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Research Article

ASSESSING THE EFFICACY OF NOVEL SYSTEMIC INSECTICIDES ON RICE STEM BORERS AND THEIR IMPACT ON BENEFICIAL INSECT FAUNA SURVIVAL

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ABSTRACT

Rice (*Oryza sativa* L.) is a staple food crop worldwide, but its production is threatened by pests like rice stem borers. Effective pest management strategies are crucial for ensuring high yields and food security. In this study, the effectiveness of various insecticides was evaluated against rice stem borers while considering their impact on the survival of beneficial insect fauna. Five treatments were tested: chlorantraniliprole, chlorantraniliprole + thiamethoxam, fipronil, flubendiamide, and a control group. The efficacy of each treatment was assessed by measuring pre- and post-treatment infestation levels of deadhearts and whiteheads, along with the survival percentage of beneficial insect fauna after one week. Chlorantraniliprole exhibited the highest effectiveness, with post-treatment percent infestation of deadhearts reduced to 2.10% after 72 hours and 1.24% after one week, and an effectiveness rate of 82.53% after 72 hours and 91.17% after one week. Chlorantraniliprole + thiamethoxam showed similar efficacy, with post-treatment percent infestation of deadhearts at 1.00% after 72 hours and 0.67% after one week, and an effectiveness rate of 91.71% after 72 hours and 95.18% after one week. Fipronil and flubendiamide also demonstrated significant effectiveness, albeit slightly lower than chlorantraniliprole-based treatments. The control group exhibited high post-treatment infestation levels and no effectiveness against deadhearts or whiteheads. However, the survival percentage of beneficial insect fauna was remarkably high in the control group. These findings highlight the potential of chlorantraniliprole and its combination with thiamethoxam as effective pest management options for rice cultivation, while emphasizing the importance of integrated approaches to minimize environmental impact. Further research is warranted to validate these results under diverse field conditions and optimize insecticide application protocols for sustainable rice production.

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most crucial staple crops globally, serving as a primary food source for over half of the world's population (Brar and Singh, 2011; Singh et al., 2023). However, its cultivation faces significant challenges from various pests, among which rice stem borers stand out as notorious adversaries (Zhu et al., 2007). Rice stem borers belonging to the orders Lepidoptera and Coleoptera, are a group of insects comprising several species such as *Scirpophaga*, *Chilo* and *Sesamia* (Dey, 2020; Li et al., 2023). These pests primarily infest rice crops during the vegetative and reproductive stages, causing substantial yield losses ranging from 5% to 30% globally, with the potential for complete crop failure under severe infestations (Wilson et al., 2021).

In combating rice stem borers, farmers have traditionally relied heavily on chemical insecticides (Boyd, 2018; Bhagat et al., 2021; Sharmitha et al., 2023). While insecticides play a vital role in pest management strategies, their indiscriminate use raises concerns regarding their ecological impact, including toxicity to non-target organisms and the development of insecticide resistance in target pests (Sánchez-Bayo et al., 2013; Su et al., 2014; Arya et al., 2022; Pathak et al., 2022). Moreover, the effectiveness of insecticides against rice stem borers may vary depending on factors such as application timing, dosage, and the presence of beneficial fauna, which play a crucial role in maintaining ecological balance within rice ecosystems (Kumari et al., 2019; Roy et al., 2019; Ray and Chakraborty, 2021; Katel et al., 2023; Propper et al., 2023).

Beneficial fauna, comprising predators, parasitoids, and pollinators, contribute significantly to pest regulation and pollination services in agroecosystems (Iwai et al., 2018; Bao et al., 2022; Propper et al., 2023). Predatory insects such as spiders, lady beetles, and predatory bugs prey on rice stem borer eggs, larvae, and adults, thus helping in reducing pest populations (Tahir and Butt, 2009; Tixier, 2018; Ali et al., 2020). Similarly, parasitoids such as *Trichogramma* spp., *Telenomus* spp., and *Bracon* spp. parasitize rice stem borer eggs, exerting biological control on their populations (Goulart et al., 2011; Khan et al., 2020; Dodiya et al., 2023; Fortes et al., 2023). Furthermore, pollinators such as bees and butterflies facilitate rice pollination, thereby enhancing yield potential (Barrios et al., 2016; Muhammad et al., 2022).

Understanding the interaction between insecticides and beneficial fauna is critical for devising sustainable pest management strategies in rice cultivation (Gianessi, 2014; Ghosal and Hati, 2019; Bao et al., 2022). While insecticides may effectively suppress rice stem borer populations, they can also have unintended consequences on beneficial fauna, potentially disrupting natural pest control mechanisms and ecosystem services (Gómez-Guzmán and González-Ruiz, 2019; Gunstone et al., 2021; Arya et al., 2022). Therefore, assessing the effectiveness of insecticides against rice stem borers alongside their impacts on beneficial fauna survival is essential for ensuring both pest control and environmental sustainability in rice production systems (Rahaman and Stout, 2019).

The present research aims to evaluate the effectiveness of different insecticides against rice stem borers and their respective impacts on the survival percentage of beneficial insect fauna. By examining the efficacy of insecticides in controlling rice stem borer populations while considering their effects on non-target organisms, this study seeks to provide insights into optimizing pest management practices in rice cultivation for enhanced crop productivity and ecological sustainability.

The current research significantly contributes to existing knowledge on integrated pest management (IPM) strategies in rice cultivation by evaluating the effectiveness of various insecticides against rice stem borers while assessing their impact on beneficial insect fauna survival. By examining the efficacy of chlorantraniliprole, chlorantraniliprole + thiamethoxam, fipronil, and flubendiamide, the study enhances our understanding of the performance of these insecticides under field conditions, aligning with previous research emphasizing the importance of insecticide efficacy for pest control in rice fields. Furthermore, the investigation extends beyond conventional assessments by quantifying the survival percentage of beneficial insect fauna post-treatment, highlighting potential trade-offs between pest control and ecological sustainability. By contextualizing its findings within the broader framework of IPM and comparing results with previous studies, the research underscores the importance of adopting sustainable pest management strategies in rice cultivation, thus advancing our knowledge of effective and environmentally friendly approaches to pest control in agricultural systems.

MATERIALS AND METHODS

Study site

The trial was conducted in rice fields situated at Rice Research Station, Bahawalnagar, Pakistan, chosen for its typical infestation levels of rice stem borers and the presence of beneficial insect fauna. This location provided a representative environment for evaluating the effectiveness of insecticides against rice stem borers while considering their impact on beneficial insect fauna populations.

Insecticides selection

Five insecticides were selected for evaluation: chlorantraniliprole, chlorantraniliprole + thiamethoxam, fipronil, flubendiamide, and a control group with no treatment (Table 1). These insecticides were chosen based on their common usage in rice cultivation and their diverse modes of action against rice stem borers, allowing for a comprehensive assessment of their efficacy.

Experimental design

The trial followed a randomized complete block design to minimize variability. Each insecticide treatment and the control group were replicated thrice across multiple blocks within the field. This design facilitated the comparison of treatment effects while accounting for potential spatial variations in pest infestation and beneficial insect fauna distribution.

Insecticides application protocol

Insecticides were applied using standard agricultural spraying equipment to ensure uniform coverage across the experimental plots. Application rates were determined based on manufacturer recommendations and adjusted as needed according to field conditions such as pest pressure and crop growth stage. Careful application techniques were employed to minimize environmental contamination and off-target effects.

Monitoring protocol for deadhearts and whiteheads

The trial included pre-treatment assessment of deadhearts (% of plants with deadhearts) to establish baseline infestation levels.

$$\text{PreT (\% DHs)} = \frac{\text{SITs}}{\text{STTs}} \times \frac{\text{NITs}}{100} \times 100$$

Where: PreT = Pre-Treatment; DHs = Deadhearts; SITs = Sum of infested tillers; STTs = Sum of total tillers; NITs = Number of infested tillers.

Post-treatment assessments of deadhearts were conducted at 72 hours and one week after insecticide application, along with monitoring of whiteheads infestation.

$$\text{PostT \% In of DHs} = \frac{\text{SITs}}{\text{STTs}} \times \frac{\text{NITs}}{100} \times 100$$

Where: PostT = Post-Treatment; In = Infestation; DHs = Deadhearts; SITs = Sum of infested tillers; STTs = Sum of total tillers; NITs = Number of infested tillers.

Visual inspection of plants allowed for the quantification of infestation levels and assessment of insecticide effectiveness over time.

Assessment of effectiveness against deadhearts and whiteheads

Percent effectiveness against deadhearts and whiteheads was calculated at 72 hours and one week post-treatment, comparing infestation levels between treated and untreated plots.

$$\text{PostT \% Ef against DHs} = \frac{\text{PostT \% In of DHs in Co Tr} - \text{PostT \% In of DHs in In Tr}}{\text{PostT \% In of DHs in Co Tr}} \times 100$$

Where: PostT = Post-Treatment; Ef = Effectiveness; DHs = Deadhearts; Co = Control; Tr = Treatment; In = Insecticide.

$$\text{PostT \% Ef against WHs} = \frac{\text{PostT \% In of WHs in Co Tr} - \text{PostT \% In of WHs in In Tr}}{\text{PostT \% In of WHs in Co Tr}} \times 100$$

Where: PostT = Post-Treatment; Ef = Effectiveness; WHs = Whiteheads; Co = Control; Tr = Treatment; In = Insecticide.

This analysis provided insights into the immediate and longer-term impacts of insecticide applications on pest populations and crop health.

Monitoring of beneficial insect fauna

Prior to insecticide application, the average number of beneficial insect fauna per 5 plants was recorded as a pre-treatment baseline. Survival percentage of beneficial insect fauna was assessed one week post-treatment by counting the average number of beneficial insect fauna per 5 plants in treated and untreated plots. This allowed for the evaluation of insecticide effects on non-target organisms crucial for natural pest control.

$$\text{Su \% of BF after 1 week} = \frac{\text{PostT BF}}{\text{PreT BF}} \times 100$$

Where: Su = Survival; BF = Beneficial insect fauna; PostT = Post-Treatment; PreT = Pre-Treatment.

Data collection procedure

For deadhearts and whiteheads infestation levels, the number of infested tillers was counted, and the percentage of infestation was calculated based on the total number of tillers in each replication (20 plants per replication). Beneficial insect fauna data were collected by counting the average number of beneficial insect fauna per 5 plants in each replication, providing insights into their abundance and response to insecticide treatments.

Statistical analysis

Collected data were subjected to appropriate statistical analyses by using Statistical Software, Statistix® (Var. 8.1) to determine the effectiveness of each insecticide against rice stem borers and its impact on beneficial insect fauna survival. Analysis of variance (ANOVA) and Least Significant Difference (LSD) were employed to compare treatment means and assess significance.

RESULTS

The study aimed to evaluate the effectiveness of various insecticides against rice stem borers while also assessing their impact on the survival percentage of beneficial insect fauna. Five treatments were tested: chlorantraniliprole, chlorantraniliprole + thiamethoxam, fipronil, flubendiamide, and a control group. The results revealed significant variations in the efficacy of the treatments against deadhearts and whiteheads, as well as their effects on beneficial insect fauna survival.

Chlorantraniliprole exhibited promising efficacy against rice stem borers. Pre-treatment deadhearts percentage stood at 8.92%. Following treatment, the post-treatment deadhearts infestation decreased to 2.10% after 72 hours and 1.24% after one week. This corresponded to a notable effectiveness rate of 82.53% after 72 hours and 91.17% after one week. Additionally, the treatment displayed a high efficacy of 89.10% against whiteheads. However, there was a decline in the survival percentage of beneficial insect fauna, dropping to 61.42% after one week (Table 2).

Chlorantraniliprole combined with thiamethoxam exhibited even higher effectiveness against rice stem borers. Pre-treatment deadhearts percentage was slightly higher at 9.32%, but post-treatment infestation reduced significantly to 1.00% after 72 hours and 0.67% after one week. The effectiveness rates were impressive, reaching 91.71% after 72 hours and 95.18% after one week. Similar to chlorantraniliprole alone, this combination also displayed a high effectiveness rate of 88.79% against whiteheads. However, the survival percentage of beneficial insect fauna decreased further to 57.21% after one week (Table 2).

Fipronil demonstrated substantial efficacy against rice stem borers as well. Pre-treatment deadhearts percentage was 10.69%, which decreased to 1.89% after 72 hours and 1.10% after one week. The effectiveness rates were noteworthy, measuring at 84.32% after 72 hours and 92.15% after one week. The treatment also exhibited a high effectiveness rate of 85.87% against whiteheads. Interestingly, the survival percentage of beneficial insect fauna increased slightly to 64.11% after one week compared to pre-treatment levels (Table 2).

Flubendiamide showed effectiveness against rice stem borers, although slightly lower compared to the previous treatments. Pre-treatment deadhearts percentage was 10.77%, decreasing to 1.61% after 72 hours and 1.14% after one week. The effectiveness rates were moderate, at 86.49% after 72 hours and 91.94% after one week. The treatment also displayed a reasonable effectiveness rate of 87.33% against whiteheads. The survival percentage of beneficial insect fauna decreased to 61.28% after one week (Table 2).

The Control group demonstrated the least efficacy against rice stem borers, with a pre-treatment deadhearts percentage of 8.06%. Post-treatment infestation increased drastically to 12.05% after 72 hours and 14.14% after one week, with effectiveness rates of 0.00% for both time intervals. Additionally, the control group showed no effectiveness against whiteheads. Surprisingly, the survival percentage of beneficial insect fauna skyrocketed to 178.11% after one week, indicating possible adverse effects of other factors on the beneficial insect fauna population (Table 2).

Overall, the main findings of the study highlight the varying effectiveness of different insecticide treatments against rice stem borers. Chlorantraniliprole, chlorantraniliprole + thiamethoxam, fipronil, and flubendiamide all demonstrated considerable efficacy in reducing infestation levels, with chlorantraniliprole + thiamethoxam showing the highest effectiveness. However, these treatments also had varying impacts on the survival of beneficial insect fauna, with some combinations leading to a decline in their population. The control group showed poor efficacy against rice stem borers but unexpectedly supported a significant increase in beneficial insect fauna survival, suggesting potential unintended consequences of chemical treatments on non-target organisms (Table 2).

Table 1. Detail of insecticides used in the study.

Treatment	Class/ Group of insecticide	Mode of action	Selectivity	Persistence
chlorantraniliprole	Anthranilic diamides	Acts on insect ryanodine receptors, disrupting calcium regulation leading to paralysis and death	Highly selective for target pests, low impact on non-target organisms	Moderately persistent, with residual activity for several weeks
chlorantraniliprole + thiamethoxam	Anthranilic diamides + Neonicotinoid	Acts on insect ryanodine receptors, disrupting calcium regulation leading to paralysis and death + Acts as a neonicotinoid targeting insect nervous system	Highly selective for target pests, low impact on non-target organisms + Less selective, some impact on non-target organisms	Moderate to long persistence, with residual activity lasting several weeks to months
fipronil	Phenylpyrazole	Blocks GABA-gated chloride channels, causing hyperexcitation and death in insects	Moderately selective, some impact on non-target insects	Highly persistent, with residual activity lasting several months
flubendiamide	Benzenedicarboxamide	Acts on ryanodine receptors, disrupting calcium regulation and causing paralysis in insects	Highly selective for target pests, minimal impact on non-target organisms	Moderately persistent, with residual activity lasting several weeks

Table 2. Effectiveness of insecticides against rice stem borers with their respective survival percentage of beneficial insect fauna.

Treatment	Pre-treatment (% deadhearts)	Post-treatment (% deadhearts)					Beneficial insect fauna/ 5 plants	
		Percent infestation		Percent effectiveness against			Pre-treatment (Average number)	Survival percentage after one week
		72 hours	one week	72 hours	one week	Whiteheads		
chlorantraniliprole	8.92	2.10 b	1.24 b	82.53 b	91.17 b	89.10 a	5.20	61.42 b
chlorantraniliprole + thiamethoxam	9.32	1.00 c	0.67 b	91.71 a	95.18 a	88.79 a	4.87	57.21 b
fipronil	10.69	1.89 b	1.10 b	84.32 b	92.15 ab	85.87 a	5.67	64.11 b
Flubendiamide	10.77	1.61 bc	1.14 b	86.49 ab	91.94 ab	87.33 a	5.27	61.28 b
Control	8.06	12.05 a	14.14 a	0.00 c	0.00 c	0.00 b	5.13	178.11 a
LSD	NS	0.88	0.94	6.09	3.63	9.60	NS	12.23

DISCUSSION

The effectiveness of various insecticides against rice stem borers and their impact on the survival of beneficial insect fauna was assessed in this study. The findings revealed notable variations in the efficacy of different insecticide treatments in controlling rice stem borers and their influence on beneficial insect fauna survival.

Chlorantraniliprole, both alone and in combination with thiamethoxam, exhibited significant efficacy in reducing deadhearts infestation and suppressing whiteheads compared to other treatments. This aligns with prior research emphasizing the effectiveness of chlorantraniliprole in controlling various pests in rice cultivation (Zhang et al., 2013; Nawaz et al., 2017; Lu et al., 2023; Zhang et al., 2023). Moreover, the combination treatment showed synergistic effects, further enhancing its efficacy against rice stem borers. These results corroborate findings by other researchers, who reported similar synergistic effects of chlorantraniliprole combined with other insecticides in controlling pests in other crops (Zhang et al., 2022; Ngegba et al., 2023; Sarkhandia et al., 2023; Wang et al., 2023; Muthusamy et al., 2024).

Similarly, fipronil and flubendiamide demonstrated substantial efficacy in reducing deadhearts infestation, although their effectiveness against whiteheads was slightly lower compared to chlorantraniliprole-based treatments. This finding is consistent with previous studies indicating the effectiveness of fipronil and flubendiamide in controlling a wide range of pests in rice fields (Tohnishi et al., 2005; Li et al., 2007; Kumar et al., 2013; Kasai et al., 2016; Suri and Makkar, 2016; Shyamrao and Raghuraman, 2019; Kooner et al., 2023).

Contrary to the insecticide treatments, the control group exhibited a significant increase in deadhearts infestation post-treatment, with no observed effectiveness against either deadhearts or whiteheads. This underscores the importance of employing effective pest management strategies in rice cultivation to mitigate yield losses caused by rice stem borers.

Furthermore, the survival percentage of beneficial insect fauna varied among treatments but generally remained above 50%, indicating that the selected insecticides had limited adverse effects on non-target organisms. This is consistent with previous studies highlighting the relatively low toxicity of chlorantraniliprole, fipronil, and flubendiamide to beneficial insect fauna (Gradish et al., 2012; Garzón et al., 2015; Un-Nisa et al., 2023).

The present study, situated within the realm of agricultural entomology, contributes significantly to the understanding of IPM strategies by evaluating the efficacy of various insecticides against rice stem borers while considering their impact on beneficial insect fauna survival. By adopting a comprehensive approach that includes rigorous experimental design, statistical analysis, and contextualization within the broader principles of IPM, the study underscores the importance of holistic pest management practices in rice cultivation. Through quantifying the survival percentage of beneficial insect fauna following insecticide treatments and assessing their potential risks to non-target organisms, the study highlights the need for balancing pest control efficacy with environmental sustainability. Furthermore, the findings of the study provide valuable insights for researchers, policymakers, and practitioners in devising sustainable pest management strategies that prioritize biodiversity conservation and minimize reliance on chemical control methods in agroecosystems.

One limitation of the study is its focus on short-term effects, potentially overlooking the long-term consequences of insecticide applications on beneficial insect fauna populations. While the study assessed beneficial insect fauna survival one week post-treatment, it did not fully explore potential sublethal effects or indirect impacts on population dynamics, such as changes in behavior, physiology or habitat quality. Additionally, the narrow scope of the study, limited to a single location and specific insecticide treatments, restricts the generalizability of findings to diverse agroecosystems and alternative pest management strategies. To address these limitations, future research should incorporate longer-term monitoring of beneficial insect fauna populations across varied agricultural landscapes, considering a broader range of insecticide formulations and management approaches to capture the full spectrum of potential impacts.

In addition to considering the survival percentage of beneficial insect fauna, it is essential to examine the broader implications of pesticide applications on ecosystem health. This includes assessing the risks posed to non-target organisms beyond beneficial insect fauna, such as soil microbes, aquatic life, and avian species, and exploring their roles in maintaining ecological balance. By delving into the indirect effects of pesticide drift and runoff on non-target habitats, the research can provide a more nuanced perspective on the environmental consequences of insecticide use. Furthermore, discussing strategies for minimizing environmental harm through IPM approaches, including cultural, biological, and mechanical controls, can offer practical solutions for reducing reliance on chemical inputs while promoting sustainable pest management practices. Emphasizing the importance of crop rotation, habitat diversification, and precision application techniques can help mitigate off-target effects and preserve ecosystem integrity, ultimately fostering resilient agroecosystems that support both crop productivity and biodiversity conservation.

The discussion underscores the imperative for further research to comprehensively assess the efficacy and environmental implications of insecticide use in rice cultivation. Long-term investigations are essential to discern the extended impacts of insecticides on pest populations, including the development of resistance and shifts in pest behavior, while also evaluating their ecological consequences beyond beneficial insect fauna, such as effects on soil health and water quality. Field trials conducted across diverse agroecological zones will provide insights into the robustness of insecticide performance under varied environmental conditions, aiding in the optimization of insecticide selection and application strategies. Continuous monitoring of insecticide resistance in target pest populations is paramount, necessitating the implementation of resistance management strategies to mitigate the emergence and spread of resistance. Moreover, research efforts should prioritize the development of novel pest control technologies, including biopesticides and genetic approaches, to diversify pest management options and reduce reliance on conventional insecticides, thereby promoting the sustainability and resilience of rice production systems.

Generally, the findings suggest that chlorantraniliprole and its combination with thiamethoxam are promising options for integrated pest management strategies in rice cultivation. However, further research is warranted to evaluate the long-term effects of these insecticides on both target pests and non-target organisms under field conditions. Furthermore, studies assessing the economic feasibility and environmental sustainability of these insecticide treatments are crucial for their adoption by rice farmers.

CONCLUSION

The findings of this study shed light on the effectiveness of various insecticides against rice stem borers and their implications for beneficial insect fauna survival in rice cultivation. Chlorantraniliprole emerged as a promising insecticide, demonstrating significant efficacy in reducing deadhearts infestation and suppressing whiteheads while maintaining a reasonable survival percentage of beneficial insect fauna. The combination treatment of chlorantraniliprole with thiamethoxam exhibited synergistic effects, highlighting the potential of integrated pest management approaches for sustainable pest control in rice fields. Furthermore, the efficacy of fipronil and flubendiamide provides additional options for rice farmers seeking alternative insecticides for pest management. While these insecticides showed slightly lower effectiveness compared to chlorantraniliprole, their role in diversifying pest control strategies is noteworthy. Overall, the results underscore the importance of judicious insecticide selection and integrated pest management practices in rice cultivation. By prioritizing the efficacy against target pests while minimizing harm to beneficial insect fauna and the environment, farmers can optimize pest control strategies for sustainable rice production. Moving forward, further research is needed to assess the long-term effects of these insecticides on pest populations, beneficial insect fauna communities, and overall ecosystem health. Field trials under diverse environmental conditions will be essential to validate the efficacy of these insecticides and optimize their application protocols for effective pest management in rice fields. Additionally, continued monitoring of insecticide resistance and the development of novel pest control technologies are critical for ensuring the resilience and sustainability of rice production systems in the face of evolving pest pressures.

AUTHORS' CONTRIBUTIONS

MAA and BA designed and conducted the experiment, collected and analysed the data, and wrote the manuscript; MDG and AMS helped in apprehending the idea of this research, designing the layout of experiment and improving the write-up, format and language of this manuscript; MJN, MI and MFA reviewed the manuscript, added and improved declaration section, edited the format of the tables according to the format of the journal; MAA, BA and MRA contributed in data setting for analysis, reviewed the final manuscript and made the format of this manuscript according to the format of the journal; t final manuscript was ultimately perused, scrutinized and approved for final submission by all the authors.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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