6 days depending on environmental conditions and start scraping the leaf surface for feeding in the early neonate stage. Larva has an inverted Y shaped mark on the front head and four spots arranged in a rectangular manner on the eighth abdominal segment dorsally. As the larva grows up it moves to the whorl and starts feeding by residing inside, where pellets can be witnessed on the damaged plants. They also attack the tassel, ears and start to feed on silk, kernels leaving a huge impact on the yield and quality of cobs produced.

Being an exotic alien pest and lack of proper natural enemies existing in nature during the early introduced year 2018, this pest has perpetuated in many folds and lead to socio-economic losses. Though Central Insecticide Board and Registration Committee recommend the use of Chlorantraniliprole 18.5 SC, Thiamethoxam 12.6% + Lambda-cyhalothrin 9.5% ZC, and Spinetoram 11.7 SC for FAW management, there a need to findout the other alternatives, new chemicals and methods which can reduce the incidence and damage of FAW (DPPQ'S 2019).

In an attempt to curtail these losses and reduce the FAW menace an experiment with different insecticides was formulated and conducted three years consecutively to identify the efficient chemical with field efficacy. The insecticides chosen for this study are having contact toxicity to pests and many of them are labeled products for Maize. The reason for selection of these treatments is that, some insecticides are effective against *Spodoptera* species in various crops, few are recommended against other major pest of Maize viz., stem borers, shoot fly and a bit are recommended by Central Insecticide Board and Registration Committee, India against fall armyworm. We hypothesized that on evaluation of these chemicals on the emerging invasion pest at different regions of Andhra Pradesh could arrive at a conclusion of effective insecticide that can be recommended to the farmers. This applied research is basically focused towards the gap filling in limitations towards management of exotic pest which caused huge losses in Maize crop to the southern states of India where the pest has impacted on the economic status of agriculture. In an effort to break the life cycle of pest in crop period and decline its multiplication, fast spreading nature across the state this research was formulated so that results and conclusion could provide the recommendations from state agriculture university.

Materials and Methods

The experiment was executed at Regional Agricultural Research Station, Nandyal, Acharya N G Ranga Agricultural University, Andhra Pradesh. This was executed from the 2018 *rab*i season to 2020 *rabi* continuously for three years and results were pooled and analyzed. The crop was sown during *rabi* season i.e. November month in each of the three years. Spacing followed was 45 X 20 cm (row to row and plant to plant). Eleven treatments along with one control were evaluated in the field against FAW. Three replications were maintained. Each replication plot size was 6 X 3 m^2. The crop was sown without any seed treatment. All other plant agronomy practices such as weeding, inter-cultivation, fertilizer application were adopted in the season to maintain healthy plants. A randomized block design with one-way Anova was followed for data analysis. Three graphical representations of per cent leaf damage, per cent cob damage and per cent leaf damage with respect to efficient insecticides observed over a period of three years (2018, 2019 and 2020) so as to study the drug resistance were represented.

Treatment imposition with insecticides was done with knapsack sprayer fitted with hollow cone nozzle. The duration between two treatments was 15 days of interval. Likewise three sprays were completed and care was taken that spray fluid was directed towards the whorl as the pest resides mainly inside the whorl. After twenty days of sowing (DAS) first spray was given which was followed by 2nd at 35 DAS and third at 50 DAS. Percent leaf damage data of pest was recorded one day before the spray and later at 7 and 14 days after treatment (DAT). In taking the observations of damaged leaves per plant, leaves with pin holes, window panes, leaves which were ragged and which were torn with frass are taken into count (Prasanna et al. 2018). Percent leaves damaged by fall armyworm and percent cobs damaged was calculated as per the equations Eqs. 1 and 2. Field scouting was done weekly so as to observe damage starting from seedling stage. Emerging leaves were seen clearly for damage as the larva mainly resides in whorl part damaging the early leaves and usually edge rows were avoided for sampling. At twenty days of crop growth stage, data on leaves with pin holes and cluster window panes were noted. At 35 days of crop, leaves with enlarged and scattered window panes along with whorl damage with frass were recorded. In 50 days of crop growth data on leaves with horizontal series of holes which were emerging out of damaged whorl with frass were noted. Each time fresh damage seen was recorded. The market available insecticides used for testing are given in Table 1.

$$\text{Percent leaf damage} = \frac{\text{Damaged leaves per plant}}{\text{Total number of leaves per plant}} \times 100 \quad (1)$$

$$\text{Percent cob damage} = \frac{\text{Damaged cobs per plot}}{\text{Total number of cobs per plot}} \times 100 \quad (2)$$

Results

Results reveal that all the treatments were significant in reducing the pest load compared to untreated control. At twenty days of crop growth, infestation by fall armyworm, *Spodoptera frugiperda* on the plants ranged from 78.20% to 92.60% in experimental plots (Table 2). Most of the leaves were damaged by larvae in all the plots (Fig. 1a).

Percent leaf damage

First spray

The first treatmental imposition was given at 20 days after sowing and leaf damage was recorded at one day before spray, later at 7 days and 14 days after treatment (DAT). At 7 DAT, numerically lowest leaf damage percent was (68.80%) recorded in T9-Poison bait (50 kg rice bran + 5 kg Jaggery + 500 g Thiodicarb 75 SP @ 50 kg/ha), T5-Novaluron 5.25 + Emamectin Benzoate 0.9% SC (65.4%), which was on par statistically with and T11- Profenophos 40 EC + Cypermethrin 4 EC (71.40%), T4- Novaluron 10 EC (72.23%), T7-Spinetoram 11.7 SC (72.50%), T1-Chlorantraniliprole 20 SC @ 200 ml/ha (73.73%) and T5- Novaluron 5.25 + Emmamectin benzoate 0.9% (73.83%). At 14 DAT, the significantly lowest leaf damage (55.65%) was recorded in the treatment T9- Poison bait @ 50 kg/ha (Table 2).

Second spray

The second spray was given fifteen days after the first spray i.e. at 35 days after sowing. At 7 DAT, the lowest leaf damage (47.87%) was recorded in, T9- Poison bait @ 50 kg/ha. At 14 DAT also the lowest leaf damage was recorded in T9- Poison bait (30.20) which was on par with T7-Spinetoram 11.7 SC (36.77%) and T6-Spinosad 45 SC (39.27%) (Table 2).

Third spray

The third spray was given at 50 DAS. The results at 7 DAT revealed that the lowest leaf damage was recorded (23.20%) in T9 i.e. poison bait (50 kg rice bran + 5 kg Jaggery + 500 g Thiodicarb 75 SP @ 50 kg/ha) and the treatments T6-Spinosad 45 SC (25.63%) and T7-Spinetoram 11.7 SC (26.73%) were on par with T9. At 14 days after the third spray also the treatment T9 (poison bait 20 kg rice bran + 2 kg Jaggery + 200 g Thiodicarb 75 SP @ 50 kg/ha) recorded the lowest leaf damage of16.33 percent, the treatments Spinosad 45 SC@ 175 ml/ha (20.90%) and Spinetoram 11.7 SC@ 250 ml/ha (21.43%) were on par with poison bait treatment (Table 2).The highest leaf damage of 93.4% was observed in the control plot.

Table 1 Insecticides evaluated against the fall armyworm in Maize crop

S. No	Treatment ID	Treatments	Dosage/ha	Company name
1	T1	Chlorantraniliprole 20 SC	200 ml	Dupont Private India Ltd
2	T2	Flubendiamide 480 SC	100 ml	Bayer crop Science Private Ltd
3	T3	Emamectin benzoate 5% SG	200 gm	Bayer crop Science Private Ltd
4	T4	Novaluron 10 EC	500 ml	Indofil Industries Ltd
5	T5	Novaluron 5.25 + Emamectin Benzoate 0.9% SC	1500 ml	ADAMA India Private Limited
6	T6	Spinosad 45 SC	175 ml	Dow Agro Science Private Ltd
7	T7	Spinetoram 11.7 SC	250 ml	Dow Agro Science Private Ltd
8	T8	Thiodicarb 75 SP	1050 g	Bayer crop Science Private Ltd
9	T9	Poison bait (50 kg rice bran + 5 kg Jagerry + 500 g Thiodicarb 75 SP)	50 kg	Bayer crop Science Private Ltd
10	T10	Carbofuran 3 G (Whorl appl)	10 kg	FMC Private Ltd
11	T11	Profenophos 40 EC + Cypermethrin 4 EC	1500 ml	ADAMA India Private Limited
12	T12	Control—Water spray		–

Table 2 Evaluation of various insecticides on percent leaf damage by fall armyworm *Spodoptera frugiperda* in Maize crop

Tr. ID	Treatments	Dose (g or ml/ ha)	Leaf damage (%) by FAW(Pre-treatment)	Leaf damage (%) by FAW (I spray)		Leaf damage (%) by FAW (II spray)		Leaf damage (%) by FAW (III spray)	
				7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT1
T1	Chlorantraniliprole 20 SC	200 ml	86.5(68.79)	73.73(59.8)>	64.62(54.07)	66.6(55.44)	51.13(45.68)	35.9(36.69)	29.43(32.8)
T2	Flubendiamide 480 SC	100 ml	78.2(62.46)	80.2(65.88)	66.62(54.97)	68.53(56.08)	60.5(51.1)	51.17(45.7)	47.17(43.39)
T3	Emamectin benzoate 5 % SG	200 gm	85.6(68.34)	79.9(64.26)	66.22(54.62)	69.67(57.11)	59(50.21)	50.17(45.13)	43.57(41.32)
T4	Novaluron 10 EC	500 ml	83.7(67.13)	72.23(58.57)	61.54(51.8)	64.27(53.87)	48.77(44.32)	34.03(35.65)	29.47(32.88)
T5	Novaluron 5.25 + Emamectin Benzoate 0.9 % SC	1500 ml	89.9(72.39)	73.83(60.49)	61.71(51.96)	65.83(55.33)	49.8(44.91)	37.2(37.52)	32.5(34.73)
T6	Spinosad 45 SC	175 ml	87.9(69.93)	75.73(61.77)	58.72(50.13)	60.33(51.91)	39.27(38.82)	25.63(30.4)	20.9(27.18)
T7	Spinetoram 11.7 SC	250 ml	86.7(68.88)	72.5(59.1)	56.42(48.86)	60.8(52.07)	36.77(37.34)	26.73(31.06)	21.43(27.56)
T8	Thiodicarb 75 SP	1050 g	82.7(65.88)	81.8(66.24)	68.27(55.9)	69.87(57.11)	60.47(51.1)	56.33(48.69)	60.8(51.28)
T9	Poison bait (Thiodicarb 75 SP)	50 kg	84.5(67.78)	68.8(56.73)	51.65(46.01)	57.87(50.16)	30.2(31.43)	23.2(28.7)	16.33(23.79)
T10	Carbofuran 3 G (Whorl appl)	10 kg	92.6(74.52)	87.13(69.61)	82.66(65.66)	88.17(70.15)	84.97(67.98)	82.57(65.53)	84.8(67.22)
T11	Profenophos 40 EC + Cypermethrin 4 EC	1500 ml	90(71.67)	71.4(58.2)	57.91(49.65)	71.03(58.36)	64(53.19)	57.67(49.46)	60.03(50.84)
T12	Control - Water spray		86.6(68.99)	89.3(71.01)	85.87(68.15)	93.17(76.3)	92.4(75.59)	95.43(79.99)	93.4(78.14)
	F test		NS	S	S	S	S	S	S
	SEm±		3.68	1.94	1.29	3.58	3.07	2.66	2.34
	CD (P=0.05)		NS	5.68	3.77	10.51	9.02	7.8	6.85
	CV(%)		9.26	5.35	4.1	10.73	10.8	10.34	9.5

*Figures in the parenthesis are arcsine transformed values

Fig. 1 **a** Damage by FAW in the experimental plots. **b** Larvae feeding on cobs in the control plot. **c** Whorl application of Thiodicarb in the whorls of the Maize plant

Drug resistance studies on per cent leaf damage

Results reveal that two treatments i.e. poison bait and Spinosad has not shown drug resistance during the three years. Whereas in case of Spinetoram in the third year of experimentation (2020) drug resistance was observed as the per cent leaf damage instead of declining, increased for the same dose of chemical which was applied in the initial two years (2018 and 2019) of study (Fig. 4).

Percent cob damage and Yield

This was recorded at the cob maturity stage and during threshing. Per cent cobs damage was low (8.5%) in the treatment T9 (poison bait: (50 kg rice bran + 5 kg Jaggery + 500 g Thiodicarb 75 SP @ 50 kg/ha) which was on par with Spinosad 45 SC@ 175 ml/ha (11.5%), and Spinetoram 11.7 SC@250 ml/ha (14.3%) (Table 3). The highest cob damage of 40.25% was observed in the control plot (Fig. 1b). Percent cob damage was represented graphically in Fig. 2. Regarding yield, a higher yield of 7344 kg/ha was recorded in the treatment "poison bait 50 kg rice bran + 5 kg Jaggery + 500 g thiodicarb 75 SP @ 50 kg/ha (Fig. 1c). The next best treatments which were on par were Spinosad 45 SC@ 175 ml/ha (6852 kg/ha) and Spinetoram 11.7 SC@250 ml/ha (6813 kg/ha) (Table 3).

In the tested 11 insecticides along with chemicals best result along with higher yield was noticed in plot treated with poison bait (application of thiodicarb in whorls) (Fig. 3), which was followed by Spinosad 45 SC and Spinetoram 11.7 SC.

Discussion

In the present study, all the insecticides tested were toxic to fall armyworm in bringing down the infestation and caused significant mortality over the control. There was significant

Table 3 Effect of insecticides on percent cob damage and yield in Maize crop

Tr. ID	Treatments	Dose (g or ml/ ha)	Per cent cob damage (%)	Yield (Kg/ha)
T1	Chlorantraniliprole 20 SC	200 ml	15.51	6498.79
T2	Flubendiamide 480 SC	100 ml	18.83	6243.75
T3	Emamectin benzoate 5% SG	200 gm	22.66	6304.19
T4	Novaluron 10 EC	500 ml	15.1	6472.38
T5	Novaluron 5.25 + Emamectin Benzoate 0.9% SC	1500 ml	19.01	6145.71
T6	Spinosad 45 SC	175 ml	11.57	6852.56
T7	Spinetoram 11.7 SC	250 ml	14.3	6813.34
T8	Thiodicarb 75 SP	1050 g	19.22	6141.45
T9	Poison bait (50 kg rice bran + 5 kg Jagerry + 500 g Thiodicarb 75 SP)	50 kg	8.567	7344.23
T10	Carbofuran 3 G (Whorl appl)	10 kg	30.45	5467.98
T11	Profenophos 40 EC +	1500 ml	22.4	6056.68
T12	Control—Water spray	–	40.25	3729.54
	SEm ±		2.18	205.78
	CD (P = 0.05)		6.41	603.54
	CV (%)		14.63	5.77

difference noticed among the various treatments, which was also graphically represented in per cent cob damage and yield of treated plots (Figs. 2 and 3).

Minimum damage to leaves and cobs along with higher yields was observed with thiodicarb, Spinosad 45 SC and Spinetoram 11.7 SC followed by Chlorantraniliprole 20 SC, Novaluron 10 EC and Flubendiamide 480 EC. The insecticides found effective against the fall armyworm are novel insecticides with variant mode of actions on the insect. Spinosad and Spinetoram are nicotinic acetylcholine receptor (nAChR), Chlorantraniliprole and Flubendiamide are ryanodine receptor modulators and Novaluron is a growth regulator inhibits the chitin biosynthesis. These chemicals with their unique mode of actions could delay the insect resistance, sustain for longer periods and effectively fits in integrated pest management modules.

In the present investigation thiodicarb bait has given a long protection against FAW with higher yields. The effectiveness of Thiodicarb against fall army worm and its contribution to increased yield of Maize was proven by Lunagariya et al. (2020) and Omprakash et al. (2020). Shinde et al., (2021) in their research concluded that along with entomopathogen fungui, *Nomuraea rileyi, Metarhizium anisopliae, Beauveria bassiana,* poison bait (Thiodicarb) and sand + lime was effective against fall army worm in maize crop.

The effectiveness of Spinosad, Spinetoram and Chlorantraniliprole against fall armyworm was observed in the study and was also proven by many scientists. Spinetoram when applied at 5 ml/kg, 2.5 ml/kg and Novaluron 5 ml/kg along with rice bran as the poison baits, they have effectively managed the FAW population and the damage on the crop (Dileep Kumar et al. 2020). Field efficacy studies, as well as laboratory leaf dip bioassay on FAW by Sharanabasappa et al. (2020), revealed that Emamectin benzoate 5 SG followed by Chlorantraniliprole18.5 SC, and Spinetoram 11.7 SC resulted in the highest acute toxicity against *Spodoptera frugiperda* in Maize. When eleven botanical extracts along with nine chemical insecticides were tested against FAW on Maize crop, in laboratory, greenhouse and field studies, 90 percent of mortality was observed within 72 h with the Spinosad 480 SC, Lambda Cyhalothrin 5 EC, Chlorantraniliprole 10% + Lambda cyhalothrin 5%) 150 SC and Spinetoram 120 EC. These insecticides being systemic in nature, their residual toxicity might have caused increased effect over a time period from the time of application (Birhanu et al. 2019). In America and Mexico, the application of synthetic pyrethroids as a part of FAW management is much followed (Andrews et al. 1988; Malo et al. 2004). In the experiments done by Dow Agro Sciences (DAS) Research Station at Santa Isabel, Puerto Rico during June 2010, Spinosad, Spinetoram, Thiodicarb and Acephate showed the significant highest 16-h mortality of FAW (Difabachew et al, 2012). In the diet incorporated bioassay studies for evaluation of LC_{50} values against FAW with four insecticides (Flubendiamide, Cyantraniliprole, Chlorantraniliprole, and Spinetoram) and five commercial chemicals (Lambda-cyhalothrin, Indoxacarb, Novaluron, Methoxy-Fenozide, and Spinosad), it was observed that LC_{50} values of Chlorantraniliprole and Spinetoram were less in comparison with the remaining products employed. In a study done

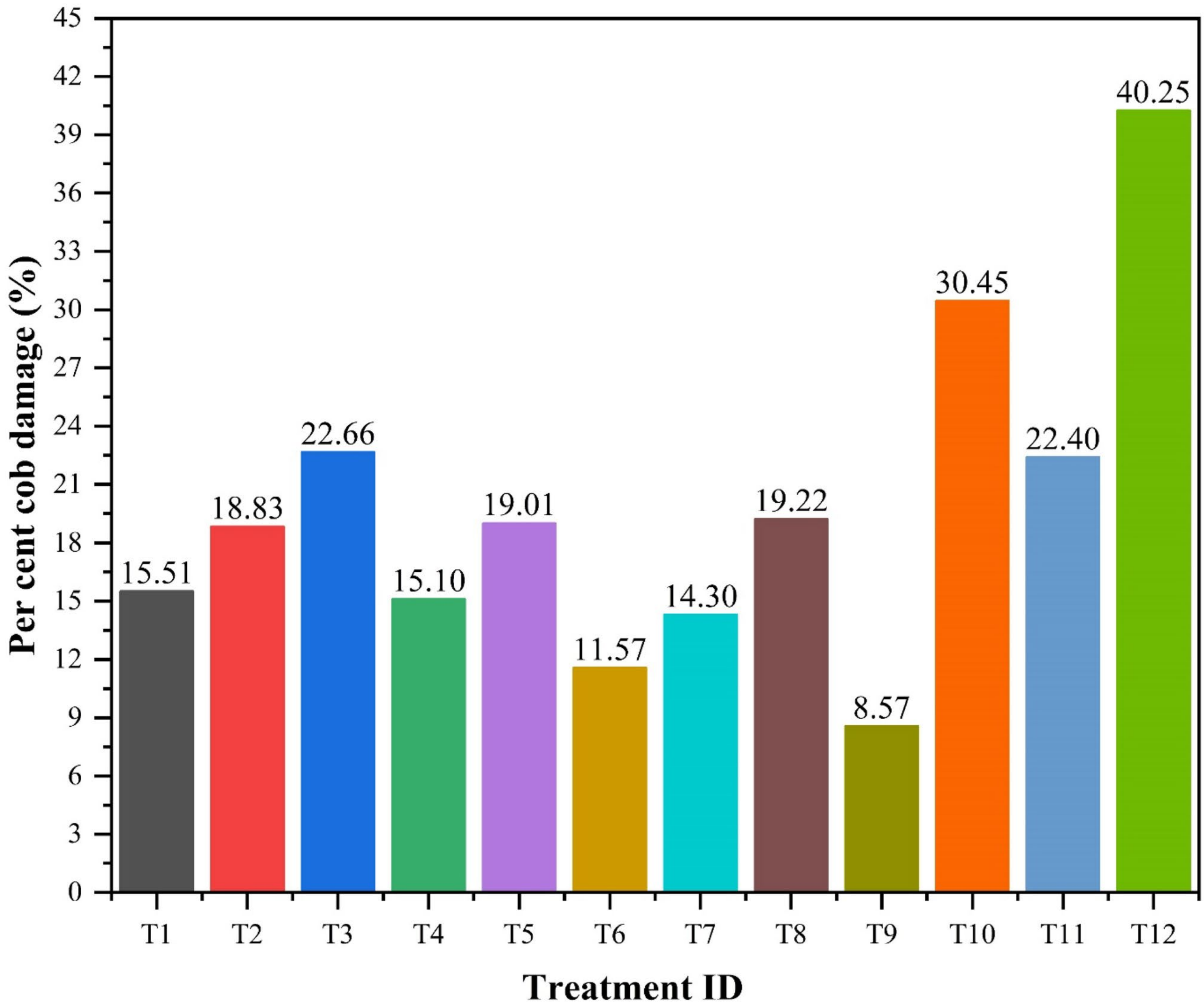

Fig. 2 Effect of the insecticides on the percent cob damage in Maize crop

by Daves et al. (2009), Spinosad has effectively reduced infestation up to 13 days after treatment. Muddasar et al. (2017) observed that when Spinosad was applied as a foliar spray has effectively controlled *Spodoptera litura* followed by poison bait with Spinosad on lettuce crop.

In the research of three years it was proved that Emamectin Benzoate 5 SG alone as well as Novaluron 5.25 + Emamectin Benzoate 0.9% SC combination product has recorded lower damage of FAW. This was also noticed in the study done by Sreedhar (2018) to test the efficacy of Novaluron 5.25 + Emamectin Benzoate 0.9% SC mixed product in comparison with individual chemicals Novaluron 10 EC and Emamectin Benzoate 5 SG against *Spodoptera litura* in tobacco. The results proved that Emamectin Benzoate 5 SG alone has recorded lowest damage of seedlings followed by combination product i.e. Novaluron 5.25 + Emamectin Benzoate 0.9% SC.

Though many chemicals are highly effective in managing the lepidopteran pests, but FAW larva's peculiar behavior of burrowing deep the whorls and causing infestation has been an important constraint for controlling pest control in the initial time of pest invasion in the country. Application at a crucial time with whorl directed spray fluid has given better results in the research.

Conclusion

This investigation revealed that, following proper agronomy practices, along with usage of chemicals at right time with a different mode of action and varied chemistry alternatively during the crop period will bring down the FAW infestation and yield good results. As the pest mainly stays in the whorl part in later stages of the life cycle till the cob formation,

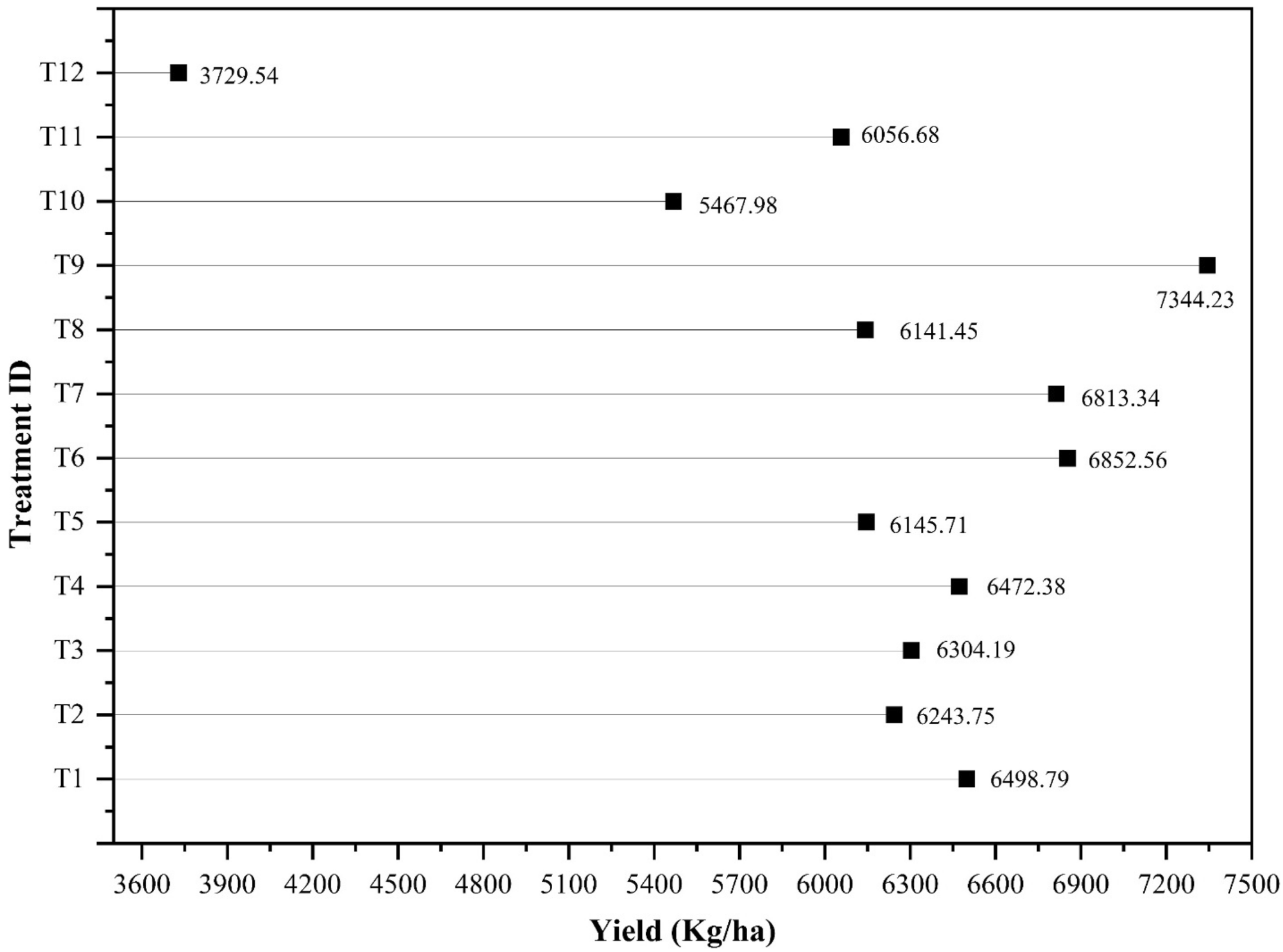

Fig. 3 Effect of the insecticides on the yield levels in Maize crop

Thiodicarb poison bait application in the whorls might have given fruitful results in reducing the pest load and its losses in crop. Spinosad 45 SC and Spinetoram 11.7 SC are very much advisable to farmers and also safe to natural enemies with a less adverse effect on the environment and ecofriendly in nature. Integrated pest management practices and biological control trials of FAW are also in progress in Andhra Pradesh state of India, so as to formulate efficient package of practices for Maize crop. In a bid to avoid chemical resistance problems alternate pest mitigation eco-friendly options are also much needed in future strategy of research.

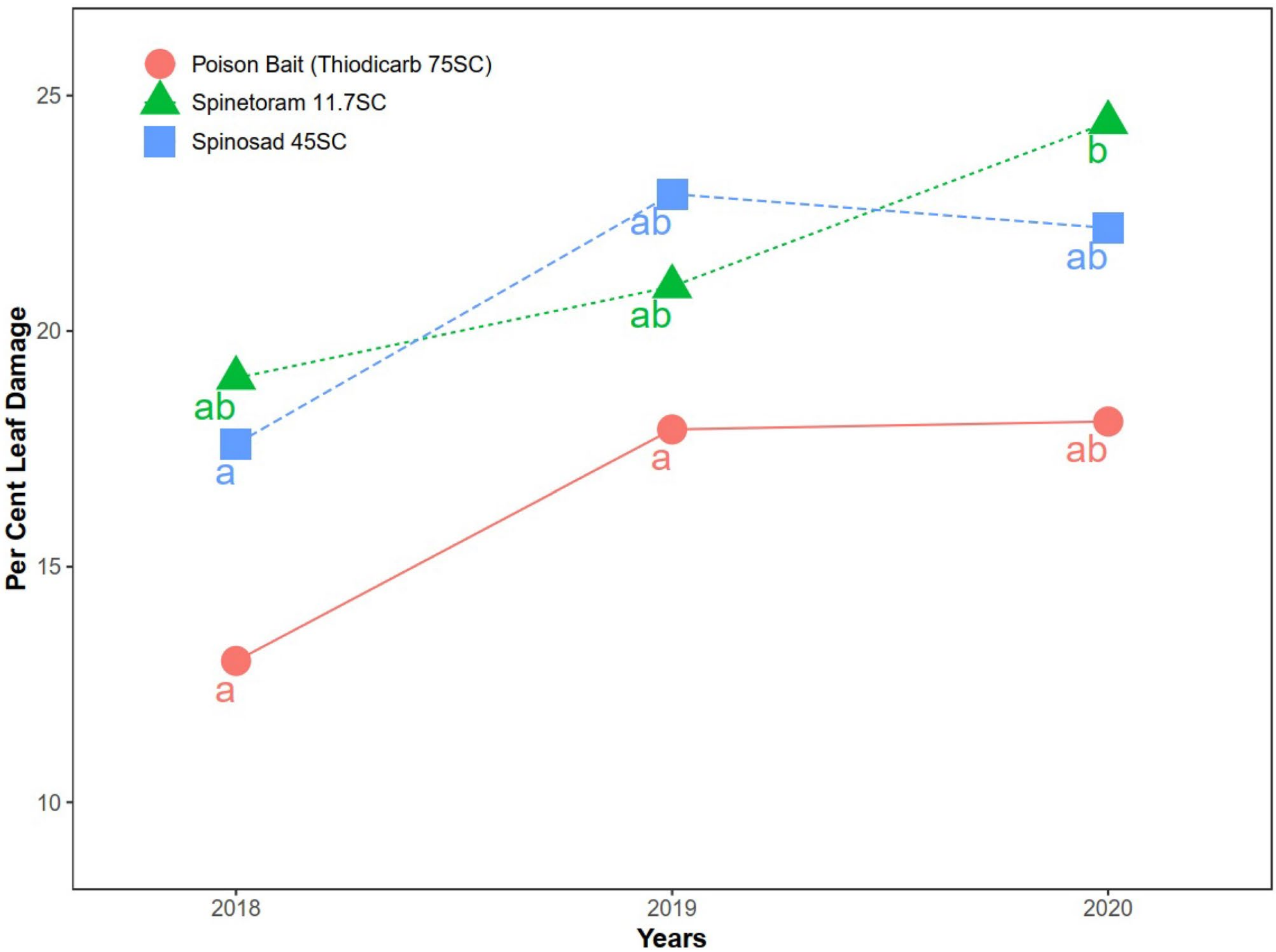

Fig. 4 Efficacy of best insecticides on per cent leaf damage in the three years of experimentation

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Code availability Not applicable.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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