



RESEARCH ARTICLE

Assessment of selectivity of insecticides against hymenopteran egg parasitoids (*Telenomus dignus* G. and *Trichogramma japonicum* A.) of yellow stem borer (*Scirpophaga incertulas* W.) in Kharif rice

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Abstract

The compatibility of insecticides with hymenopteran egg parasitoids (natural enemies), viz. *Telenomus dignus* and *Trichogramma japonicum* of yellow stem borer (*Scirpophaga incertulas*) in kharif rice (*Oryza sativa*) was investigated in Purba Bardhaman district of West Bengal during 2022–23. A total of seven chemical insecticides were chosen for the experiment along with one control treatment where only water was sprayed. The field design was set up with a randomised block design (RBD) with eight treatments in three replications. A few parameters were studied in this experiment and those were parasitism rate of eggs in egg masses (%), parasitism reduction (%), parasitic potential (%), adult emergence (%), emergence reduction (%) and selectivity classification of applied insecticides based on parasitism reduction. From the results of the experiment, it was observed that, for the above mentioned first four parameters which were found effective for the three insecticides like Thiamethoxam + Chlorantraniliprole, Tetraniiprole and Chlorantraniliprole and other chemicals were not so effective for the first four parameters. From the selectivity classification of insecticides, it was found that the three chemical treatments (Thiamethoxam + Chlorantraniliprole, Tetraniiprole and Chlorantraniliprole) fall under the harmless class (parasitism reduction < 30 %) while the rest of the other chemicals came under the slightly harmful class (30 % ≤ parasitism reduction ≤ 79 %) for *T. dignus* as well as for *T. japonicum*. The results highlight the compatibility of selected chemicals with biological control agents and their incorporation into integrated pest management (IPM) programmes with minimum non-target effects in the rice ecosystem.

Keywords: Biological control; integrated pest management (IPM); natural enemies; non-target effects; *Oryza sativa*

Introduction

The rice (*Oryza sativa* L.), primarily a kharif crop, is grown in a wide variety of environments, from hills to coastal areas. Over the years, rice production in India has witnessed remarkable growth, driven by advancements in agricultural practices, improved irrigation infrastructure and the adoption of high-yielding varieties, enabling the country to attain self-sufficiency in rice and further produce a surplus that supports consistent exports to international markets. It is one of the most important food crops, grown extensively across the country and is considered a crucial crop for ensuring food security, serving as a primary food source for almost half of the global population. West Bengal, Uttar Pradesh, Punjab, Odisha, Andhra Pradesh, Bihar and Chhattisgarh are the leading rice-producing states in India (1). In West Bengal, rice is cultivated in 14 out of the 23 districts, covering more than 45 % of the state's agricultural land and among these, the former district of Burdwan is rightly referred to as the 'Rice Bowl of Bengal' as it yields the

highest annual rice production in the state (2). Rice covers the largest proportion of the gross cropped area in this region and is grown both in kharif and rabi seasons.

Insect pests pose one of the main challenges to the global rice economy. It is estimated that over a hundred species of insects feed on rice, causing significant damage that hampers its yield potential (3). Stem borers, contributing to about 40 % of the total damage, along with planthoppers (25 %), gall midges (10 %) and various other pests (25 %), collectively lead to significant crop losses in rice cultivation (4). However, some insects cause significant damage to rice growth and yield, making them major pests of rice and of primary importance. Rice stem borers, belonging to the order Lepidoptera, are major pests (5). In India, documentation includes 18 species of stem borers from the Crambidae family and three species from the Noctuidae family (6). The yellow stem borer (YSB), scientifically identified as *Scirpophaga incertulas*, is recognised as one of the most destructive and economically significant insect pests affecting rice

cultivation, causing substantial yield losses and posing a serious threat to rice production in many regions and is responsible for causing substantial economic losses ranging from 27 to 34 % (7, 8). These losses occur due to the pest's damaging activity during critical growth stages of the rice crop; specifically, it induces 'dead heart' symptoms during the active tillering phase and 'white ear' or empty ear panicles during the reproductive stage. This destructive impact is observed consistently across all growing seasons. It has been identified as an important insect pest of rice in the Burdwan district of West Bengal. The importance of addressing these challenges is clear, given the vital role of rice in global food security. This underscores the urgent necessity of implementing effective and well-planned pest management strategies, which are crucial for safeguarding rice crops from yield-reducing pests and ensuring both the sustainability and enhancement of rice production in the long term (9).

Conventional methods to control borer pests in paddy fields typically involve the use of agrochemicals. However, these approaches can harm the environment and raise food safety concerns, especially since broad-spectrum insecticides with significant toxicity are commonly applied (10). There is a growing demand for optimised methods that have a lower environmental impact and higher sustainability, such as the release of biological control agents. Egg parasitoids are a specific group of organisms that lay their eggs inside the eggs of a host insect (11). These parasitoids complete their entire developmental cycle within the host egg, ultimately leading to the death of the host embryo and preventing its further development into a mature insect. Egg parasitoids of stem borer, which parasitize the majority of the egg mass and stop stem borer eggs from developing, are crucial to the population control of YSB. Hymenopteran members belonging to the family *Mymaridae*, *Trichogrammatidae* and *Platygastridae* are exclusively egg parasitoids (12). In addition, a diverse range of species belonging to several chalcid wasp families—including *Eulophidae*, *Encyrtidae*, *Pteromalidae* and *Eupelmidae*—have also been reported to parasitize the eggs of various insects and arthropods, playing a significant role in natural biological control by regulating the populations of their hosts. Effective suppression of the YSB population can be achieved by promoting the activity of promising egg parasitoids, in combination with the judicious use of insecticides. Egg parasitoids such as *Telenomus rowani*, *Telenomus dignus*, *Tetrastichus schoenobii* and *Trichogramma japonicum* serve an important function in maintaining ecological balance through behaving as effective bioagents against a variety of agricultural insect pests and are widely distributed across rice fields (13). *Trichogramma* species are highly adaptable and capable of surviving across a wide range of temperatures, making them well-suited for use in diverse climatic conditions (14). They have demonstrated effective control of various lepidopteran pests across numerous crops, contributing significantly to the overall effectiveness and long-term sustainability of biological pest control programs implemented within agricultural production systems. In the rice ecosystem, a remarkably high level of natural parasitism, reaching up to 95 %, was recorded in the eggs of YSB, resulting from the combined activity of three egg parasitoid genera: *Trichogramma* sp., *Telenomus* sp. and *Tetrastichus* sp. (15). This significant level of biological control highlights the vital role these parasitoids play in naturally suppressing YSB populations and contributing to the preservation of ecological balance and the stability of natural interactions among organisms within rice field

ecosystems.

Despite the significance of biological control of insect pests, the application of insecticides remains essential in the current agricultural system due to their speed, efficiency, ease of use and cost-effectiveness (16). In this context, a range of strategies have been adopted under the integrated pest management (IPM) framework, demonstrating that the strategic and judicious use of insecticides, when integrated with complementary approaches such as cultural, mechanical and biological control methods, can significantly enhance the overall effectiveness and sustainability of biological pest control measures. Ideal insecticides should cause minimal harm to the beneficial insects (17). Therefore, gaining a comprehensive understanding of the compatibility between insecticides and the natural enemies of insect pests, as well as assessing the potential impacts of these chemicals on beneficial organisms, is essential for the successful and harmonious integration of chemical and biological control strategies in pest management programs (18). Additionally, it is crucial to protect these naturally occurring potential parasitoids from the detrimental and potentially disruptive effects caused by the application of synthetic chemical pesticides. In this regard, one of the primary objectives of this research was to thoroughly investigate and evaluate the effects of pesticide applications on the parasitism activity and effectiveness of YSB egg parasitoids within rice field ecosystems, with the aim of understanding their interactions and potential disruptions caused by chemical inputs in order to gather fundamental information for an integrated pest management program. However, there exists only a limited amount of documented information or research-based evidence currently available on the harmful effects of currently popular insecticides on *T. japonicum* and *T. dignus*.

Materials and Methods

Experimental location

The present study was conducted at the College of Agriculture (CoA), which is an extended campus of Bidhan Chandra Krishi Viswavidyalaya (BCKV), located in East Burdwan district of West Bengal. This location provided a suitable agro-climatic setting for carrying out the research effectively, which is situated at 87.8955° E longitude and 23.2408° N latitude.

Experimental site

The field studies were carried out at the Teaching Farm of CoA, BCKV, Burdwan. The field data were collected from the experimental site and kept in the laboratory for further studies.

Layout of field studies

The field experiment was carried out with eight treatments and three replications over the course of two consecutive growing seasons, specifically during the kharif seasons of 2022 and 2023, allowing for the observation and analysis of results across multiple crop cycles. A total of 600 sq. m. area was used for the experiment in both seasons (Table 1).

Crop and variety

The crop selected was paddy and the variety chosen was MTU 7029 (Swarna), which is popularly cultivated by the farmers of the district. Therefore, insecticide compatibility of hymenopteran egg parasitoids of YSB was studied using the said variety during kharif, 2022 and 2023.

Table 1. Experimental setup details at field (kharif, 2022 and 2023) for insecticide compatibility

Location	Teaching Farm, CoA, (BCKV) Burdwan
Crop	Rice
Variety	MTU 7029 (Swarna)
Season	Kharif, 2022 and 2023
Design	randomized block design (RBD)
Plot size	25 m ² (5 m × 5 m)
Spacing	20 cm × 15 cm
Treatment	8
Replication	3

Experimental design

The required statistical design followed for this field experiment was randomized block design (RBD), which had a total of eight treatments and three replications for each treatment.

Selection of chemicals

Locally available and mostly used insecticides by farmers against YSB were selected for this experiment. Each insecticide was sprayed at an appropriate time for each treatment. Then the effect of all insecticides on hymenopteran egg parasitoids of YSB was checked. The names of the chemicals and their doses are mentioned in the following table (Table 2).

Sowing

For the kharif season, the seed was treated with *Trichoderma viride* (5.5 g/kg) on 13th July. The nursery seed bed was prepared on 16th July and sowing of germinated seeds was done on 18th July. In the kharif season of 2023, the same works were done exactly on the same date.

Transplanting

Properly grown seedlings were transplanted in the main field on 21st August for each season of experiment during the kharif, 2022 and 2023 following, RBD.

Intercultural operations

Intercultural operations, including soil enrichment through the application of fertilizers, timely irrigation and regular weeding, were carried out at appropriate intervals throughout the crop growth period in accordance with the recommended package of practices to ensure optimal crop development.

Spraying

Here for each plot, a total of two sprayings were done for both seasons. The first spraying was done 20 days after transplanting (20 DAT) and the next spraying was carried out 35 days after transplanting (35 DAT). This method of spraying was followed for both seasons (Kharif, 2022 and 2023).

Table 2. Treatment details along with their chemical name, formulation, trade name and formulation doses for two seasons (kharif, 2022 and 2023)

Treatment	Chemical name with composition	Trade name	Applicable dose volume	Formulation dose
T ₁	Lamda cyhalothrin 5 % EC	Agent Plus	5mL/2.5L	1L/Ha
T ₂	Chloropyrifos 50 % + Cypermethrin 5 % EC	Indra 505	5mL/2.5L	1L/Ha
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	Volium Flexi	1.25mL/2.5L	0.25L/Ha
T ₄	Tetraniliprole 18.18 % w/w SC	Vayego	1.5mL/2.5L	0.30L/Ha
T ₅	Chlorantraniliprole 18.5 % w/w SC	Cosko	1.2mL/2.5L	0.24L/Ha
T ₆	Bifenthrin 10 % EC	Bifenstar	3.25mL/2.5L	0.65L/Ha
T ₇	Cartap hydrochloride 50 % SP	Kritap	7.5gm/2.5L	1.5Kg/Ha
T ₈	Water spray (Untreated control)	-	-	-

Parameters studied under this experiment

The YSB egg masses were collected from all replications of each treatment at 1 day (1 DAS) and 3 days (3 DAS) after each of the two sprayings for both seasons of the experiment. Then the collected egg masses were washed with 70 % alcohol to remove the hairs on the egg masses easily and the total eggs of YSB were counted. After that the egg masses were stored in a test tube plugged with muslin cloth for keeping newly emerged adult parasitoids inside it. All those test tubes were taken in test tube stands for easy handling. Regular observation was kept on egg masses to identify parasitized eggs, which were counted for treatment-wise needful calculation. All the parameters were calculated based on the following formula:

Parasitism rate of eggs in egg masses (%) = (No. of parasitized eggs/ Total no. of eggs in an egg mass) × 100 (19).

$$\text{Parasitism reduction (\%)} = [(1 - V_t / V_c) \times 100]$$

Where V_t = Parasitism for the treatment, V_c = Parasitism in the control treatment (20).

$$\text{Parasitic potential (\%)} = (A / E) \times 100;$$

Where, A represents the number of larvae that successfully emerged and E denotes the total number of eggs present in an individual egg mass. The total number of eggs (E) is calculated using the formula $E = A + B + C + D$, where B corresponds to the number of larvae that did not emerge, C represents the number of parasitoids that successfully emerged and D accounts for the parasitoids that failed to emerge (21).

$$\text{Adult emergence (\%)} = (a / b) \times 100$$

Where, a = No. of egg mass with adult emerged, b = No. of parasitized egg mass (21).

$$\text{Emergence reduction (\%)} = [(1 - E_t / E_c) \times 100]$$

where, E_t = Emergence for the treatment, E_c = Emergence in the control treatment (19).

Selectivity classification of insecticides

At first, parasitism reduction of each egg parasitoid for each treatment was pooled for two seasons (kharif, 2022 and 2023) and then based on the pooled data of parasitism reduction, different insecticides that were applied in this experiment were grouped into different classes as presented in Table 3 (20).

Table 3. Selectivity classification of used insecticides based on Parasitism Reduction (PR%)

Class No.	Class Name	Parasitism reduction (PR%)
1	Harmless	PR < 30 %
2	Slightly harmful	30 % ≤ PR ≤ 79 %
3	Moderately harmful	80 % ≤ PR ≤ 99 %
4	Harmful	PR > 99 %

Data analysis

An analysis of variance (ANOVA) was conducted to evaluate differences among the various treatments, followed by a Tukey multiple comparison test ($p < 0.05$) to determine which specific parameters differed significantly between treatment groups. Analysis was carried out by RStudio software.

Results

Parasitism rate (%) of hymenopteran egg parasitoids

During both kharif seasons (2022 and 2023), there were notable differences in the parasitism rates (PR %) of *T. japonicum* and *T. dignus* between treatments. Among insecticide-treated plots, the Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC treatment showed somewhat greater parasitism levels, although the untreated control consistently showed the highest parasitism in both years. Both parasitoid species showed a similar pattern, suggesting that diamide-based treatments were more compatible with natural enemy activity (Table 4; Fig. 1 & 2).

Parasitism reduction (%) of hymenopteran egg parasitoids

In the case of parasitism reduction of egg parasitoids, a lower value of parasitism reduction depicted a higher parasitism rate. For *T. dignus*, the lowest average parasitism reduction (%) was observed in case of Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC (8.81 ± 0.41 % and 11.36 ± 0.16 %) in kharif, 2022 and 2023 respectively. Whereas for *T. japonicum*, the lowest average parasitism reduction (%) was observed in case of Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC treatment in kharif, 2022 and 2023. Therefore, it is clearly observed that for these parasitoids, Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC is safer in terms of parasitism reduction compared to other chemical treatments. Results are presented in Table 5 and Fig. 3 & 4.

Parasitic potential (%) of hymenopteran egg parasitoids

The parasitic potential (%) also showed an inverse relationship with the parasitism of egg parasitoids as described in the materials and methods part. In the case of *T. dignus*, the lowest average parasitic potential (%) was found in case of Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC treatment among the chemical treatments in kharif, 2022 and 2023. Whereas for *T. japonicum*, the lowest average parasitic potential (%) was observed in case of Chlorantraniliprole 18.5 % w/w SC treatment in kharif, 2022 and Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC treatment was found the lowest in kharif, 2023. All the data are presented in Table 6 and Fig. 5 & 6. Here it is also clearly observed

that Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC and Chlorantraniliprole 18.5 % w/w SC are more effective in terms of parasitic potential (%) compared to other chemical treatments. In our experiment, the combination insecticide product of Thiamethoxam and Chlorantraniliprole has very little adverse effect on the controlling mechanism of egg parasitoids on YSB egg masses. This is also similar for Chlorantraniliprole 18.5 % w/w SC in the case of *T. japonicum*.

Emergence rate (%) of hymenopteran egg parasitoids

For the emergence rate (%) of *T. dignus*, the highest average emergence rate was found in the case of Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC among the chemical treatments in kharif, 2022 and 2023. For *T. japonicum*, the highest average emergence rate was observed for Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC among the chemical treatments in kharif, 2022 and 2023 (Table 7; Fig. 7 & 8). Here one thing is clear, that the emergence rate of *T. japonicum* is much less compared to *T. dignus* in both seasons. Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC insecticide has less adverse effect on the emergence of adult egg parasitoids compared to other tested chemicals.

Adult emergence reduction (%) of hymenopteran egg parasitoids

Across both seasons (kharif, 2022 and 2023), the lowest average emergence reduction (%) of *T. dignus* was found for Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC. Whereas for *T. japonicum*, the lowest average emergence reduction (%) was observed in the case of Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC in kharif, 2022 and 2023. The results are presented in Table 8 and Fig. 9 & 10. Here emergence reduction (%) for both species was minimum for (Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC) i.e., this novel insecticide had less adverse effect on the emergence of both parasitoids compared to other chemicals.

Selectivity classification of treated insecticides based on parasitism reduction (PR %) of both seasons

Selectivity classification of treated insecticides based on parasitism reduction indicated that, Thiamethoxam + Chlorantraniliprole, Tetraniliprole and Chlorantraniliprole fall under the harmless class (Class 1). Whereas the rest of the chemicals like Lambda Cyhalothrin, Chlorpyrifos + Cypermethrin, Bifenthrin and Cartap Hydrochloride came under Class 2 i.e., slightly harmful class ($30\% \leq PR \leq 79\%$). These findings revealed that Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC, Tetraniliprole 18.18 % w/w SC and Chlorantraniliprole 18.5% w/w SC can be applied in rice fields with egg parasitoids like *T. dignus* and *T. japonicum*. All the data are presented in Table 9.

Discussion

Table 4. Parasitism rate (%) of *Telenomus dignus* and *Trichogramma japonicum* in kharif, 2022 and 2023

Tr. No.	Treatment	Formulation dose	<i>Telenomus dignus</i> (Mean±SE)		<i>Trichogramma japonicum</i> (Mean±SE)	
			Kharif, 2022	Kharif, 2023	Kharif, 2022	Kharif, 2023
T ₁	Lambda cyhalothrin 5 % EC	1L/Ha	13.15±0.61 ^a	10.71±0.43 ^a	12.01±0.61 ^{ab}	7.12±0.33 ^b
T ₂	Chlorpyrifos 50 % + Cypermethrin 5 % EC	1L/Ha	15.54±0.67 ^{ab}	11.60±0.56 ^b	15.08±0.58 ^{bc}	8.62±0.44 ^{bc}
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	0.25L/Ha	21.28±0.80 ^c	19.45±0.77 ^c	18.75±0.54 ^c	14.93±0.51 ^a
T ₄	Tetraniliprole 18.18 % w/w SC	0.30L/Ha	18.60±0.65 ^d	15.29±0.68 ^{ab}	17.54±0.57 ^{de}	11.69±0.58 ^{cde}
T ₅	Chlorantraniliprole 18.5 % w/w SC	0.24L/Ha	19.38±0.74 ^{de}	17.52±0.70 ^{cd}	18.16±0.77 ^{cd}	12.86±0.55 ^{ce}
T ₆	Bifenthrin 10 % EC	0.65L/Ha	17.09±0.53 ^{df}	13.25±0.66 ^e	15.72±0.50 ^a	10.73±0.63 ^f
T ₇	Cartap Hydrochloride 50 % SP	1.5Kg/Ha	9.72±0.56 ^g	7.59±0.48 ^f	8.62±0.52 ^f	4.19±0.16 ^d
T ₈	Control	-	23.49±0.96 ^{cd}	22.01±0.89 ^{ec}	22.80±0.78 ^b	18.30±0.69 ^g
LSD			3.16	1.65	4.40	1.86
CV (%)			8.60	5.10	13.20	7.90

*Means within columns separated by ANOVA at 5 % level of significance

**Means in columns followed by the different letters shown in superscript are significantly different

Table 5. Parasitism reduction (%) of *Telenomus dignus* and *Trichogramma japonicum* in kharif, 2022 and 2023

Tr. No.	Treatment	Formulation dose	<i>Telenomus dignus</i> (Mean±SE)		<i>Trichogramma japonicum</i> (Mean±SE)	
			Kharif, 2022	Kharif, 2023	Kharif, 2022	Kharif, 2023
T ₁	Lambda cyhalothrin 5 % EC	1L/Ha	43.93±0.52 ^e	51.26±0.25 ^{ef}	47.43±1.06 ^{cd}	60.37±1.16 ^a
T ₂	Chlorpyrifos 50 % + Cypermethrin 5 % EC	1L/Ha	33.65±0.28 ^d	47.56±0.53 ^{de}	33.72±0.49 ^{bcd}	52.21±1.29 ^{de}
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	0.25L/Ha	8.81±0.41 ^{ab}	11.36±0.16 ^{ab}	16.15±1.94 ^{ab}	16.61±1.69 ^b
T ₄	Tetraniliprole 18.18 % w/w SC	0.30L/Ha	20.03±0.58 ^{bc}	30.64±0.65 ^{bc}	22.36±0.08 ^d	35.56±0.86 ^{bc}
T ₅	Chlorantraniliprole 18.5 % w/w SC	0.24L/Ha	16.87±0.48 ^c	20.07±0.40 ^{cd}	20.34±0.83 ^{de}	28.04±1.68 ^{cd}
T ₆	Bifenthrin 10 % EC	0.65L/Ha	26.43±0.91 ^f	40.10±0.53 ^e	30.60±0.37 ^f	41.15±1.92 ^{ab}
T ₇	Cartap Hydrochloride 50 % SP	1.5Kg/Ha	58.57±0.87 ^{cf}	65.70±3.29 ^f	62.20±1.12 ^{ef}	76.78±0.38 ^{ef}
T ₈	Control	-	0±0 ^a	0±0 ^a	0±0 ^a	0±0 ^a
LSD			6.49	7.76	10.46	7.52
CV (%)			14.80	17.10	19.30	15.20

*Means within columns separated by ANOVA at 5 % level of significance

**Means in columns followed by the different letters shown in superscript are significantly different

Table 6. Parasitic potential (%) of *Telenomus dignus* and *Trichogramma japonicum* in kharif, 2022 and 2023

Tr. No.	Treatment	Formulation dose	<i>Telenomus dignus</i> (Mean±SE)		<i>Trichogramma japonicum</i> (Mean±SE)	
			Kharif, 2022	Kharif, 2023	Kharif, 2022	Kharif, 2023
T ₁	Lambda cyhalothrin 5 % EC	1L/Ha	36.49±0.67 ^a	38.71±0.09 ^{ac}	45.50±0.86 ^e	44.51±0.99 ^f
T ₂	Chlorpyrifos 50 % + Cypermethrin 5 % EC	1L/Ha	27.98±0.80 ^{ab}	32.93±0.20 ^b	37.50±0.71 ^{de}	35.26±0.92 ^a
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	0.25L/Ha	10.13±0.06 ^c	8.85±0.10 ^{bc}	23.72±1.82 ^b	8.16±0.26 ^{ab}
T ₄	Tetraniliprole 18.18 % w/w SC	0.30L/Ha	17.48±1.22 ^{bc}	20.31±0.24 ^{cd}	32.00±1.20 ^{cd}	18.58±1.07 ^c
T ₅	Chlorantraniliprole 18.5 % w/w SC	0.24L/Ha	13.67±0.56 ^{ab}	12.74±0.19 ^e	19.94±0.89 ^f	13.85±0.61 ^{de}
T ₆	Bifenthrin 10 % EC	0.65L/Ha	20.65±1.59 ^d	25.64±0.12 ^{ef}	30.51±1.59 ^{ed}	23.12±1.47 ^e
T ₇	Cartap Hydrochloride 50 % SP	1.5Kg/Ha	41.43±2.33 ^e	56.85±1.99 ^f	62.60±1.22 ^f	60.10±1.83 ^{ac}
T ₈	Control	-	7.61±0.27 ^{af}	5.38±0.18 ^g	6.11±0.07 ^{ef}	3.10±0.21 ^d
LSD			7.02	7.52	3.21	5.95
CV (%)			9.30	10.70	8.70	14.10

*Means within columns separated by ANOVA at 5 % level of significance

**Means in columns followed by the different letters shown in superscript are significantly different

Table 7. Adult emergence rate (%) of *Telenomus dignus* and *Trichogramma japonicum* in kharif, 2022 and 2023

Tr. No.	Treatment	Formulation dose	<i>Telenomus dignus</i> (Mean±SE)		<i>Trichogramma japonicum</i> (Mean±SE)	
			Kharif, 2022	Kharif, 2023	Kharif, 2022	Kharif, 2023
T ₁	Lambda cyhalothrin 5 % EC	1L/Ha	14.21±0.62 ^c	15.34±0.98 ^a	6.42±0.41 ^b	4.92±0.26 ^a
T ₂	Chlorpyrifos 50 % + Cypermethrin 5 % EC	1L/Ha	15.88±0.66 ^b	21.34±1.41 ^{ab}	8.09±0.47 ^{bc}	6.31±0.31 ^{bc}
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	0.25L/Ha	38.35±1.64 ^{ab}	39.30±1.85 ^d	16.20±0.85 ^{ad}	11.93±0.33 ^{ab}
T ₄	Tetraniliprole 18.18 % w/w SC	0.30L/Ha	26.95±1.68 ^{cd}	29.95±1.46 ^{bc}	12.01±0.57 ^{abc}	9.42±0.37 ^c
T ₅	Chlorantraniliprole 18.5 % w/w SC	0.24L/Ha	33.77±1.63 ^{bc}	34.01±1.72 ^e	13.78±0.60 ^{cd}	11.12±0.42 ^d
T ₆	Bifenthrin 10 % EC	0.65L/Ha	25.45±1.75 ^e	26.58±1.42 ^{ef}	9.86±0.40 ^{de}	7.67±0.29 ^{de}
T ₇	Cartap Hydrochloride 50 % SP	1.5Kg/Ha	6.07±0.35 ^f	8.03±0.33 ^f	4.00±0.38 ^c	2.37±0.17 ^f
T ₈	Control	-	45.70±2.28 ^g	53.66±1.36 ^{abc}	20.22±0.83 ^{ab}	13.66±0.40 ^{ef}
LSD			8.36	5.95	3.21	7.21
CV (%)			20.20	14.10	17.50	16.20

*Means within columns separated by ANOVA at 5 % level of significance

**Means in columns followed by the different letters shown in superscript are significantly different

Table 8. Adult emergence reduction (%) of *Telenomus dignus* and *Trichogramma japonicum* in kharif, 2022 and 2023

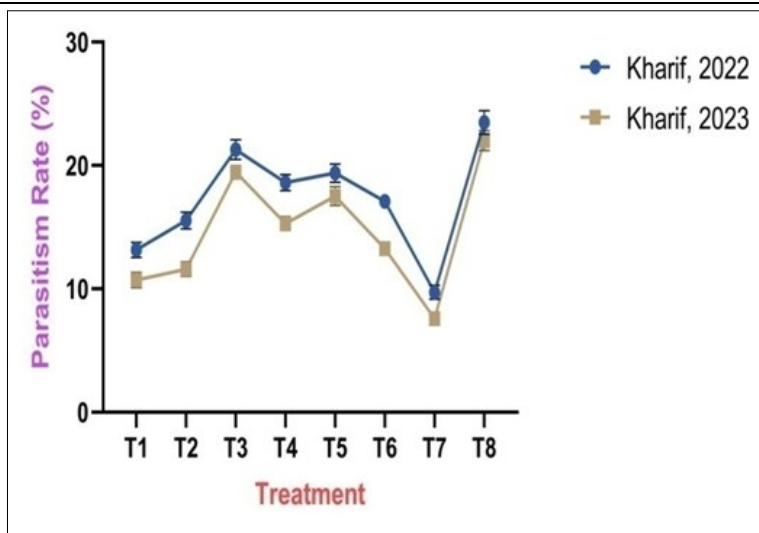
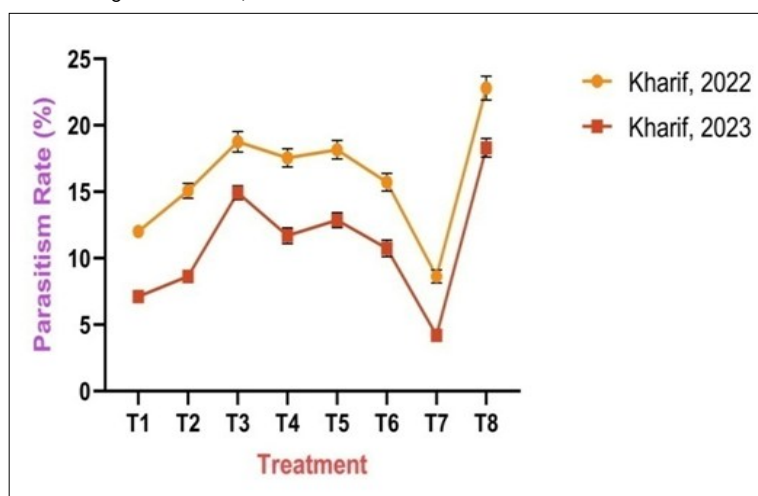
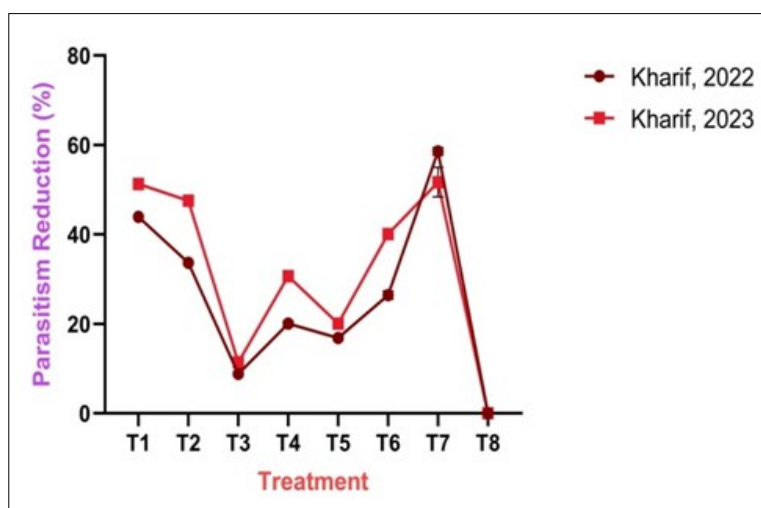
Tr. No.	Treatment	Formulation dose	<i>Telenomus dignus</i> (Mean±SE)		<i>Trichogramma japonicum</i> (Mean±SE)	
			Kharif, 2022	Kharif, 2023	Kharif, 2022	Kharif, 2023
T ₁	Lambda cyhalothrin 5 % EC	1L/Ha	68.29±0.38 ^c	71.71±1.14 ^{ad}	68.73±0.95 ^{bc}	64.36±0.93 ^c
T ₂	Chlorpyrifos 50 % + Cypermethrin 5 % EC	1L/Ha	64.43±0.89 ^{ab}	60.63±1.67 ^d	60.05±1.56 ^b	53.98±1.05 ^e
T ₃	Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	0.25L/Ha	15.04±0.81 ^c	26.95±1.85 ^e	20.15±1.33 ^c	12.11±0.88 ^b
T ₄	Tetraniliprole 18.18 % w/w SC	0.30L/Ha	41.37±1.47 ^d	44.22±1.54 ^{de}	40.18±1.47 ^d	31.04±0.85 ^{bc}
T ₅	Chlorantraniliprole 18.5 % w/w SC	0.24L/Ha	25.51±1.24 ^{ef}	34.11±2.12 ^f	29.91±1.82 ^{ad}	15.98±0.61 ^{ab}
T ₆	Bifenthrin 10 % EC	0.65L/Ha	44.18±1.77 ^f	50.80±1.51 ^{bc}	50.62±1.53 ^{abc}	43.74±0.59 ^{abc}
T ₇	Cartap Hydrochloride 50 % SP	1.5Kg/Ha	86.84±0.30 ^{bcd}	85.03±0.32 ^e	80.85±1.30 ^{cd}	82.98±0.82 ^d
T ₈	Control	-	0±0 ^a	0±0 ^a	0±0 ^a	0±0 ^a
LSD			5.26	4.62	3.78	4.58
CV (%)			10.40	13.48	7.65	8.95

*Means within columns separated by ANOVA at 5 % level of significance

**Means in columns followed by the different letters shown in superscript are significantly different

Table 9. Selectivity classification of treated insecticides against hymenopteran egg parasitoids based on pooled data of parasitism reduction (PR %) of both seasons (Kharif, 2022 and 2023)

Species	<i>Telenomus dignus</i>		<i>Trichogramma japonicum</i>	
Treatment	PR (%) (Mean±SE)	Class	PR (%) (Mean±SE)	Class
Lambda cyhalothrin 5 % EC	47.59±1.06	2 (Slightly harmful)	53.90±1.87	2 (Slightly harmful)
Chlorpyriphos 50 % + Cypermethrin 5 % EC	40.60±2.01	2 (Slightly harmful)	42.96±2.67	2 (Slightly harmful)
Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC	10.08±0.37	1 (harmless)	16.38±0.07	1 (harmless)
Tetraniliprole 18.18 % w/w SC	25.33±1.53	1 (harmless)	28.96±1.90	1 (harmless)
Chlorantraniliprole 18.5 % w/w SC	18.47±0.46	1 (harmless)	24.19±1.11	1 (harmless)
Bifenthrin 10 % EC	33.26±1.98	2 (Slightly harmful)	35.87±1.52	2 (Slightly harmful)
Cartap Hydrochloride 50 % SP	62.13±1.03	2 (Slightly harmful)	69.49±2.10	2 (Slightly harmful)
Control	0±0	-	0±0	-

**Fig. 1.** Parasitism rate (%) of *Telenomus dignus* in Kharif, 2022 and 2023.**Fig. 2.** Parasitism rate (%) of *Trichogramma japonicum* in Kharif, 2022 and 2023.**Fig. 3.** Parasitism reduction (%) of *Telenomus dignus* in Kharif, 2022 and 2023.

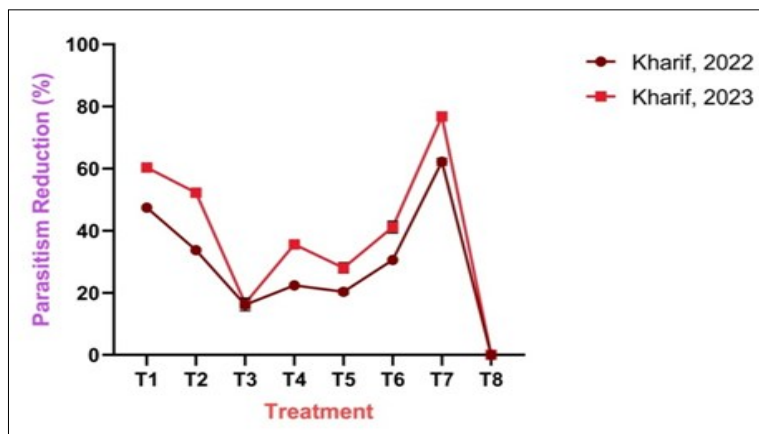


Fig. 4. Parasitism reduction (%) of *Trichogramma japonicum* in Kharif, 2022 and 2023.

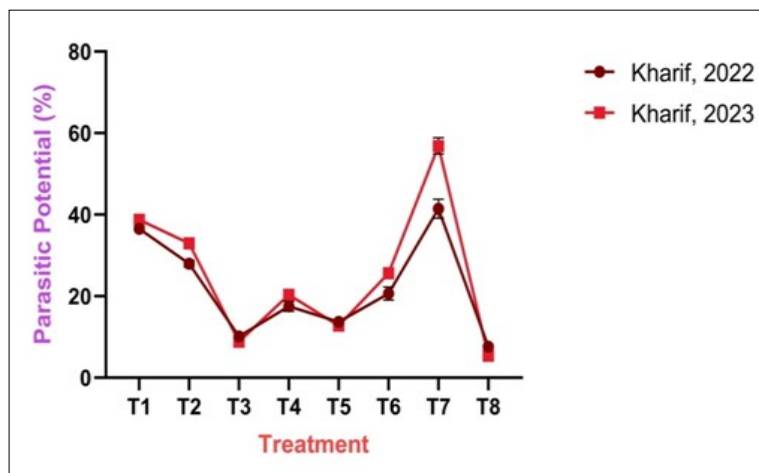


Fig. 5. Parasitic potential (%) of *Telenomus dignus* in Kharif, 2022 and 2023.

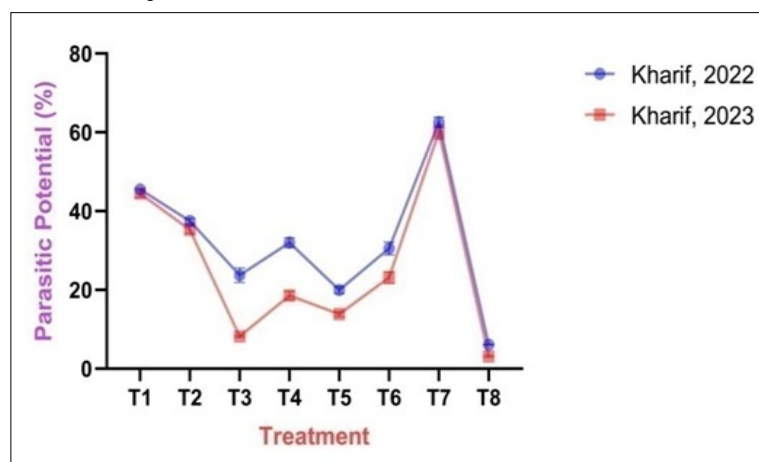


Fig. 6. Parasitic potential (%) of *Trichogramma japonicum* in Kharif, 2022 and 2023.

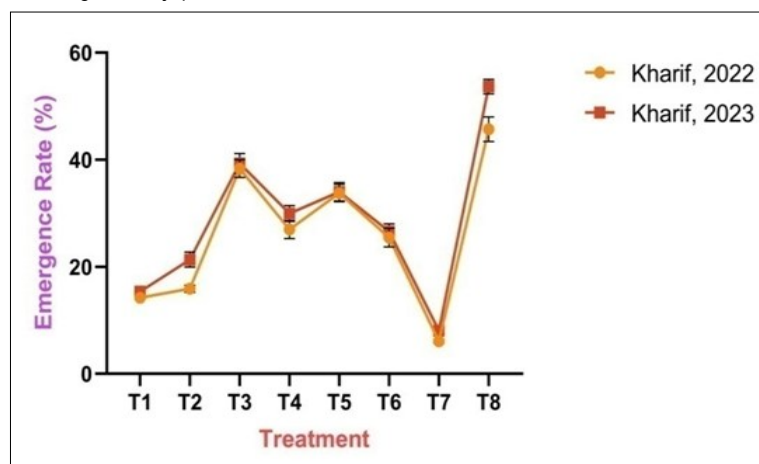


Fig. 7. Adult emergence rate (%) of *Telenomus dignus* in Kharif, 2022 and 2023.

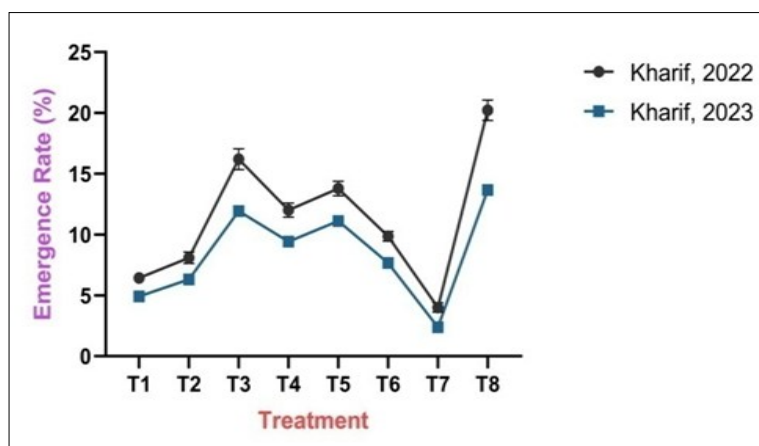


Fig. 8. Adult emergence rate (%) of *Trichogramma japonicum* in Kharif, 2022 and 2023.

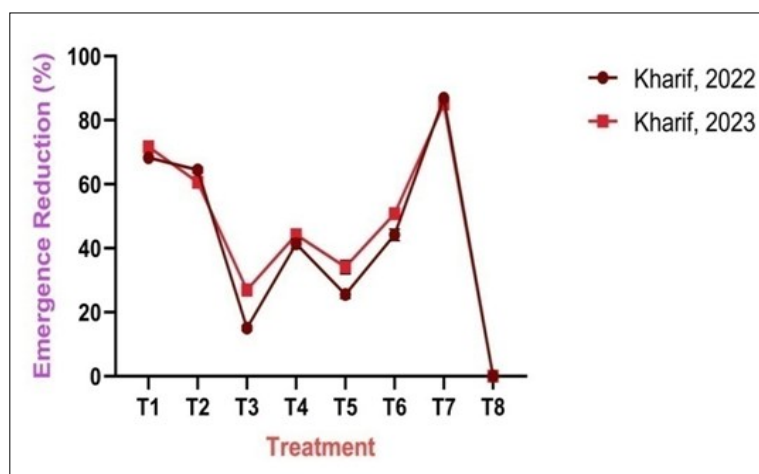


Fig. 9. Adult emergence reduction (%) of *Telenomus dignus* in Kharif, 2022 and 2023.

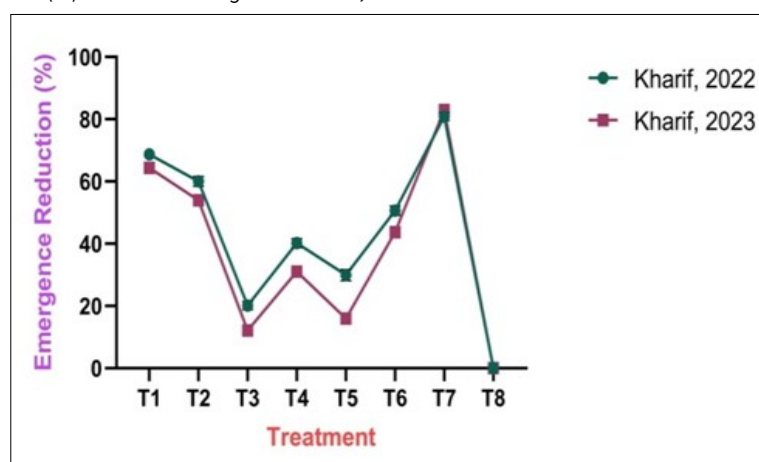


Fig. 10. Adult emergence reduction (%) of *Trichogramma japonicum* in Kharif, 2022 and 2023.

According to the current study, YSB was successfully controlled by Chlorantraniliprole-based treatments, which also preserved significant egg parasitoids in field conditions. These results support the goal of selecting insecticides that promote biological control and ecologically sound rice pest management.

The parasitism rate of *T. dignus* and *T. japonicum* is in conformity with the findings from Indonesia (22). They found that the mixed insecticide Chlorantraniliprole + Thiamethoxam had no harmful effects on the parasitism rate of *T. japonicum* and *T. dignus*. A few researchers also found that the average parasitism rate of *T. dignus* was 50 % in October, whereas the average parasitism rate of *T. japonicum* was recorded to be 23.08 % in November in the location of Tiruchirappalli, Tamil Nadu (21). However, in the present study, the average parasitism rate was

found to be 14.93–18.75 % in the kharif season. Changes in the environment might have resulted in fluctuations in the parasitism rate of the egg parasitoids mentioned during the study. According to their report, the first insecticides considered safe for beneficial parasitoids such as *T. japonicum*, *Telenomus* sp. and *T. schoenobii* were Emamectin benzoate, followed by a combination of Chlorantraniliprole and Thiamethoxam (21). The results indicate that diamide insecticides, particularly Chlorantraniliprole-based treatments, were comparatively safer for key egg parasitoids, thereby supporting biological control in rice ecosystems. Their selective mode of action minimizes adverse effects on beneficial insects while effectively managing YSB. These insecticides effectively target pests while minimizing harm to important natural enemies, thus supporting sustainable pest management

strategies. Another research reported a clear ranking of various insecticides based on their toxic effects on the egg parasitization activity of female *T. japonicum*. According to their observations, the order of increasing toxicity started with the control treatment, which had the least harmful effect, followed by Chlorantraniliprole 18.5 SC, Thiacloprid 21.7 SC, Thiamethoxam 25 WG, Flubendiamide 39.35 SC, Fipronil 5 SC, Lambda-cyhalothrin 5 EC and finally Quinalphos 25 EC, which exhibited the highest level of toxicity. This ranking provides valuable insight into selecting insecticides that minimize adverse impacts on beneficial parasitoids in IPM. Here, they also observed that the parasitism rate of *T. japonicum* in Chlorantraniliprole 18.5 EC was 63.09 %. The observed results corroborate the present findings, owing to a similar mode of action and belonging to the same chemical group. A laboratory bioassay in Brazil reported that Chlorantraniliprole, Flubendiamide and Diflubenzuron, as novel chemical insecticides, resulted in parasitism reduction of less than 10 % for *Telenomus podisi* and *Trichogramma pretiosum* (20). These findings are consistent with our results. Little variation might be observed due to different species of the same genus. A few scientists also reported that Chlorantraniliprole was the least harmful insecticide, with the lowest parasitism reduction (%) among other treated chemicals (24). Another group of researchers found that Thiamethoxam showed a significant reduction in parasitism of Trichogrammatid species (25). These findings highlight the relative safety of Chlorantraniliprole and Thiamethoxam for the beneficial parasitoid in comparison to other insecticides tested. Their records support our present investigation except for the data of adult emergence rate, but they also agreed that Chlorantraniliprole has the highest adult emergence rate. The data may vary due to the environmental condition of the research location as their research work was conducted in laboratory conditions. Few scientists observed that Flubendiamide and Chlorantraniliprole were found to be safer to the adult emergence of *Trichogramma chilonis* when treated with the respective insecticide at 1st, 2nd, 3rd, 4th, 5th and 7th days after parasitization which is also in support of the present investigation (26). Moreover, the results of the present study closely align with previous findings that observed that Thiamethoxam was generally regarded as harmless to the adult emergence of *T. chilonis* when the insecticide was applied during the egg and prepupal stages of the parasitoid's development (27). However, their research also indicated that Thiamethoxam exhibited a slightly harmful effect when applied at the larval stage of the parasitoid, suggesting that the timing of exposure plays a significant role in determining the insecticide's impact on these beneficial insects. Additional support for the present study comes from several researchers who have reported that the insecticides Lambda-cyhalothrin, Thiamethoxam and Thiacloprid are generally categorized as harmless to the adult emergence of *T. pretiosum* (28). These findings align closely with the results of the current investigation, thereby reinforcing and validating the conclusions drawn by previous workers in this field. This consistency across studies highlights the relative safety of these insecticides for beneficial parasitoids involved in biological control programs. The data of adult emergence of these two parasitoids are in close agreement with the findings of several other researchers who have reported that the insecticides Chlorantraniliprole and Thiacloprid are considered non-toxic, or harmless, to the adult emergence of beneficial egg parasitoids such as *T. chilonis* and *T. pretiosum* (29). These observations further

strengthen the evidence supporting the compatibility of these insecticides with biological control agents, reinforcing their suitability for inclusion in IPM programs. A notable discrepancy exists between the present findings and those reported earlier that the combination of Lambda-cyhalothrin and Thiamethoxam exhibited a slightly harmful effect on the adult emergence of *T. pretiosum* (30). In that study, this negative impact was specifically recorded when parasitized eggs were treated with the insecticide mixture on the 8th day after parasitization. This contrast in outcomes suggests that factors such as the timing of insecticide application and the developmental stage of the parasitoid may significantly influence the observed toxicity levels. The observed variation in the relative toxicity of different insecticides on the adult emergence of Trichogrammatid parasitoids may be attributed to several influencing factors. These include the specific species of *Trichogramma* used in the studies, as different species may respond differently to chemical exposure; the concentrations or doses of the insecticides applied and the distinct modes of action associated with each insecticide. Additionally, discrepancies could arise from variations in the experimental methodologies employed by different researchers, as well as the prevailing environmental and weather conditions during the time of investigation, which can significantly impact both the insecticides' efficacy and the parasitoids' development and survival. Lambda-cyhalothrin + Thiamethoxam was found to be moderately harmful (in the present finding lambda-cyhalothrin was found under slightly harmful class) to the egg parasitization of *T. pretiosum* which is in accordance with the present findings (30). A group of researchers reported that the parasitism efficiency of all egg parasitoids targeting the YSB remained largely unaffected up to 91.70 % when exposed to the combination insecticide Chlorantraniliprole + Thiamethoxam. Similarly, a high level of unaffected parasitism, approximately 83.30 %, was observed when the parasitoids were exposed to Pymetrozine and Deltamethrin (22). Their findings further revealed that the combined formulation of Chlorantraniliprole + Thiamethoxam had no negative impact on the parasitism ability of *T. japonicum* and *Telenomus* species; however, it caused a slight reduction in parasitism effectiveness in *T. schoenobii*. On the other hand, the insecticides Pymetrozine and Deltamethrin did not affect the parasitism efficiency of *T. schoenobii*, but they showed a minor negative effect on *T. japonicum* and *Telenomus* species. These results highlight the selective compatibility of certain insecticides with specific parasitoid species and underscore the importance of carefully choosing pest control agents in integrated pest management programs. Several researchers have reported that the insecticides Chlorantraniliprole and Thiacloprid are considered to be non-toxic or harmless to the adult emergence of beneficial egg parasitoids, specifically *T. chilonis* and *T. pretiosum* (29). These findings indicate that the use of these insecticides does not significantly interfere with the developmental process of these parasitoids, thereby supporting their continued survival and effectiveness as biological control agents in IPM programs.

The findings reported by the scientists are in strong agreement with the results of the present investigation, lending further support to its conclusions. However, the observed differences in the relative toxicity levels of various insecticides on the egg parasitization efficiency of *Trichogramma* and *Telenomus* wasps may be attributed to several contributing factors. These may include variations in the specific test insect species used in

different studies, differences in the modes of action of the insecticides under evaluation and the type of host eggs utilized during the experiments. Such factors can significantly influence the outcome and should be carefully considered when comparing results across different studies. The findings also contribute to the ecological pest management strategies in rice field. It also provides useful advice to farmers to eradicate pests by applying selective insecticides with the least amount of disturbance of natural enemies especially egg parasitoids in rice field.

Conclusion

From the present experiment, it can be concluded that Thiamethoxam 17.5 % + Chlorantraniliprole 8.8 % w/w SC, Chlorantraniliprole 18.5 % w/w SC and Tetrilaniliprole 18.18 % w/w SC can be widely used in rice fields as these insecticides were found safer for the available egg parasitoids viz. *T. dignus* and *T. japonicum* than other applied chemicals (Lambda-cyhalothrin, Chlorpyrifos + Cypermethrin, Bifenthrin and Cartap Hydrochloride). So, Chlorantraniliprole may be the best option for controlling YSB because of its strong effectiveness against the insect and comparatively safer effects on beneficial parasitoids, supporting integrated and sustainable pest management techniques. Farmers can achieve constant rice productivity with fewer environmental risks, conserve beneficial insects and eliminate needless pesticide applications by adopting such selective insecticides.

However, the higher cost of Chlorantraniliprole remains a constraint for large-scale adoption. Future research should focus on optimizing dosage, evaluating cost benefit ratios under farmers' field conditions and integrating this molecule with biological control approaches to develop economically viable and farmer-friendly pest management modules.

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Authors' contributions

SS prepared the manuscript; LCP checked the manuscript and helped execute the research work fruitfully. SS was responsible for conducting the experimental work, while SAM carried out the data analysis and interpretation. All authors were actively involved in the development of the manuscript, contributed to its content through critical revisions and provided their approval for the final version submitted for publication.

Compliance with ethical standards

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

Ethical issues: None

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