

RESEARCH ARTICLE

Exploring Newer Molecules With Novel Modes of Action For The Management of The Invasive Maize Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith)

T. Srinivasan^{1*}, P.S. Shanmugam¹, V. Baskaran¹, B. Vinothkumar², A. Suganthi¹, T. Elaiyabharathi¹, P. Lakshmi Soujanya³, S. Bagyaraj¹, V. Somasundaram¹, S. Sivakumar⁴, J.C. Sekar³, R. Ravikesavan⁵

¹Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore - 641 003, Tamil Nadu, India

²ICAR - Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Wood House Farm, Dodabetta, Ooty - 643002, Tamil Nadu, India

³ICAR- Indian Institute of Maize Research, Winter Nursery Centre, Rajendranagar, Hyderabad - 500 030, Telangana, India

⁴Department of Millets, Tamil Nadu Agricultural University, Coimbatore - 641 003, Tamil Nadu, India

⁵Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore - 641 003, India

ABSTRACT

Maize is affected by more than 30 insect pests and the recent attack by the invasive fall armyworm *Spodoptera frugiperda* has been a serious concern to maize growers all over the country. Being polyphagous with a wider host range, the pest necessitates the use of insecticides in the hitherto unsprayed maize ecosystems of the country. Evaluation of newer insecticides against fall armyworm revealed that, the combination insecticide, chlorantraniliprole 9.3% + lambda cyhalothrin 4.6%ZC registered lesser infestation after first round of spraying. However after two rounds of spraying, emamectin benzoate 5%SG, spinetoram 11.7%SC, chlorantraniliprole 18.5%SC, flubendiamide 480%SC and chlorantraniliprole 9.3% + lambda cyhalothrin 4.6%ZC were on par in their efficacy in reducing the fall armyworm infestation, though emamectin benzoate and flubendiamide treated plots registered comparatively higher yields. With respect to B:C ratio, emamectin benzoate and chlorantraniliprole 18.5%SC registered comparatively higher BC ratio followed by flubendiamide 480%SC, spinetoram 11.7%SC and chlorantraniliprole 9.3% + lambda cyhalothrin 4.6% ZC. Thus the above insecticides can be used in maize ecosystems to effectively tackle the fall armyworm menace.

Received: 11 Aug 2024

Revised: 22 Aug 2024

Accepted: 13 Sep 2024

Keywords: Maize; Fall Armyworm; *Spodoptera frugiperda*; New Insecticides; Evaluation

INTRODUCTION

Maize (*Zea mays* L.), the “Queen of cereals” is a staple crop in India, grown in an area of 8.8 million ha with a production of 22.5 million tonnes per year (Sharanabasappa *et al.* 2020). The crop is cultivated in an area of 3.55 lakh ha in the state with an annual production of 25.3 lakh tonnes and productivity of 7.1 tonnes/ha (INDIASTAT, 2021). The crop is affected by more than 30 insect pests in field as well as storage (Mathur, 1992) and with the recent introduction of the invasive fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) there is a growing concern among maize growers of the country (Lackisha

Navin *et al.*, 2021). It was recorded as a polyphagous invasive pest in Africa during 2016 (Goergen *et al.*, 2016) which expanded to show its presence in Asia, in 2018. The pest was first observed in Shivamogga, Karnataka during May, 2018 and in quick succession in different parts of the country viz., Tamil Nadu, Andhra Pradesh, Telangana, Maharashtra, Madhya Pradesh, Odisha, Bihar, West Bengal, Gujarat, Chhatisgarh and Kerala at alarming levels in farmer's field (IIMR-2020). The fall armyworm is having a wider host range

of more than 353 hosts causing widespread threat in the Americas (Montezano *et al.* 2018). Yield losses in maize due to fall armyworm infestation goes up to 32% in the United States (Wiseman and Isenhour, 1993) and 45-60% in Nicaragua (Hruska and Glandstone, 1988).

The infestation by maize starts at a very early stage viz., 14-21 days causing extensive defoliation in maize whorls, besides feeding upon tassels and cobs at later stages of the crop (Lamsal *et al.* 2020). The first three instars cause damage by scrapping, while late instar larval stages tend to reside and feed inside the central whorls or funnel leaves (Tefera *et al.* 2019) causing severe injury to the whorls. The central whorl is often filled with moist frass and excreta, and the developing larvae plug the whorl region with frass and feeds inside in a protective environment leading to control failures occasionally (Nidhi *et al.*, 2019). An attempt was made to evaluate newer molecules with differential mode of action for effectively tackling the invasive pest and to integrate the same in the IPM programmes.

Emamectin benzoate belongs to the avermectin family, derived as a natural fermentation product from the soil microorganism, *Streptomyces avermitilis* (Stavarakaki, 2022). It is a broad-spectrum, macrocyclic lactone insecticide effective against agricultural and forestry pests and possess less toxic effects to predators, parasitoids and honeybees) (Jansson *et al.* 1996). It is a chloride channel activator, stimulates the γ -aminobutyric acid receptor (GABA-R) and glutamate-gated chloride channels (GluCl_s), resulting in increased membrane chloride ion permeability and disrupts nerve signals in target insect pests (Wu *et al.* 2016). Spinetoram, is a biological product derived from the soil actinomycete, *Saccharopolyspora polyspinosa*. the insecticide affects nicotinic acetyl choline receptors and gamma-amino butyric acid receptors in the post synaptic membranes. It has a broad spectrum insecticidal activity and widely used for the management of lepidopteran pests (Zhang *et al.* 2018). Chlorantraniliprole was the first commercialised diamide belonging to the anthranilic diamide group and has been proved effective against a range of lepidopteran insect pests (Satpathy *et al.* 2020). The insecticide activates ryanodine receptors by stimulating calcium release from muscle cells causing impaired regulation, paralysis and death of the target insect species (William *et al.* 2020). Flubendiamide belongs to the phthalic acid diamide and has been proven effective against a wide range

of lepidopterans including *Helicoverpa*, *Spodoptera*, etc. Flubendiamide stimulates calcium pump activity leading to a decreased internal calcium concentration (Masaki *et al.* 2006). This results in disruption of muscle function, leading to cessation of feeding paralysis, regurgitation and ultimate death of the insect. Chlorantraniliprole + lambda cyhalothrin has a dual mode of action against lepidopteran pests and is available as a ready mix formulation (Osae *et al.* 2022). Lufenuron belongs to the the class of benzoxylurea and acts as chitin synthesis inhibitors to a wide range of insects, leading to abnormal moulting from neonate to adult stages. It is widely used against several army worm species belonging to Lepidoptera (Gelbic *et al.* 2011). The present investigations were carried out to compare the efficacy of novel insecticides against maize fall armyworm.

MATERIAL AND METHODS

An experiment with eight treatments and three replications was taken up in the Department of Millets, Tamil Nadu Agricultural University, Coimbatore during two seasons viz., *kharif*, 2021 and *kharif*, 2022. The maize hybrid, Co(H)M 8 was planted at a recommended spacing of 75 x 20 cm. Plots of 4.5 x 3.0 m size were laid out for imposing different treatments. The insecticidal treatments were imposed, using a battery operated knapsack sprayer using 500 lit spray fluid per hectare, preferably during early morning hours when the wind speed was considerably low. Observations on fall armyworm infestation was recorded by randomly sampling 20 plants per plot and the individual plants were scored on 1-9 scale of Davis and Williams (1992). The per cent infestation was worked out based on the number of plants showing fresh whorl infestation

$$\text{Per cent infestation} = \frac{\text{No. of plants showing fresh infestation}}{20} \times 100$$

Two rounds of spraying were imposed in the trial plots; the first when the Davis score in all the treatments exceeded 4.0 and the second spraying fifteen days later. Observations on per cent infestation and score have been recorded just prior to spraying and at 10 days after each spraying. The 1-9 Davis and Williams Scale (1992) followed for recording scores is furnished in Table 1. Besides recording whorl injury, the cob injury was also recorded at the time of harvest following a similar 1-9 scale of ear and kernel

Table 1. Whorl leaf feeding rating scale for FAW by Davis et al., (1992)

Rating Scale	1-9 scale description
1	No damage or few pinholes
2	Few short holes (also known as shot holes) on several leaves
3	Shot holes on several leaves
4	Several leaves with shot holes and a few long lesions
5	Several holes with long lesions
6	Several leaves with lesions < 2.5 cm
7	Long lesions common on one half of the leaves
8	Long lesions common on one half to two thirds of leaves
9	Most leaves with long lesions

Table 2. Ear and kernel damage rating scale by Williams et al. (2006)

Rating Scale	1-9 scale description
1	No damage to any ears
2	Tip (<30 mm) damage to 1-3 ears
3	Tip damage to 4-6 ears
4	Tip damage to 7 or more ears and damage below ear tips to 1-3 kernels of 1-3 ears
5	Tip damage to 7 or more ears and damage to 1-3 kernels below tips of 4-6 ears
6	Ear tip damage to 7-10 ears and damage to 1-4 kernels below tips of 7-10 ears
7	Ear tip damage to 7-10 ears and 4-6 kernels destroyed on 4-6 ears
8	Ear tip damage to all ears and 4-6 kernels below tips destroyed on 7-8 ears
9	Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9-10 ears

damage rating (Table 2) proposed by Williams et al. (2006). At the time of harvest, the individual plot yield was recorded and extrapolated to grain yield per ha. Based on the current price of the insecticides used for the experiment the Benefit: Cost (BC) ratio was also worked out. The data on per cent damage and FAW score were subjected to appropriate transformations and analysed through one way ANOVA.

RESULTS AND DISCUSSION

The pretreatment infestation ranged between 66.7 and 71.7 per cent in different treatments. The pooled mean of two years revealed that after the first round of spraying, the least infestation was recorded in plots treated with chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC (16.7%) followed by flubendiamide 480% SC (20.0%) and spinetoram 11.7% SC (20.0%) as against 86.7 per cent in control plots (Table 3). The score also reflected a similar trend with chlorantraniliprole 9.3% + lambda cyhalothrin 4.6% ZC registering the least score (1.4) followed by flubendiamide (1.5) and spinetoram (1.5) as against 5.8 in control plots. After second round of spraying too, chlorantraniliprole 9.3% + lambda

cyhalothrin 4.6% ZC exhibited the least infestation (10.0%) with a score of 1.4 and was on par with emamectin benzoate (10.0% infestation; 1.2 score). Chlorantraniliprole-lambda-cyhalothrin combination was found more effective than emamectin benzoate in reducing the infestation by the tomato pinworm, *Tuta absoluta* (Fanigliulo, 2012). It should be noted that, the combination product, chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC was found to be toxic to the egg parasitoid, *Telenomus podisi*, an effective one against the soybean pentatomid, *Euschistus heros* (Fabricius), wherein the insecticide chlorantraniliprole was less toxic to the aforesaid parasitoid (Silva et al. 2018). Chlorantraniliprole + Lambda cyhalothrin has been found to significantly reduce the population of fall armyworm at 200-240 ml/ha recommendation (Osae et al. 2022). The combination insecticide has also been proved effective against the brinjal fruit and shoot borer, *Leucinodes orbonalis* (Sen et al. 2017) under field conditions and the tomato pin worm, *Tuta absoluta* under laboratory conditions (Braham et al. 2017). Emamectin benzoate 5% SG,

Table 3. Evaluation of newer molecules for the management of maize fall armyworm (Pooled mean of two years viz., kharif 2021 &kharif 2022)

Treatments	Dose (g or ml/lit)	Pre-treatment count		10 DAS I Spray		10 DAS II Spray		Cob damage		Plot yield (kg/ha)	BC ratio*
		% infestation #	Score \$	% infestation #	Score \$	% infestation #	Score \$	% infestation #	Score \$		
Chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC	0.5	71.7 (57.9)	4.0 (2.1)	16.7a (24.1)	1.4a (1.4)	18.3bc (18.4)	1.4a (1.4)	45.0c (42.1)	2.3bc (1.7)	5563b	2.09
Novaluron 5.25% + Emamectin benzoate 0.9% SC	2.0	68.3 (55.7)	4.1 (2.1)	21.7ab (27.8)	1.7b (1.5)	25.0c (30.0)	2.1b (1.6)	35.0ab (36.3)	2.0ab (1.6)	5289c	2.01
Emamectin benzoate 5% SG	0.4	71.7 (57.9)	3.8 (2.1)	25.0bc (30.0)	1.7b (1.5)	10.0a (18.4)	1.2a (1.3)	40.0bc (39.2)	2.0ab (1.6)	5880a	2.31
Spinetoram 11.7%SC	0.5	68.3 (55.7)	4.2 (2.2)	20.0ab (26.6)	1.5ab (1.4)	11.7ab (20.0)	1.2a (1.3)	35.0ab (36.3)	2.0ab (1.6)	5542b	2.09
Chlorantraniliprole 18.5%SC	0.4	66.7 (54.8)	4.0 (2.1)	31.7c (34.3)	2.0c (1.6)	15.0ab (22.8)	1.3a (1.3)	30.0a (33.2)	1.8a (1.5)	5658b	2.16
Flubendiamide 480%SC	0.3	70.0 (56.8)	3.9 (2.1)	20.0ab (26.6)	1.5ab (1.4)	15.0ab (22.8)	1.4a (1.4)	30.0a (33.2)	1.8a (1.5)	5855a	2.10
Lufenuron	0.6	68.3 (55.7)	4.2 (2.2)	45.0d (42.1)	2.4d (1.7)	45.0d (42.1)	4.4c (2.2)	61.7d (51.8)	2.8c (1.8)	4862d	1.91
Untreated control	--	70.0 (56.8)	4.3 (2.2)	86.7e (68.6)	5.8e (2.5)	78.3e (62.2)	5.4d (2.4)	53.3d (46.9)	2.7c (1.8)	3989e	1.55
SEd		-	-	2.30	0.04	3.04	0.06	2.12	0.08	--	--
CD (p< 0.05)		NS	NS	4.94	0.08	6.52	0.14	4.56	0.17	--	--

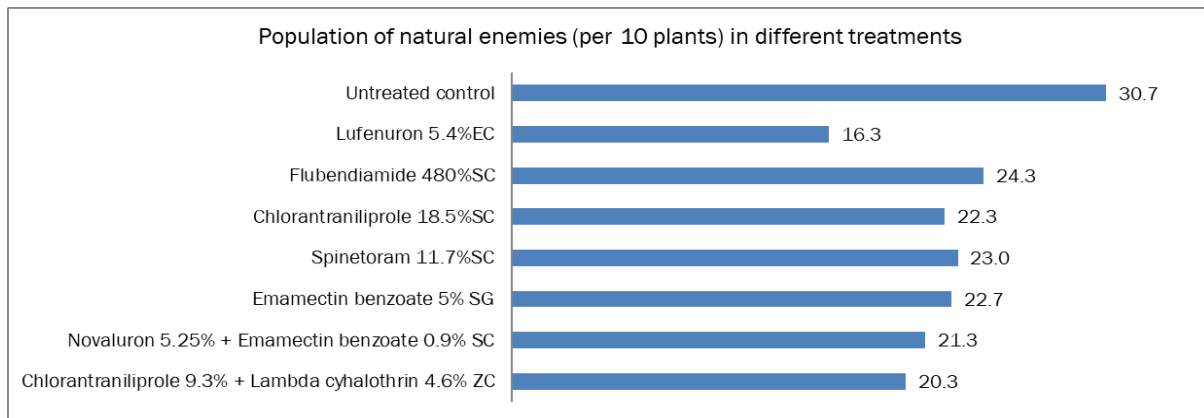
#Values in paranthesis are arcsine transformed values

\$ Values in paranthesis are square root transformed values

*Cost of maize grains fixed at Rs. 2400/quintal to work out B:C ratio

Values in a column followed by a common letter are not significantly different by LSD (P<0.05)

Fig 1. Population of natural enemies in different treatments (Pooled mean of two years viz., kharif 2021 & kharif 2022)



spinetoram 11.7%SC, chlorantraniliprole 18.5%SC and flubendiamide 480%SC registered fall army worm infestation in the range of 10.0 to 15.0 per cent while the scores were also on par with each other (1.2 – 1.4) in all these treatments with the control exhibiting 78.3 per cent infestation and a score of 5.4. The efficacy of chlorantraniliprole, emamectin benzoate, spinetoram and flubendiamide were proved by Deshmukh *et al.* (2020) in both laboratory bioassay and field evaluation studies under Indian conditions. Chlorantraniliprole was one of the insecticides that resulted in more than 40 per cent mortality of larval population at 28 days after treatment in studies conducted by Hardke *et al.* (2011). Mian *et al.* (2022) observed the efficacy of chlorantraniliprole and emamectin benzoate in terms of reduction in larval population which was the reason behind reduced levels of infestation in the aforesaid treatments in trials conducted at Pakistan. Emamectin benzoate 5%SG possess selective efficacy against lepidopteran pests due to its contact action and translaminar activity (Fanigliulo and Sacchetti, 2008). Emamectin benzoate has also been proved effective against *Helicoverpa armigera* in tomato (Fanigliulo and Sacchetti, 2008), diamond back moth infesting cabbage (Zhao *et al.* 2006), cotton boll worm (Ahmad *et al.*, 2019), etc. Out of the seven insecticides evaluated against maize fall armyworm under laboratory conditions, spinetoram exhibited poor performance when compared to broflanilide and abamectin (Idrees *et al.* 2022). With respect to cob infestation, all the treatments except lufenuron exhibited a significant reduction (30.0 – 45.0 %) while lufenuron exhibited a cob infestation of 53.3 per cent as against 61.7 per cent in untreated control. However, the cob infestation score did not exceed 2.7 in all the

treatments while the control registered a cob score of 2.8. The maximum yield was recorded in emamectin benzoate 5%SG and flubendiamide 480%SC treated plots (5880 kg/ha and 5855 kg/ha, respectively). This was followed by spinetoram 11.7%SC and chlorantraniliprole 18.5%SC treated plots wherein the yields were 5542 kg/ha and 5658 kg/ha, respectively as against 3989 kg/ha in the untreated control. Vinothkumar *et al.* (2023) observed that, spinetoram registered significantly higher yields followed by chlorantraniliprole while registering lesser larval population and minimum levels of infestation. The Central Insecticide Board and Registration Committee also recommends the use of chlorantraniliprole 18.5 SC, emamectin benzoate 5%SG, spinetoram 11.7 SC, combination insecticides such as novaluron 5.25 % + emamectin benzoate 0.9 % SC for fall armyworm management (DPPQS, 2023).

The Benefit: Cost ratio (B:C) was worked out based on the yield obtained in different treatments keeping the cost of maize grains @ Rs. 2400/quintal. It was observed that, the maximum BC ratio was realised with emamectin benzoate 5%SG (2.31) followed by chlorantraniliprole 18.5%SC (2.16), flubendiamide 480%SC (2.10) and spinetoram 11.7%SC (2.09) in that order while the untreated control registered a BC ratio of 1.55.

CONCLUSION

Evaluation of newer insecticides against fall armyworm revealed that, chlorantraniliprole 9.3% + lambda cyhalothrin 4.6% ZC registered lesser infestation after first round of spraying.



Emamectin benzoate 5%SG, Spinetoram 11.7%SC, Chlorantraniliprole 18.5%SC, Flubendiamide 480%SC and Chlorantraniliprole 9.3% + Lambda cyhalothrin 4.6% ZC were on par in their efficacy in reducing the fall armyworm infestation after second round of spraying, though emamectin benzoate and flubendiamide treated plots registered comparatively higher yields. With respect to B:C ratio, emamectin benzoate and chlorantraniliprole 18.5%SC registered comparatively higher BC ratio. Thus, the above insecticides at the recommended doses can be used in maize ecosystems to effectively tackle the fall armyworm menace.

Funding and Acknowledgment

The authors acknowledge the facilitation provided through All India Coordinated Research Project on Maize.

Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

The authors assure that the contents are written by us and were not plagiarised.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required. If

anything is required from the MS, certainly, this will be extended by communicating with the corresponding

author through corresponding official mail

Author Contributions

Research grant - US

Idea conceptualization – TS, PLS, JCS

Experiments – TS, PSS, BV, AS, TE, SB, VS

Guidance – JCS, SS, RR

Writing-original draft - TS, PSS

Writing- reviewing & editing – TS, PSS, TE

REFERENCES

Ahmad, M., Rasool, B., Ahmad, M. and Russell, D.A. 2019. Resistance and Synergism of Novel Insecticides in Field Populations of Cotton

Bollworm *Helicoverpa armigera* (Lepidoptera: Noctuidae). Pakistan. *J. Econ. Entomol.*, **112(2)**: 859-871.

Braham, M., Glida-Gnidez, H. and Hajji, L. 2012. Management of the tomato borer, *Tuta absoluta* in Tunisia with novel insecticides and plant extracts. *EPPO Bull.* (doi.org/10.1111/epp.2572).

Davis, F. and Williams, W. 1992. Visual rating scales for screening whorl stage corn for resistance to fall armyworm. (Technical Bulletin No. 186). Mississippi State University, MS39762, USA.

Deshmukh, S., Pavithra, H.B., Kaleshwaraswamy, C.M., Shivanna, B.K., Maruthi, M.S. and David, M. 2020. Field Efficacy of Insecticides for Management of Invasive Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on Maize in India. *Fla. Ent.*, **103(2)**: 221-227.

Dileep Kumar, N.T. and Murali Mohan, K. 2020. Bio-efficacy of selected insecticides against fallarmyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera), in maize. *J. Entomol. Zool. Studies*, **8(4)**: 1257-1261.

Fanigliulo, A. and Sacchetti, M. 2008. Emamectin benzoate: new insecticide against *Helicoverpa armigera*. *Commun. Agric. Appl. Biol. Sci.*, **73(3)**: 651-653.

Fanigliulo, A., Mancino, O., Fanti, P. and Crescenzi, A. 2012. Chlorantraniliprole/lambda-cyhalothrin, a new insecticide mixture to control *Tuta absoluta* and *Spodoptera littoralis* in tomato. *Commun. Agric. Appl. Biol. Sci.*, **77(4)**: 677-84.

Gelbic, I., Adel, M.M. and Hussein, H.M. 2011. Effects of nonsteroidal ecdysone agonist RH-5992 and chitin biosynthesis inhibitor lufenuron on *Spodoptera littoralis* (Boisduval, 1833). *Cent. Eur. J. Biol.*, **6**: 861– 869. (doi: 10.2478/s11535-011-0046-4).

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A. and Tamo, M. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PLoS One*, **11(10)**: e0165632.

Hardke, J.T., Temple, J.H., Leonard, B.R. and Jackson, R.E. 2011. Laboratory toxicity and field efficacy of selected insecticides against fall armyworm (Lepidoptera: Noctuidae). *Fla. Ent.*, **94(2)**: 272-278.



- Hruska, A.J. and Gladston, S.M. 1988. Effect of period and level of infestation of the fall armyworm, *Spodoptera frugiperda*, on irrigated maize yield. *Fla. Ent.*, **71**: 249-54.
- Idrees, A., Qadir, Z.A., Afzal, A., Ranran, Q. and Li, J. 2022. Laboratory efficacy of selected synthetic insecticides against second instar invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. *PLoS One*, **17(5)**: e0265265.
- IIMR. 2020. <https://www.milletres.in/>. (Accessed on 20 June 2023)
- INDIASTAT. 2021. <https://www.indiastat.com/>. (Accessed on 13 June 2023).
- Jansson, R.K., Brown, R., Cartwright, B., Cox, D., Dunbar, D.M. and Dybas, R.A. 1996. Emamectin benzoate: A novel avermectin derivative for control of lepidopterous pests. In Proceedings of the 3rd International Workshop on Management of Diamondback Moth and Other Crucifer Pests, Kuala Lumpur, Malaysia, 29 October–1 November 1996; Vegetable Pest Management. Malaysian Agricultural Research and Development Institute: Selangor, Malaysia, 1997; pp. 1–7.
- Lackisha Navin, A., Saminathan, V. and Sheeba Joyce Roseleen, S. 2021. Host plant resistance in maize hybrids to fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (JE Smith). *J. Entomol. Zool. Studies*, **8(4)**: 580-587.
- Lamsal, S., Sibi, S. and Yadav, S. 2020. Fall Armyworm in South Asia: Threats and Management. *Asian J. Adv. Agric. Res.*, 21-34.
- Masaki, T., Yasokawa, N., Tohnishi, M., Nishimatsu, T., Tsubata, K., Inoue, K. and Hirooka, T. 2006. Fubendiamide, a novel Ca²⁺ channel modulator reveals evidence for functional cooperation between Ca²⁺ pumps and Ca²⁺ release. *Mol. Pharmacol.*, **69**: 1733-1739.
- Mathur, L.M.L. 1992. Insect pest management and its future in Indian maize programme. Proceedings of the XI International Congress of Entomology, June 21 to July 4, 1992, Beijing, China.
- Mian, F.M., Khan, I., Ullah, N., Gondal, A.H., Ajmal, M.S., Qureshi, M.S., Ihsan, A., Raziq, M., Qazi, I. and Jabbar, A. 2022. Efficacy of Insecticides against Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera, Noctuidae) in Maize. *J. Biores. Mgt.*, **9 (2)**:
- Montezano, D.G., Specht, A., Sosa-Gomez, D.R., Roque-Specht, V.F., Sousa-Silva, J.C. and Paula-Moraes, S.V. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera:Noctuidae) in the Americas. Bio-efficacy of selected insecticides against fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera), in maize. *African Ent.*, **26(2)**: 286-300.
- Nidhi, K., Joshi, M., Pandey, R. and Anand, K. 2019. Fall army worm: An invasive pest in India and its management. *J. Entomol. Zool. Studies*, **7(5)**: 1034-1037.
- Osae, M.Y., Frimpong, J.O., Sintin, J.O., Offei, B.K., Marri, D. and Ofori, S.E.K. 2022. Evaluation of different rates of Ampligo insecticide against fall armyworm, *Spodoptera frugiperda* (J.E. Smith); Lepidoptera: Noctuidae in the coastal Savannah agroecological zone of Ghana, *Advances in Agriculture*. (doi.org/10.1155/2022/5059865).
- Satpathy, S. and Gotyal, B.S. and Babu, V.R. 2020. Role of novel insecticides in crop protection and their selectivity to natural enemies: a review. *J. Environ. Biol.*, **41**: 149-160.
- Sen, K., Samanta, A., Alam, S.K.F., Dhar, P.P. and Samanta, A. 2017. Field evaluation of a new ready mix formulation Ampligo 150 ZC (chlorantraniliprole 9.3% + lambda cyhalothrin 4.6% ZC) against shoot and fruit borer (*Leucinodes orbonalis* Guen.) infestation in brinjal. *J. Pharmacog. Phytochem.*, **6(5)**: 1674-1678.
- Silva, G.V., Bueno, A.F., Favetti, B.M. and Neves, P.M.O.J. 2018. Selectivity of chlorantraniliprole and lambda-cyhalothrin to the egg parasitoid *Telenomus podisi* (Hymenoptera: Platygasteridae). *Cien. Agr.*, **39(2)**: 549-563.
- Stavarakaki, M., Ilias, A., Ioannidis, P., Vontas, J. and Roditakis, E. 2022. Investigating mechanisms associated with emamectin benzoate resistance in the tomato borer *Tuta absoluta* *J. Pest Sci.*, **95**: 1163–1177.
- Tefera, T., Gofishu, M., Ba, M. and Muniappan, R. 2019. A Guide to Biological Control of Fall Armyworm in Africa Using Egg Parasitoids. First Edition, Nairobi, Kenya. 108p.
- Vinothkumar B., Arulkumar, G., Srinivasan, T., Shanmugam, P.S., Baskaran, V., Suganthi, A., Jeyarani, S., Krishnamoorthy, S.V., Muthukrishnan, M. and N. Sathiah 2023. Acute

- and Persistent Toxicity of Newer Insecticide Molecules Against Invasive Pest of Maize, Fall Armyworm *Spodoptera frugiperda* (J.E.Smith). *Madras Agric. J.*, **110 (1-3)**: 92-102. <https://doi.org/10.29321/MAJ.10.000752>
- Williams, J.R., Swale, D.R. and Anderson, T.D. 2020. Comparative effects of technical grade and formulated chlorantraniliprole to the survivorship and locomotor activity of the honey bee, *Apis mellifera* (L.). *Pest Mgt. Sci.*, **76**: 2582-88.
- Williams, W.P., Buckley, P.M. and Daves, C.A. 2006. Identifying resistance in corn to southwestern corn borer (Lepidoptera: Crambidae), fall armyworm (Lepidoptera: Noctuidae), and corn earworm (Lepidoptera: Noctuidae). *J. Agric. Urban Entomol.*, **23(2)**: 87-95.
- Wiseman, B.R. and Isenhour, D.J. 1993. Response of four commercial corn hybrids to infestations of fall armyworm and corn earworm (Lepidoptera: Noctuidae). *Fla. Ent.*, **76**: 283-292.
- Wu, X., Zhang, L., Yang, C., Zong, M., Huang, Q. and Tao, L. 2016. Detection on emamectin benzoate-induced apoptosis and DNA damage in *Spodoptera frugiperda* Sf-9 cell line. *Pestic. Biochem. Physiol.*, **126**: 6–12.
- Zhang, K., Li, J., Liu, H., Wanf, H. and Lamusi, A. 2018. Semisynthesis and insecticidal activity of spinetoram, J and its D-forosamine replacement analogues. *Bielstein J. Org. Chem.*, **14**: 2321-30.
- Zhao, J.Z., Collins, H.L., Li, Y.X.,Mau, R.F., Thompson, G.D., Hertlein, M., Andalaro, J.T., Boykin, R. and Shelton, A.M. 2006. Monitoring of diamondback moth (Lepidoptera: Plutellidae) resistance to spinosad, indoxacarb, and emamectin benzoate. *J. Econ. Entomol.*, **99(1)**: 176-181.