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RESEARCH ARTICLE

Evaluation of granular and foliar insecticide modules against major insect pests and their natural enemies in the irrigated rice ecosystem

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Abstract

Ten granular and foliar insecticide modules were tested against the major insect pests of rice and their impacts on natural enemies were also noted during 2021 and 2022. Three commonly used granular formulations, namely chlorantraniliprole 0.4 % G, cartap hydrochloride 4 % G and fipronil 0.3 % G, were tested along with three commonly used foliar insecticides: flubendiamide 480 % SC, chlorantraniliprole 18.5 % SC and spinetoram 11.7 % SC. The first application with granular formulations was made 20 days after transplantation (DAT) and the second application with foliar insecticides was made at 50 DAT. Observations on stem borer, leaf folder, gall midge and whorl maggot (WM) incidence were recorded at 30, 45 and 60 DAT. Observations on predatory insects were recorded from the same plots used for evaluating insecticide efficacies. Application of chlorantraniliprole 0.4 % G at 20 DAT and spraying of either flubendiamide 480 % SC or chlorantraniliprole 18.5 % SC at 50 DAT proved highly effective in controlling the stem borer incidence at the vegetative stage as well as at the reproductive stage. The application of chlorantraniliprole, either as a granular or spray, proved highly effective in controlling the leaf folder in rice. Among the three granular formulations tested, fipronil 0.3 % G granules recorded the lowest silver shoots. Chlorantraniliprole, available in both granular and spray formulations, has proven highly effective in controlling stem borers and leaf folders in rice. Fipronil 0.3 % G granules recorded the lowest silver shoot incidence caused by gall midge.

Keywords: foliar sprays; granular formulations; insecticides; rice insect pests

Introduction

Rice (*Oryza sativa* L.) is one of the world's most important crops, providing stable food for nearly half of the global population (1). It is cultivated on 47.83 million hectares, occupying a significant area compared to other food crops grown in India, with a production of 135.75 million tonnes and a productivity of 4,300 kg ha^{-1}. Andhra Pradesh produces 126.25 lakh tons of rice annually, over 24.84 lakh hectares of area, with a productivity of 5048 kg ha^{-1}.

Various factors contribute to reduced rice yield, with insect pests accounting for 20–30 % of these losses each year (2, 3). Lepidopteran insect pests typically result in a significant reduction in crop plant output. Under field conditions, the primary pest that might result in significant crop loss is the rice yellow stem borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae). After emerging from eggs, stem borer larvae eat inside the rice stems, severing the upper portions of the damaged stem's supply of nutrition and photosynthesis. Dead hearts (DH) are indicators of stem borer assault during the vegetative stage of plant growth, whereas white ear heads (WE) are symptoms of attack during the reproductive stage. One of the most damaging pests to rice ecosystems is the rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) (Lepidoptera: Pyralidae), a common foliage feeder. Previously regarded as a minor problem, the rice leaf folder has now become a significant issue in India's rice-growing states, particularly in areas with high fertiliser usage. This insect can cause significant damage to the crop during its peak tillering and flowering stages in a conducive environment, resulting in 60–70 % leaf loss and a 50 % yield reduction (4).

The Asian rice gall midge, *Orseolia oryzae* (Wood Mason) (Diptera: Cecidomyiidae), is one of the most important insects prevalent in almost all rice-growing states in India (5). The development of a silver shoot, also known as an onion shoot or a tubular leaf sheath gall, is the outward sign of damage brought by gall midge because the larvae's eating and salivary secretion cause the growing shoot meristem to become a gall (5). This renders the tiller sterile and does not bear a panicle (6). Beginning with transplanting, the rice whorl maggot (WM), *Hydrelliasasakii* Yuasa and Isitani (Diptera: Ephydridae) infests the crop and feeds on the central whorl leaf throughout the vegetative stage, potentially reducing rice crop yield (7). Insecticide application time is crucial to manage the stem borer and gall midge (8) since it considerably reduces the frequency of sprays, which in turn reduces the amount of insecticide consumed by farmers. Use of insecticides offers a quick method of insect control and has a positive impact on rice yields. (9–15). Insecticides are often highly effective, fast-acting, convenient and economical tools in pest management. The purpose of this two-year study was to assess the effectiveness of next-generation granular formulations and foliar sprays against stem borer, leaf folder, gall midge and WM, as well as their harmful effects on natural enemy populations.

Materials and Methods

Experimentation

Identical experiments were conducted at Acharya N G Ranga Agricultural University (ANGRAU)-Agricultural Research Station (ARS), Nellore, during the kharif seasons of 2021–22 and 2022–23. The experiments were performed in a randomised block design (RBD) with 10 treatments and three replications. The entire experimental area measured 748.8 m^2, which was divided into three equal blocks. Each block was divided into 10 plots and the 10 treatments were randomly allocated to the plots within each block. Thus, there were 30 (10 × 3) plots altogether in the experiment each year. The plot size was 24.96 m^2. Borders between plots were 0.6 m to facilitate cultural operations and insecticide applications. Field bunds were properly maintained to prevent water and dissolved product from draining out of target plots into adjacent areas. The rice variety NLR 34449 was used during the two-year experimentation period, as it is a popular rice variety grown in many parts of Andhra Pradesh.

In the present experiment, three commonly used granular formulations, i.e., chlorantraniliprole 0.4 % G, cartap hydrochloride 4 % G and fipronil 0.3 % G, were tested along with three widely used foliar insecticides, i.e., flubendiamide 480 % SC, chlorantraniliprole 18.5 % SC and spinetoram 11.7 % SC. The granular insecticides were applied at 20 days after transplantation (DAT) when the initial DH symptoms were visible in some hills. The second application of foliar insecticides was applied at 50 DAT when initial WE symptoms were visible. Along with stem borer incidence, leaf folder, gall midge and WM incidence were also recorded.

The insecticides were applied at the rates specified in Table 1. The granular formulations were weighed on an electronic balance according to plot size. Similarly, the doses of liquid insecticides were measured with a micropipette and sprayed uniformly on the respective plots. Granular insecticides were broadcast by hand in the plots with 2 cm of standing water. For uniform application, granular insecticides were mixed with sand in a 1:10 ratio. Sprayable insecticides were applied using a hand-operated knapsack sprayer at a rate of 500 L of spray fluid per hectare.

Assessment of insect pest infestation

At 30, 45 and 60 days following transplantation, observations were made on the incidence of stem borer, leaf folder, gall midge and WM. At the vegetative stage, the number of tillers with DH was counted to determine the extent of stem borer damage. At the reproductive stage, the number of panicle-bearing tillers and the stem borer-infested ones was counted. In each plot, ten randomly chosen hills were counted to determine the quantity of WE and DH. Five rows on the edges of plots were left as buffers and observations were taken from the inner rows of each plot. The percentage of DH and WE were calculated using the following formulae:

% of DH = Mean number of hearts killed per hill/Mean number of tillers per hill × 100 (Eqn. 1)

% of WE = Mean number of WE per hill/ Mean number of tillers per hill × 100 (Eqn. 2)

The leaf damage by the leaf folder and WM was assessed by counting the total number of leaves and the number of leaf folder and WM-damaged leaves on 10 random hills per plot by leaving the border lines intact. The percentage leaf folder and WM incidence was computed by using the following formulae:

% Leaf folder incidence = Mean number of leaf folder damaged leaves per hill/Mean number of leaves per hill × 100 (Eqn. 3)

% WM incidence = Mean number of WM damaged leaves per hill/ Mean number of leaves per hill × 100 (Eqn. 4)

The gall midge damage was assessed by counting the number of healthy and infested tillers with white elongated galls (silver shoots) on 10 random hills of each plot by leaving the border lines intact. The % silver shoots were calculated by following the formula:

% Silver shoots = Mean number of silver shoots per hill/Mean number of tillers per hill × 100 (Eqn. 5)

The quantity of broad-shouldered water striders (*Microvelia douglasi* Bergroth), mirid bugs (*Cyrtorhinus lividipennis* Reuter), coccinellids (*Micraspis crocea* Mulsant) and spiders (*Pardosa pseudoannulata*) were counted visually at 30 DAT (i.e., 10 days after granular formulations were applied). Care was taken to avoid disturbing natural enemies during the observation process. Due to extremely low or insignificant population densities, observations of the predatory population following the application of foliar pesticides were not documented. When 90 % of the grain had developed across all treatments, the crop was harvested. By removing the border rows, the grain yield of each plot was measured independently and calculated in quintals per hectare.

Statistical analysis

Duncan's multiple range test (DMRT) was used to differentiate the

Table 1. Granular and foliar spray insecticide modules imposed

Treatment	Applied 20 days after transplantation	Applied 50 days after transplantation
T1	Chlorantraniliprole 0.4 % G	Flubendiamide 480 % SC
T2	Chlorantraniliprole 0.4 % G	Chlorantraniliprole18.5 % SC
T3	Chlorantraniliprole 0.4 % G	Spinetoram 11.7 % SC
T4	Cartap hydrochloride 4 % G	Flubendiamide 480 % SC
T5	Cartap hydrochloride 4 % G	Chlorantraniliprole 18.5 % SC
T6	Cartap hydrochloride 4 % G	Spinetoram 11.7 % SC
T7	Fipronil 0.3 % G	Flubendiamide 480 % SC
T8	Fipronil 0.3 % G	Chlorantraniliprole 18.5 % SC
T9	Fipronil 0.3 % G	Spinetoram 11.7 % SC
T10	Untreated check	--

treatment means at the 5 % level of significance after the data were analysed using analysis of variance (ANOVA) with SPSS version 13.0.

Results and Discussion

Efficacy against stem borer

From the data generated after the application of granular formulations at 20 DAT given in Table 2, it was found that at 30 DAT (at 10 days after application of granules), chlorantraniliprole 0.4 % G showed greater efficacy over the other treatments with 8.78 % DH as against other treatments with a record of 9.17–11.79 % DH. In contrast, in untreated check plots, 21.58 % DH was observed. Mean data over three periods of observation (30, 45 and 60 DAT) also showed greater efficacy of chlorantraniliprole 0.4 % G granules. This new molecule, through a unique mode of action, inactivates muscle contraction in insects, showing excellent results in controlling this important rice pest. Chlorantraniliprole, being a green-label insecticide, can be considered a novel insecticide for integration into the IPM system in rice. The present finding is in agreement with that of previous workers who reported that chlorantraniliprole 0.4 % G is effective in managing the rice stem borer and yields the highest percentage reduction of DH over the control (16–19). The second insecticide application, as a foliar spray at 50 DAT, led to a declining trend in stem borer damage, with DH ranging from 0.57 to 1.27 %, compared to 7.54 % DH in the untreated check. It indicated that all three foliar sprays were found to be effective in reducing stem borer incidence. According to the mean observation, the best results were obtained by application of chlorantraniliprole 0.4 % G at 20 DAT and the foliar spray with flubendiamide at 50 DAT. This combination reduced the DH incidence to 4.19 %. In comparison, the untreated check plots experienced a mean DH incidence of 14.49 %.

The WE showed that the application of chlorantraniliprole 0.4 % G at 20 DAT and foliar spraying with flubendiamide 480 % SC at 50 DAT (T1) was highly effective against WE incidence (1.05 % WE) compared to 8.59 % WE in the untreated control plots during 2022–23. However, during 2021–22, the sprayable formulation of chlorantraniliprole showed similar performance in controlling WE incidence, with 1.15 % WE (T2) compared to untreated check plots (6.03 % WE). A study found that 0.4 g of chlorantraniliprole was highly effective in reducing the incidence of WE in rice (20). Numerous researchers have demonstrated flubendiamide's superiority against stem borers (21–24). Another study observed that rice stem borer can be effectively managed using new-generation pesticides such as flubendiamide and chlorantraniliprole 0.4 % G granules (16). Similar findings were also noted regarding the incidence of stem borer in the plot treated with chlorantraniliprole 18.5 % SC compared to the untreated control (25).

In conclusion, applying 0.4 % G chlorantraniliprole granules in combination with a foliar spray of either flubendiamide 480 % SC or chlorantraniliprole 18.5 % SC was highly successful in reducing the prevalence of stem borer at both the vegetative and reproductive stages. However, in 2022–23, sprayable formulation spinetoram 11.7 % SC also performed effectively in suppressing the incidence of stem borer. The application of cartap hydrochloride 4 % G granules also significantly reduced stem borer incidence, with results comparable to those of chlorantraniliprole 0.4 % G granules during the 2022–23 season. However, another granular formulation of fipronil (0.3 g) was less effective against stem borer in rice during both years.

Efficacy against leaf folder

The application of chlorantraniliprole 0.4 % G at 20 DAT and the application of spinetoram 11.7 % SC as a foliar spray at 50 DAT performed very well against leaf folder with 9.54 % incidence over other treatments, with a record of 9.69–17.11 % incidence. The granular fipronil, along with three foliar sprays, failed to control this pest, with an incidence of 12.50–16.27 %, compared to the untreated check, which had a 22.3 % leaf folder incidence during 2021–22 (Table 3).

From the mean of the observations taken during 2021–22, the lowest leaf folder incidence of 7.43 % was noticed in T2, i.e., the application of chlorantraniliprole 0.4 % G granules at 20 DAT and spraying with chlorantraniliprole 18.5 % SC at 50 DAT. It was followed by T1 (7.83 %), i.e., spraying with flubendiamide 480 % SC at 50 DAT.

Table 2. Effect of granular and foliar insecticide modules against rice stem borer

Treatments	Kharif, 2022–23					Kharif, 2021–22				
	% Dead heart (Mean ± SE, n=3)				% White ears (Mean±SE)	% Dead heart (Mean ± SE, n=3)				% White ears (Mean±SE)
	30 DAT	45 DAT	60 DAT	Mean		30 DAT	45 DAT	60 DAT	Mean	
T1	8.78 ± 0.23^{a}	3.21 ± 0.01^{a}	0.57 ± 0.06^{a}	4.19	1.05 ± 0.25^{a}	7.95 ± 0.53^{a}	2.40 ± 0.53^{a}	5.36 ± 0.06^{b}	5.24	2.05 ± 0.85
T2	9.14 ± 0.30^{a}	3.84 ± 0.07^{a}	1.27 ± 0.12^{a}	4.75	2.61 ± 0.01^{b}	8.24 ± 0.25^{a}	4.51 ± 0.62^{a}	4.51 ± 0.63^{a}	5.75	1.51 ± 1.12
T3	10.18 ± 0.32^{b}	4.56 ± 0.18^{c}	0.62 ± 0.23^{a}	5.12	2.46 ± 0.21^{b}	9.34 ± 0.44^{a}	3.52 ± 0.29^{a}	5.24 ± 0.36^{b}	6.03	2.12 ± 0.98
T4	13.31 ± 0.34^{d}	3.48 ± 0.06^{a}	0.56 ± 0.03^{a}	5.78	4.45 ± 0.18^{d}	8.30 ± 0.17^{a}	4.80 ± 0.35^{a}	5.07 ± 0.01^{a}	6.25	1.68 ± 0.68
T5	9.82 ± 0.39^{a}	3.24 ± 0.02^{a}	1.27 ± 0.04^{a}	4.77	1.57 ± 0.38^{a}	9.20 ± 0.38^{a}	4.81 ± 0.67^{a}	4.90 ± 0.20^{a}	6.30	2.17 ± 0.25
T6	12.84 ± 0.44^{c}	4.26 ± 0.19^{b}	0.99 ± 0.11^{a}	6.03	3.33 ± 0.31^{c}	10.43 ± 0.31^{a}	5.63 ± 0.34^{a}	5.69 ± 0.24^{c}	7.25	2.35 ± 0.45
T7	12.44 ± 0.32^{c}	3.83 ± 0.04^{a}	0.97 ± 0.08^{a}	5.75	2.31 ± 0.01^{b}	12.86 ± 0.89^{a}	5.78 ± 0.71^{a}	8.21 ± 0.19^{c}	8.95	2.99 ± 0.68
T8	13.32 ± 0.14^{d}	4.26 ± 0.27^{b}	1.24 ± 0.06^{a}	6.27	4.95 ± 0.12^{e}	11.97 ± 0.56^{a}	4.47 ± 0.45^{a}	7.77 ± 0.59^{c}	8.07	2.89 ± 0.26
T9	11.79 ± 0.50^{c}	4.49 ± 0.20^{c}	0.62 ± 0.05^{a}	5.64	3.10 ± 0.09^{c}	11.87 ± 0.44^{a}	4.08 ± 0.48^{a}	8.42 ± 0.71^{c}	8.12	3.82 ± 1.21
T10	21.58 ± 0.42^{e}	14.36 ± 0.70^{d}	7.54 ± 0.62^{b}	14.49	8.59 ± 0.56^{f}	18.31 ± 0.2^{b}	11.97 ± 0.54^{b}	12.35 ± 0.49^{d}	14.21	6.03 ± 0.56
F-test	104.59	273.31	34.96		12.06	5.13	4.55	7.01		0.412
LSD	1.077	0.78	1.39		4.01	4.15	3.61	2.76		NS
SED	0.509	0.366	0.657		1.542	1.96	1.71	1.31		0.912
CV (%)	5.06	19.91	45.59		2.62	22.16	40.18	23.69		59.20
Level of significance	**	**	**		**	*	**	**		NS
p-value	.000	.000	.000		.000	0.003	0.001	0.000		0.568

DAT: Days after transplantation; NS: Non significant; LSD: Least significant difference; SED: Standard error of difference; CV: Coefficient of variation; Duncan's multiple range test indicates that the means within a column followed by the identical lowercase letters are not significantly different; * Significant at 5 % level; **Significant a 1 % level.

Table 3. Effect of granular and foliar insecticide modules against rice leaf folder

Treatments	Kharif, 2022–23 % Leaf folder (Mean±SE, n=3)				Kharif, 2021–22 % Leaf folder (Mean±SE, n=3)			
	30 DAT	45 DAT	60 DAT	Mean	30 DAT	45 DAT	60 DAT	Mean
T1	1.92 ± 0.15^{c}	4.21 ± 0.13^{a}	2.2 ± 0.28^{a}	2.78	2.56 ± 0.43	9.69 ± 0.01^{b}	11.23 ± 0.00^{b}	7.83
T2	1.15 ± 0.30^{a}	3.59 ± 0.17^{a}	1.25 ± 0.33^{a}	2.00	1.59 ± 0.31	10.40 ± 0.03^{c}	10.31 ± 0.29^{a}	7.43
T3	1.13 ± 0.07^{a}	2.15 ± 0.32^{a}	3.7 ± 0.53^{b}	2.33	2.85 ± 0.50	9.54 ± 0.32^{a}	13.52 ± 0.35^{c}	8.64
T4	1.77 ± 0.23^{b}	3.58 ± 0.50^{a}	4.4 ± 0.58^{b}	3.25	1.62 ± 0.22	13.86 ± 0.77^{e}	14.42 ± 0.37^{c}	9.97
T5	1.25 ± 0.15^{a}	3.28 ± 0.48^{a}	0.6 ± 0.69^{a}	1.71	2.53 ± 0.47	12.70 ± 0.24^{d}	9.85 ± 0.32^{a}	8.36
T6	2.06 ± 0.15^{c}	6.80 ± 0.30^{b}	5.8 ± 0.01^{b}	4.89	2.07 ± 0.94	17.11 ± 0.07^{e}	14.76 ± 0.30^{c}	11.31
T7	1.75 ± 0.47^{b}	7.82 ± 0.13^{b}	9.2 ± 0.08^{c}	6.26	2.64 ± 0.98	13.95 ± 0.89^{e}	15.34 ± 0.65^{c}	10.64
T8	2.18 ± 1.02^{d}	9.85 ± 0.33^{c}	8.5 ± 0.11^{c}	6.84	3.25 ± 0.39	16.27 ± 0.47^{e}	13.48 ± 0.46^{c}	11.00
T9	2.85 ± 0.13^{e}	7.86 ± 0.32^{b}	10.9 ± 0.09^{d}	7.20	2.95 ± 0.05	12.50 ± 0.27^{d}	15.63 ± 0.64^{c}	10.36
T10	3.87 ± 0.19^{f}	15.52 ± 0.71^{d}	21.52 ± 0.29^{e}	12.97	4.25 ± 0.17	22.30 ± 0.57^{f}	19.27 ± 0.35^{d}	15.28
F-test	1.88	59.63	3.01		1.52	11.56	10.40	
$LSD_{0.05}$	NS	1.498	7.131		NS	3.461	2.62	
SED	1.486	0.708	3.368		0.906	1.635	14.57	
CV (%)	42.03	7.92	41.8		10.40	2.62	1.24	
Sig.	*	*	**		NS	**	**	
p value	.042	.039	.000		0.186	0.000	0.000	

DAT: Days after transplantation; NS: Non significant; LSD: Least significant difference; SED: Standard error of difference; CV: Coefficient of variation; Sig.: Level of significance; Duncan's multiple range test indicates that the means within a column followed by the identical lower-case letters are not significantly different; * Significant at 5 % level; **Significant a 1 % level.

Indicating that the chlorantraniliprole, either as granular or as spray, was proven highly effective in controlling the leaf folder in rice. This new molecule, through a unique mode of action that inactivates muscle contraction in insects, shows excellent results in controlling the leaf folder. Similar findings were also reported, showing that chlorantraniliprole performed better and demonstrated high efficacy against *C. medinalis* in rice (26–28).

Efficacy against gall midge

The incidence of gall midges varied significantly between the studied granular formulations at 45 DAT and those applied at 20 DAT. In treatments T9, T7 and T8, which involved the application of fipronil 0.3 % G granules, the lowest incidence of silver shoots was observed at 3.45, 4.47 and 4.89 % respectively. Chlorantraniliprole 0.4 % G granules (T1) were also applied at times and the outcomes were comparable to those of fipronil 0.3 % G granules, with a 5.22 % silver shoot incidence in 2022 compared to the untreated control (11.64 %) (Table 4). Similarly, in 2021, 45 days following transplanting, a significant difference in gall midge was noted between the treatments. Fipronil 0.3 % G granules had the lowest silver shoots among the three granular formulations evaluated, at 1.22, 2.07 and 2.15 % (T9, T8 and T7 respectively). When compared to an untreated check with a silver shoot incidence of 7.89 %, the use of chlorantraniliprole 0.4 % G granules also occasionally showed effective control against gall midge, with 3.00 % silver shoots in the T2 treatment.

Table 4. Effect of granular and foliar insecticide modules against rice gall midge

Treatments	Kharif, 2022–23 % Silver shoots (Mean±SE, n=3)				Kharif, 2021–22 % Silver shoots (Mean±SE, n=3)			
	30 DAT	45 DAT	60 DAT	Mean	30 DAT	45 DAT	60 DAT	Mean
T1	2.18 ± 0.15	5.22 ± 0.21^{b}	2.72 ± 0.42	3.37	1.25 ± 0.77	3.99 ± 0.48^{c}	3.78 ± 0.77	3.01
T2	1.30 ± 0.27	6.77 ± 0.49^{c}	1.61 ± 0.25	3.23	0.86 ± 0.55	3.00 ± 0.10^{b}	4.05 ± 0.15	2.64
T3	1.47 ± 0.17	6.39 ± 0.30^{c}	3.68 ± 0.30	3.85	0.27 ± 0.27	3.91 ± 0.57^{c}	3.75 ± 0.39	2.65
T4	2.66 ± 0.74	6.63 ± 0.70^{c}	1.87 ± 0.28	3.72	0.42 ± 0.21	3.15 ± 0.56^{c}	4.63 ± 0.67	2.73
T5	1.65 ± 0.35	9.01 ± 0.10^{d}	3.11 ± 0.14	4.59	0.42 ± 0.42	3.96 ± 0.29^{c}	5.41 ± 0.72	3.26
T6	2.41 ± 0.23	10.38 ± 0.51^{e}	2.43 ± 0.35	5.07	1.33 ± 0.82	3.23 ± 0.36^{c}	4.52 ± 0.01	3.03
T7	0.92 ± 0.57	4.47 ± 0.51^{a}	2.55 ± 0.95	2.65	0.00 ± 0.00	2.15 ± 0.10^{b}	2.11 ± 0.70	1.42
T8	1.34 ± 0.36	4.89 ± 0.26^{b}	1.85 ± 0.08	2.69	0.44 ± 0.44	2.07 ± 0.08^{b}	4.10 ± 0.40	2.20
T9	1.45 ± 0.13	3.45 ± 0.21^{a}	1.47 ± 0.80	2.12	0.81 ± 0.81	1.22 ± 0.06^{a}	3.93 ± 0.70	1.99
T10	3.64 ± 0.32	11.64 ± 0.74^{f}	4.78 ± 0.47	6.69	2.99 ± 0.99	7.89 ± 0.34^{d}	5.08 ± 0.43	5.32
F-test	2.44	74.51	1.49		0.56	2.84	0.56	
$LSD_{0.05}$	NS	0.925	NS		NS	2.08	NS	
SED	0.741	0.437	1.197		0.831	0.985	2.011	
CV (%)	47.22	7.77	56.21		49.60	37.77	58.15	
Sig.	NS	**	NS		NS	*	NS	
p value	0.094	0.000	0.208		0.849	0.020	0.959	

DAT: Days after transplantation; NS: Non significant; LSD: Least significant difference; SED: Standard error of difference; CV: Coefficient of variation; Sig.: Level of significance; Duncan's multiple range test indicates that the means within a column followed by the identical lower-case letters are not significantly different; * Significant at 5 % level; **Significant a 1 % level.

Table 5. Effect of granular and foliar insecticide modules against rice whorl maggot

Treatments	Kharif, 2022–23				Kharif, 2021–22			
	% Whorl maggot incidence (Mean±SE, n=3)				% Whorl maggot incidence (Mean±SE, n=3)			
	30 DAT	45 DAT	60 DAT	Mean	30 DAT	45 DAT	60 DAT	Mean
T1	2.60 ± 0.31	2.04 ± 0.09[a]	1.54 ± 0.19	2.06	2.32±0.21	1.35 ± 0.08	0.78 ± 0.05[b]	1.48
T2	3.86 ± 0.55	2.70 ± 0.24[a]	1.22 ± 0.10	2.59	1.63±0.01	1.12 ± 0.95	0.02 ± 0.25[a]	0.92
T3	5.63 ± 0.63	1.45 ± 0.76[a]	0.99 ± 0.06	2.69	1.45±0.56	2.23 ± 0.52	0.98 ± 0.58[b]	1.55
T4	5.11 ± 0.24	1.47 ± 0.45[a]	1.88 ± 0.18	2.82	2.32±0.89	1.23 ± 0.01	1.02 ± 0.87[b]	1.52
T5	5.03 ± 0.23	1.39 ± 0.53[a]	1.54 ± 0.19	2.65	1.92±0.42	1.75 ± 0.56	1.46 ± 0.36[c]	1.71
T6	5.01 ± 0.22	1.97 ± 0.05[a]	1.59 ± 0.06	2.86	2.13±0.65	1.63 ± 0.98	1.52 ± 0.28[c]	1.76
T7	4.89 ± 0.57	0.97 ± 0.64[a]	2.81 ± 0.44	2.89	2.42±0.28	1.32 ± 0.85	1.59 ± 0.12[c]	2.11
T8	7.62 ± 0.29	2.27 ± 0.14[a]	1.11 ± 0.07	3.67	2.78±0.01	0.72 ± 0.68	1.75 ± 0.72[c]	1.75
T9	5.25 ± 0.14	2.20 ± 0.12[a]	1.27 ± 0.15	2.90	2.21±0.25	0.58 ± 0.21	2.51 ± 0.5[d]	2.10
T10	6.80 ± 0.20	7.99 ± 0.51[b]	4.35 ± 0.67	6.38	2.25±0.31	1.58 ± 0.08	3.13 ± 0.11[d]	2.32
F-test	0.389	13.21	1.11		0.524	0.452	40.12	
$LSD_{0.05}$	NS	3.245	NS		NS	NS	1.33	
SED	0.892	1.628	0.706		0.984	0.758	0.623	
CV (%)	45.21	2.60	15.24		25.56	NS	23.58	
Sig.	NS	**	NS		NS	NS	**	
p value	0.525	0.000	0.065		0.849	0.651	0.002	

DAT: Days after transplantation; NS: Non significant; LSD: Least significant difference; SED: Standard error of difference; CV: Coefficient of variation; Sig.: Level of significance; Duncan's multiple range test indicates that the means within a column followed by the identical lower-case letters are not significantly different; * Significant at 5 % level; **Significant a 1 % level.

Efficacy against whorl maggot incidence

During 2022, there was a significant difference among the treatments, i.e., among the three granular formulations and the untreated check in reducing the WM incidence at 45 DAT, where granules were applied at 20 DAT. All three granular formulations were found to be effective and were on par with each other in terms of WM incidence, with rates ranging from 0.97 to 2.70 %, similar to the untreated check, where a 7.99 % WM incidence was observed. However, with regard to mean WM incidence, the lowest of 2.06 % was observed in T1 treatment, i.e. application of chlorantraniliprole 0.4 % G at 20 DAT and foliar spray with flubendiamide 480 % SC at 50 DAT, as against the untreated check with 6.38 % WM incidence (Table 5).

During 2021, at 60 DAT, a significant difference was observed among the treatments in terms of WM incidence. Application of chlorantraniliprole 0.4 % G granules at 20 DAT and spraying with either flubendiamide 480 % SC (T1: 0.78 % WM) or chlorantraniliprole 18.5 % SC (T2: 0.02 % WM) or spinetoram 11.7 % SC (T3: 0.98 %) proved to be effective in controlling WM incidence as against the untreated check (3.13 % WM).

Efficacy against natural enemies

While variations in predatory population were not statistically significant, the use of pesticides had a substantial impact on the populations of water striders, mired bugs, coccinellids and spiders (Fig. 1 and 2). Plots treated with chlorantraniliprole 0.4 % G (T1, T2 and T3) had the highest number of water striders (26.2–29.02 m^{-2}) among the insecticide-treated plots, whereas plots treated with cartap hydrochloride 4 % G (T4, T5 and T6) and fipronil 0.3 % G (T7, T8 and T9) had the lowest number of water striders (19.45–21.12 m^{-2}). In contrast, in untreated control plots, an area of 33.82 m^2 was recorded.

Plots treated with fipronil 0.3 % G granules (T7, T8 and T9) had the lowest mean number of spiders/plant (0.97–1.89/plant) compared to chlorantraniliprole and cartap hydrochloride-treated plots, where spider population ranged from 1.25–1.85 spiders per

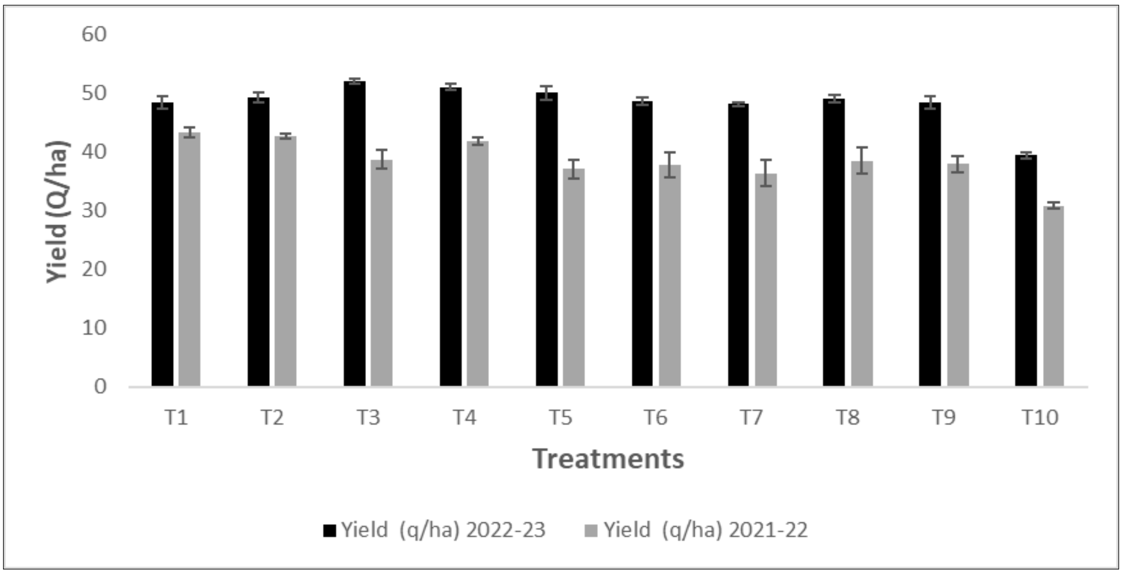

Fig. 1. Effects of insecticide modules on rice yields.

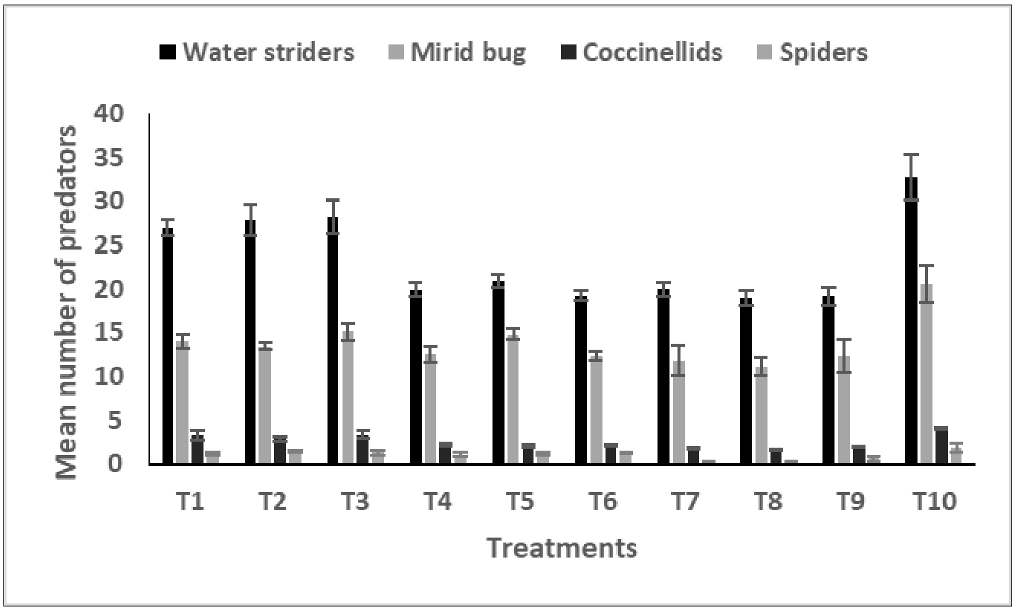

Fig. 2. Predatory population densities in granular insecticide-treated and untreated plots during 2022–23.

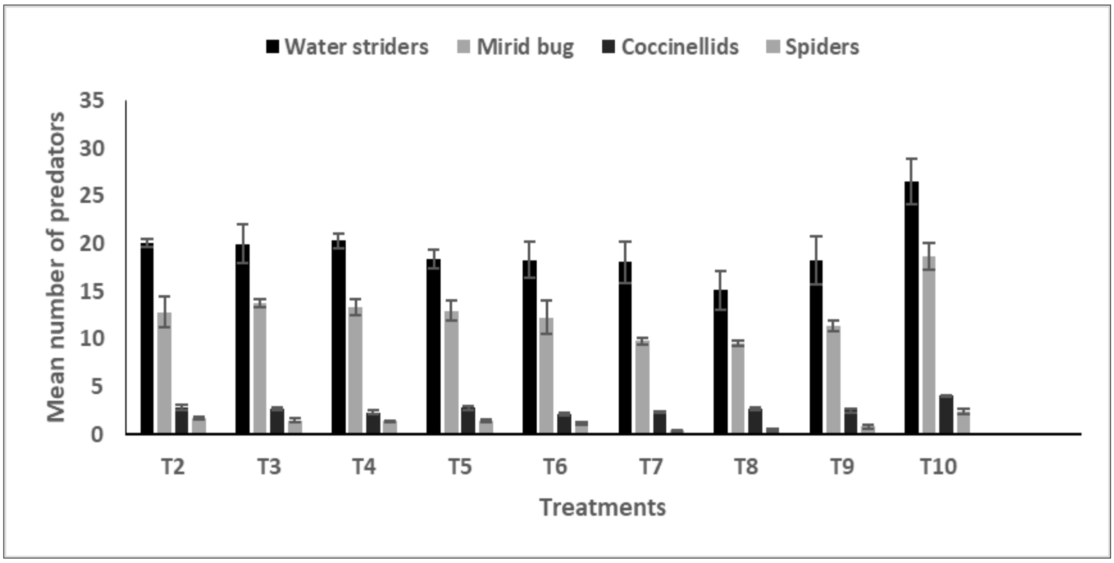

Fig. 3. Predatory population densities in granular insecticide-treated and untreated plots during 2021–22.

plant. In contrast, on untreated check plots, 2.45 spiders per plant were noticed. Similar findings were reported by previous workers (29–32). In comparison to the liquid formulations, a higher spider population was seen in the plots treated with chlorantraniliprole granules (33, 34).

Yield

In 2022, yields from all treatments varied from 4823 to 5208 kg ha^{-1}, which was comparable to the untreated check's yield of 3946 kg ha^{-1}. However, in 2021, notable differences in grain yields were observed among the treatments (Fig. 3). Plots treated with insecticides yielded larger amounts than the untreated plots. Plots treated with chlorantraniliprole 0.4 % G granules at 20 DAT and foliar sprayed with flubendiamide 480 % SC, chlorantraniliprole 18.5 % SC and spinetoram 11.7 % SC had the highest grain yields, with yields of 4345 kg ha^{-1}, 4271 kg ha^{-1} and 3877 kg ha^{-1} in T1, T2 and T3, respectively. In contrast to the untreated control, which yielded 3083 kg ha^{-1}, T4 also recorded comparable peak yields of 4188 kg ha^{-1}.

Conclusion

Application of chlorantraniliprole 0.4 % G at 20 DAT and spraying of either flubendiamide 480 % SC or chlorantraniliprole 18.5 % SC at 50 DAT proved highly effective in controlling the stem borer incidence at the vegetative stage as well as at the reproductive stage, with the lowest DH and WE incidence as compared to the untreated check. However, sprayable formulations flubendiamide 480 % SC, chlorantraniliprole 18.5 % SC and spinetoram 11.7 % SC showed similar performance in controlling stem borer during 2022. The lowest leaf folder incidence of 7.43 % was observed in T2, i.e., the application of chlorantraniliprole 0.4 % G granules at 20 DAT and spraying with chlorantraniliprole 18.5 % SC at 50 DAT, followed by T1 (7.83 %), i.e., spraying with flubendiamide 480 % SC at 50 DAT, indicating that the chlorantraniliprole, either as granular or as spray, was proven highly effective in controlling the leaf folder in rice. Among the three granular formulations, fipronil 0.3 % G granules recorded the lowest silver shoots, at 1.22, 2.07 and 2.15 % (T9, T8 and T7, respectively). Sometimes, the application of chlorantraniliprole 0.4 % G granules also provided effective control against gall midge, with 3.00 % silver shoots in the T2 treatment, compared to the untreated check with 7.89 % silver shoot incidence.

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Authors' contributions

IP planned and conducted the research work and drafted the manuscript. UV and PM contributed to the experimental design, while CS and SS critically reviewed and refined the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

Ethical issues: None

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