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Trade-Offs in Rice Pest Management: Enhanced Biological Control and Yield Equivalence Compared with Prophylactic Insecticide Use

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A R T I C L E I N F O

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A B S T R A C T

The study was conducted in four consecutive T. Aman seasons from 2021 to 2024 at the experimental farm of the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh, to evaluate the impacts of insecticide application on the abundance of harmful and beneficial arthropods in rice ecosystems, comparing conventional farmer practices (prophylactic insecticide application) and researcher-guided practices (need based/rational). Prior to insecticide application, no significant differences were observed in the populations of both harmful insects and beneficial arthropods, confirming a balanced initial baseline. After the 1st and 2nd insecticide applications, several pest species-including yellow stem borer (YSB), green leafhopper (GLH), rice leafroller (RLR), white leafhopper (WLH), brown planthopper (BPH), short-horned grasshopper (SHG), and white-backed planthopper (WBPH) showed significantly higher abundance in researcher-guided plots, suggesting that insecticide use initially suppressed insect pests but later (after 3rd application) rebound. Conversely, all studied natural enemies were consistently and significantly more abundant in researchers-guided plots throughout all sampling periods indicated that, insecticide applications reduce pest populations rapidly and temporarily, but also drastically diminish the abundance of natural enemy, disrupting biological control and fostering potential pest resurgence risk. The higher parasitism rates of BPH (20.20%), RLR (26.78%), and YSB (27.56%) in researcher-practice fields further highlight the contribution of parasitoids and predators to natural pest suppression. Despite reduced chemical insecticide applications, rice yield showed no significant difference between researcher practice (6.21 t ha^{-1}) and prophylactic insecticide-applied (6.23 t ha^{-1}) plots. The findings underscore that judicious or minimal insecticide use guided by economic threshold levels can conserve natural enemies, sustain pest regulation, and maintain yield stability.

1. Introduction

Rice (*Oryza sativa* L.) remains the world's most vital cereal crop, particularly in Asia. In Bangladesh, rice is a dietary staple and a key determinant of national food security. More than half of the world population primarily depends on rice, specifically in Asia, Latin America, the middle-East and the West Indies. The people of Bangladesh primarily depend on rice and rice consumed here as a staple food and so rice plays a crucial role for ensuring food security. There are three rice cultivation seasons namely; Aus, Aman and Boro, and extensively cultivated throughout the year. However, insect pests pose persistent threats to rice productivity, attacking crops from seedling to maturity. Farmers in Bangladesh typically apply

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insecticides 3–5 times per season (Roy et al., 2025a), often before pest densities reach economic thresholds. While these inputs provide short-term relief, they suppress beneficial arthropods, promote pest resistance, and degrade environmental quality. The production of rice decreases directly and indirectly due to presence of insect-pests at different growth stage of rice from seedling to maturity (Roy et al., 2024). Some arthropods complete their life cycle in rice plant; some are used as host plants. About 232 harmful insect species and 375 natural enemy species have been recorded, and only 20-33 species are identified as the most economically damaging insect pests (Ali et al., 2019; Islam and Catling, 2012; Roy et al., 2024; Roy et al., 2025b). The major pest species of significant concern in Bangladesh encompasses the rice leaf folders (*Cnaphalocrocis medinalis* Guenée), stem borer (*Scirpophaga incertula* Walker), green leafhopper (*Nephotettix virescens* Distant), brown planthopper (*Nilaparvata lugens* Stal°), rice hispa (*Dicladispa armigera* Olivier), white-backed planthopper (*Sogatella furcifera* Horv´ath), small brown planthopper (*Laodelphax striatellus* Fallen), and gall midge (*Orseolia oryzae*, Wood-mason) as substantiated by a recent investigation (Ali et al., 2019; Islam and Catling, 2012; Roy et al., 2025a). Among the insect pests, some are directly damage plants by feeding on leaves, cell sap sucking from stem, internal feeder, grain sucking etc.

Farmers in Bangladesh depends heavily on synthetic insecticides to manage rice insect pests because of their easy availability, active marketing, relatively low cost, ease of use, and quick efficacy in either eliminating insect pests or changing their detrimental habits (Horgan et al., 2021; Roy, et al., 2025a). Farmers of Bangladesh normally use 3-5 times pesticides for rice cultivations (Roy et al., 2025a). Application of insecticides not only kill insect pests but also make them resistance against insecticides. In addition, farmers of Bangladesh start insecticide application from early stage of rice when pest populations might under the economic threshold levels (Bari et al., 2015). Moreover, insecticides negatively influence the habitat of natural enemies, human health and the environment. The natural enemies (comprising parasitoids and predators) perform diverse ecological roles. Which engage from herbivory on rice plants to pollination, parasitization, predation, nutrient cycling and decomposition (Bari et al., 2025). The intricate relationships among rice plants, insect-pests, and numerous natural enemy species are designed to create equilibrium and prevent epidemics of abnormal pests. So, to protect natural enemies some strategies need to take. Natural enemies, predators and parasitoids can play critical ecological roles by maintaining pest populations below outbreak levels. Hence, strategies such as ecological engineering and rational insecticide use are essential to protect natural enemies and foster sustainable pest regulation (Bari et al., 2025). Nevertheless, information remains limited regarding the long-term effects of prophylactic insecticide applications on pest-natural enemy interactions in Bangladeshi rice ecosystems. Therefore, the present study was undertaken to compare continuous insecticide application (farmer practice) with rational/ need-based application (researcher practice), focusing on pest and natural enemy dynamics and their influence on grain yield, with the objective of identifying a more sustainable and ecologically sound pest management strategy for rice production in Bangladesh.

2. Materials and methods

2.1. Study Area

The present investigation was conducted in the research field of Entomology Division at Bangladesh Rice Research Institute (BRRI), Gazipur (23°59′29.3″N and 90°24′25.2″E) during T. Aman season from 2021 to 2024 (Fig. 1).

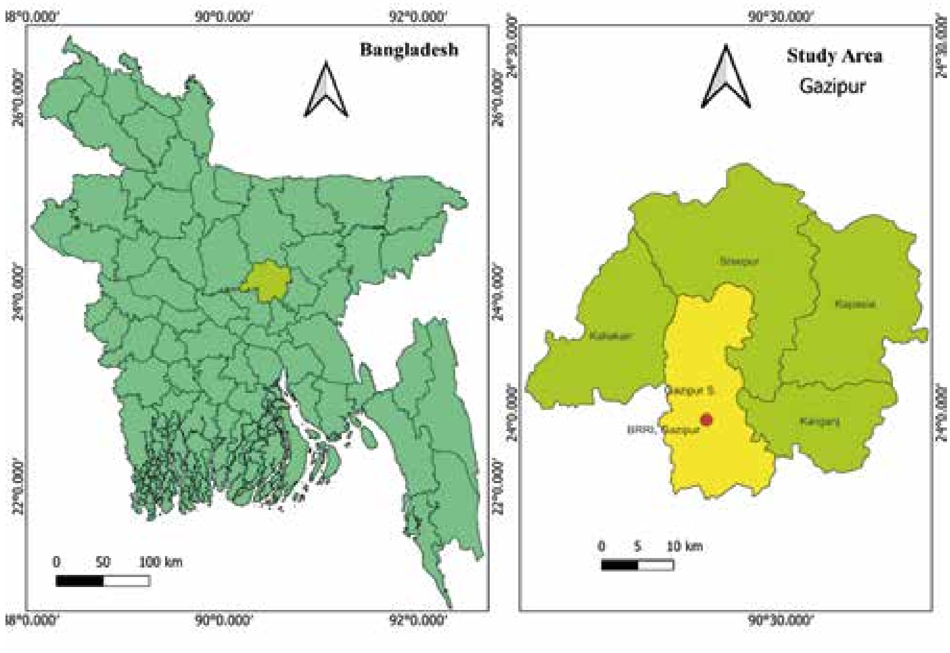

Fig. 1. Location map of study area.

2.2. Treatment, Agronomic management and Application of insecticide

There were two treatments (a) T_1 = Farmers practice (3 times application of insecticide), (b) T_2 = Researcher practice (judicial use of insecticide/ almost insecticide free). The experiment followed a randomized complete block design (RCBD) with three replications. BRRI dhan87 was used during T Aman season in 2021 and 2022, whereas BRRI dhan103 was used in 2023 and 2024. Firstly, seeds were soaked for 24 hours and after germination of the seeds, they were sown on the wet seedbed of BRRI research fields. Twenty-five days old seedlings were transplanted in the main fields. The spacing 20 × 20 cm was maintained between plants and rows, with a 60 cm spacing from one plot to another plot. Individual plot was 15 decimals in size, so one treatment required 45 decimals land. The crop was cultivated following the BRRI recommended fertilizer management package, which included urea, muriate of potash (MoP), triple superphosphate (TSP), zinc sulfate and gypsum, applied at rates of 165, 60, 105, 5 and 61 kg ha^{-1} respectively in both treatments.

The experimental fields were kept weed free by herbicide use and manual hand weeding. Supplementary irrigation was provided as per requirement until flowering stage. In farmers practice (T_1) plots, herbicide was used one time, consequently three times of insecticides applications were done by hand broadcast (granular insecticide) and by spraying with knapsack sprayer (wettable granule and wettable powder). In the T_1 treatment, insecticides were applied three times following standard farmer practices. A granular insecticide, fipronil 3GR @ 10.0 kg/ha, was applied once, while a foliar spray mixture of (chlorantraniliprole + thiamethoxam) 40 WG @ 75.0 g/ha was applied twice at 25-day intervals. The first granular application coincided with the first top dressing of nitrogenous fertilizer (urea), followed by two subsequent foliar applications at 25-day intervals.

The experimental fields T_2 (Research practice plots) were maintained at an even water level to suppress weed growth followed by hand weeding. Rice seedlings were ensured to be free from weed contamination at the time of transplanting. Balanced doses of basal fertilizers were applied, along with split applications of nitrogenous fertilizers, to minimize the incidence of planthopper infestation, bacterial blight, and stem rot diseases. In research practice field (T_2), insecticide applications were deliberately withheld for the first 30 days after transplanting (DAT) to promote the buildup of natural enemies and maintain ecological balance within the rice ecosystem. But in 2022 and 2024, only one-time insecticide (Isoprocarb 75 WP) was applied at 60 DAT in researcher practice (T_2) plots due to high abundance of brown planthopper at economic threshold levels.

2.3. Data Collection

Insect pests and their natural enemies were collected four times by 20 complete hand sweeping. The first sweeping was done before application of insecticide. The 2nd, 3rd and 4th sweeping was done 3 days after application of insecticide in T_1, respectively. Sweeping was also done at similar time frame in T_2. After collection of insect-pests, they were kept in a killing jar with chloroform rinsed cotton inside it for an hour for mortality. Then identification was done by naked eye and helps of stereo-microscope. The number of insect pests and natural enemies obtained from all sweeps in both treatments was counted and recorded separately for comparative analysis. The egg parasitism percentage of brown planthopper, yellow stem borer and larval parasitism of rice leaf folder was calculated by the following formula-

$$\text{Parasitism (\%)} = \frac{\text{Number of Parasitized Eggs or Larvae}}{\text{Total Number of Host or Larvae}} \times 100$$

Egg parasitism was studied using the retrieval method, while larval parasitism was assessed by collecting larvae from the field, which naturally infested.

2.4. Statistical Analysis

The number of insect pests and natural enemies obtained from all sweeps in both treatments was counted and recorded separately for comparative analysis. All data were analyzed separately using analysis of variance (ANOVA) via "doebioresearch" package in R studio software (version2025.09.00 + 387). The Least Significant Difference (LSD) test, with a significance level of 5%, was used to find significant differences between treatment means. Graphical analysis was performed using the "AgroR" package in R studio. The QGIS software (versions 3.22.9) was used to build the study area map.

3. Results

3.1. Status of harmful insects and their natural enemies before insecticide application

The abundance of the brown planthopper (BPH), green leafhopper (GLH), yellow stem borer (YSB), white leafhopper (WLH), short horned grasshopper (SHG), white-backed planthopper (WBPH), long horned grasshopper (LHG), rice leafroller (RLF), rice bug (RB) and rice whorl maggot (RWM) showed statistically non-significant at both farmers practice and researcher practice field (Table 1). Similarly, the prevalence of spider, damsel fly, dragon fly, ladybird beetle, parasitic wasps, green mirid bug and carabid beetle exhibited non-significance at farmers practice and researcher practice (Table 2). Before insecticide application, no significant differences were observed between treatments for pest or natural enemy abundance, indicating comparable initial field conditions. These results indicate that both treatments started with similar pest pressure and natural enemy abundance, providing a uniform baseline for evaluating the effects of insecticide application.

Table 1

Prevalence of insect pests (number per 20 complete sweeps) before insecticide application in both researcher practice and farmers practice fields during T. Aman season from 2021 to 2024.

Treatment	BPH	GLH	YSB	RB	WLH	SHG	RLR	LHG	WBPH	RWM
T_1 = Farmers practice	0.88	3.63	0.88	0.63	2.13	4.13	0.63	1.13	0.88	2.88
T_2 = Researcher practice	1.00	3.50	0.63	0.50	2.00	4.38	0.50	1.25	0.50	2.88
Levels of Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
p-value	0.3	0.7	0.3	0.7	0.3	0.7	0.7	0.6	0.2	0.9

(**Legend:** BPH; brown planthopper; GLH: green leafhopper; YSB: yellow stem borer; RB: rice bug; WLH: white leafhopper; SHG: short horned grasshopper; RLR: rice leaffolder; LHG: long horned grasshopper; WBPH: white backed planthopper; RWM: rice whorl maggot; LSD: least significance difference; CV: coefficient of variation)

Table 2

Prevalence of natural enemies (number per 20 complete sweeps) before insecticide application in both researcher practice and farmers practice fields during T. Aman season from 2021 to 2024.

Treatment	Spider	Dam. fly	Drag. fly	LBB	PW	GMB	CBB
T_1 = Farmers practice	2.00	2.38	1.25	2.25	2.00	2.50	2.38
T_2 = Researcher practice	2.13	2.50	1.38	2.50	1.88	2.63	2.50
Levels of Significance	ns	ns	ns	ns	ns	ns	ns
p-value	0.7	0.7	0.7	0.5	0.7	0.7	0.8

(**Legend:** LBB: ladybird beetle; PW: parasitic wasps; GMB: green mirid bug; CBB: carabid beetle; LSD: least significance difference; CV: coefficient of variation).

3.2. Status of insect pests and their natural enemies in farmers practice (T_1) and researcher practice (T_2) field after 1st application of insecticide

Statistically significant differences were observed in the abundance of GLH, WLH, SHG, YSB, RLR, BPH and WBPH in farmers practice fields (T_1) and researchers practice field (T_2). However, LHG, RB and RWM showed non-significant difference (Table 3). Whereas researcher practice (T_2) demonstrated highest prevalence of these harmful insects compared with farmers practice (T_1) at first application of insecticide in farmers practice fields. The prevalence of natural enemies after 1st applications of insecticide in farmers practice fields showed statistically significant differences (Table 4) and the studied natural enemies (spider, damsel fly, dragon fly, ladybird beetle, parasitic wasps, green mirid bug and carabid beetle) found highest at researcher practice fields.

Table 3

Abundance of insect pests (number per20 complete sweeps) after 1st application of insecticides in farmers practice field (T_1) during T. Aman season from 2021 to 2024.

Treatment	BPH	GLH	YSB	RB	WLH	SHG	RLR	LHG	WBPH	RWM
T_1 = Farmers practice	0.38	1.63 b	0.25 b	0.50	1.00b	2.13 b	1.13 b	0.63	0.36	1.38
T_2 = Researcher practice	0.88	3.88 a	1.00 a	0.63	1.63 a	5.25 a	1.75 a	1.13	0.88	1.50
Levels of Significance	*	***	***	ns	**	***	**	ns	*	ns
LSD	0.41	0.68	0.37	-	0.36	0.64	0.43	-	0.41	-
p-value	0.02	<0.001	<0.001	0.6	0.002	<0.001	0.008	0.06	0.02	0.7

(**Legend:** BPH; brown planthopper; GLH: green leafhopper; YSB: yellow stem borer; RB: rice bug; WLH: white leafhopper; SHG: short horned grasshopper; RLR: rice leaffolder; LHG: long horned grasshopper; WBPH: white backed planthopper; RWM: rice whorl maggot; LSD: least significance difference; CV: coefficient of variation).

Table 4

Abundance of natural enemies (number per 20 complete sweeps) after 1st application of insecticides in farmers practice during T. Aman season from 2021 to 2024.

Treatment	Spider	Damsel fly	Dragon Fly	LBB	PW	GMB	CBB
T_1 = Farmers practice	1.62 b	0.75 b	0.75 b	1.50 b	1.25 b	1.00 b	1.00 b
T_2 = Researcher practice	3.13 a	2.13 a	2.38 a	3.25 a	2.25 a	2.00 a	4.63 a
Levels of Significance	***	***	***	***	***	***	***
LSD	0.41	0.43	0.49	0.50	0.78	0.41	0.64
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

(**Legend:** LBB: ladybird beetle; PW: parasitic wasps; GMB: green mirid bug; CBB: carabid beetle; LSD: least significance difference; CV: coefficient of variation).

3.3. Status of insect pests and their natural enemies in farmers practice (T_1) and researchers practice (T_2) after 2nd application of insecticide

After 2nd time application of insecticide in farmers practice (T_1) field, the abundance of GLH, WLH, SHG, YSB, RB and RWM showed statistically significant differences, whereas researcher practice demonstrated highest prevalence of these harmful insects compared with farmers practice (Table 5). Furthermore, the prevalence of LHG, RLF, BPH and WBPH demonstrated non-significant difference. Moreover, the abundance of natural enemies after 2nd application of insecticide in farmers practice fields (T_1) showed statistically significant differences (Table 6). In contrast, natural enemies (spider, damsel fly, dragon fly, ladybird beetle, parasitic wasps, green mirid bug and carabid beetle) remained significantly higher in researcher-guided plots (T_2) throughout all sampling periods.

Table 5
Abundance of insect pests (number per 20 complete sweeps) after 2nd application of insecticides in farmers practice (T_2) field during T. Aman season from 2021 to 2024.

Treatment	BPH	GLH	YSB	RB	WLH	SHG	RLF	LHG	WBPH	RWM
T_1 = Farmers practice	1.63	4.75	2.00 a	1.38 a	2.25 b	3.88 b	1.75	1.38	1.13	2.38 a
T_2 = Researcher practice	1.13	5.75	1.25 b	0.63 b	3.13 a	5.25 a	1.50	0.88	0.63	1.25 b
Levels of Significance	ns	*	**	*	**	*	ns	ns	ns	**
LSD	-	0.91	27.83	20.00	0.54	1.36	-	-	-	0.59
p-value	0.1	0.03	0.007	0.01	0.004	0.05	0.1	0.06	0.06	0.002

(**Legend:** BPH; brown planthopper; GLH: green leafhopper; YSB: yellow stem borer; RB: rice bug; WLH: white leafhopper; SHG: short horned grasshopper; RLR: rice leaffolder; LHG: long horned grasshopper; WBPH: white backed planthopper; RWM: rice whorl maggot; LSD: least significance difference; CV: coefficient of variation).

Table 6
Abundance of natural enemies (number per 20 complete sweeps) after 2nd application of insecticides in farmers practice (T_1) field during T. Aman season from 2021 to 2024.

Treatment	Spider	Damsel Fly	Dragon Fly	LBB	PW	GMB	CBB
T_1 = Farmers practice	2.13 b	0.75 b	2.00 b	0.88 b	0.63 b	1.00 b	0.75 b
T_2 = Researcher practice	4.13 a	2.63 a	3.00 a	2.38 a	3.00 a	2.00 a	3.75 a
Levels of Significance	***	***	*	***	***	***	***
LSD	0.88	0.68	0.85	0.41	0.54	0.41	0.62
p-value	<0.001	<0.001	0.02	<0.001	<0.001	<0.001	<0.001

(**Legend:** LBB: ladybird beetle; PW: parasitic wasps; GMB: green mirid bug; CBB: carabid beetle; LSD: least significance difference; CV: coefficient of variation).

3.4. Status of insect pests and their natural enemies in farmers practice (T_1) and researchers practice (T_2) field after 3rd application of insecticide

The prevalence of SHG and RLR showed significant differences between farmers practice (insecticide applied fields) and researcher practice field after 3rd application of insecticide in farmers practice (T_1) field. The prevalence of SHG showed highest in researcher practice and RLR showed highest in farmers practice field (Table 7). Moreover, the abundance of others harmful insects (GLH, WLH, LHG, YSB, BPH, WBPH, RB and RWM) showed non-significant differences between T_1 and T_2 (Table 7). The highest prevalence of natural enemies, including spiders, damsel flies, dragonflies, ladybird beetles, parasitic wasps, green mirid bugs, and carabid beetles in the researcher practice plots (T_2). Conversely, natural enemy populations were significantly lower in the farmers' practice plots due to insecticide exposure (Table 8).

Table 7
Abundance of harmful insects (number per 20 complete sweeps) after 3rd application of insecticides in farmers practice field during T Aman season from 2021 to 2024.

Treatment	BPH	GLH	YSB	RB	WLH	SHG	RLR	LHG	WBPH	RWM
T_1 = Farmers practice	1.75	3.12	1.38	0.88	2.50	3.63 b	2.25 a	1.50	1.25	0.75
T_2 = Researcher practice	1.38	3.75	0.88	0.38	2.88	5.25 a	1.25 b	1.38	0.88	0.88
Levels of Significance	ns	ns	ns	ns	ns	**	***	ns	ns	ns
LSD	-	-	-	-	-	1.08	0.41	-	-	-
p-value	0.2	0.2	0.06	0.06	0.5	0.007	<0.001	0.7	0.08	0.06

(**Legend:** BPH; brown planthopper; GLH: green leafhopper; YSB: yellow stem borer; RB: rice bug; WLH: white leafhopper; SHG: short horned grasshopper; RLR: rice leaffolder; LHG: long horned grasshopper; WBPH: white backed planthopper; RWM: rice whorl maggot; LSD: least significance difference; CV: coefficient of variation).

Table 8
Abundance of natural enemies (number per 20 complete sweeps) after 3rd application of insecticides in farmers practice field during T. Aman season from 2021 to 2024.

Treatment	Spider	Damsel fly	Dragon Fly	LBB	PW	GMB	CBB
T_1 = Farmers practice	2.00 b	1.13 b	1.38 b	0.88 b	0.75 b	0.88 b	1.00 b
T_2 = Researcher practice	4.25 a	2.00 a	3.63 a	2.88 a	2.75 a	2.50 a	3.25 a
Levels of Significance	***	**	***	***	***	**	***
LSD	0.68	0.59	0.76	0.85	0.81	1.06	0.68
p-value	< 0.001	0.007	< 0.001	< 0.001	< 0.001	0.006	< 0.001

(**Legend:** LBB: ladybird beetle; PW: parasitic wasps; GMB: green mirid bug; CBB: carabid beetle; LSD: least significance difference; CV: coefficient of variation).

3.5. Parasitism of some key insects and grain yield in both insecticide applied and rational insecticide treated plot

The percentage of egg and larval parasitism of some major insects (brown planthopper, rice leaffolder and yellow stem borer) exhibited significant differences between insecticide free (researcher practice) and with four times insecticide applied (farmers practice) fields (Figs. 2, 3, & 4). Egg parasitism percentage of BPH (20.02%), YSB (27.56%) and larval parasitism of RLR (26.78%) showed highest in researcher practice fields (T_2). The average grain yield of researcher practice field (6.23 t ha^{-1}) and prophylactic insecticide applied (6.21 t ha^{-1}) fields exhibited non-significance difference (Fig. 5), indicating that reduced insecticide use did not compromise productivity.

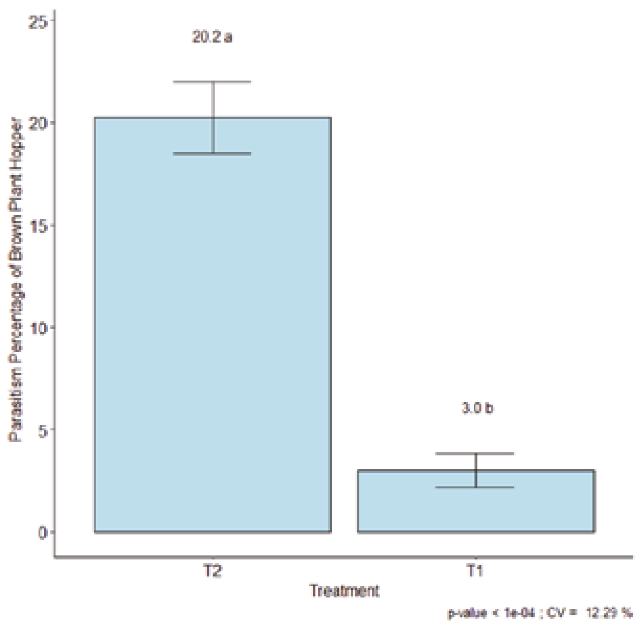

Fig. 2. Egg parasitism percentage of brown plant hopper during T. Aman season from 2021 to 2024.

(**Legend:** T_1 = Farmers practice (prophylactic insecticides applied field), T_2 = Researcher practice (“rational/need based” use of insecticides).

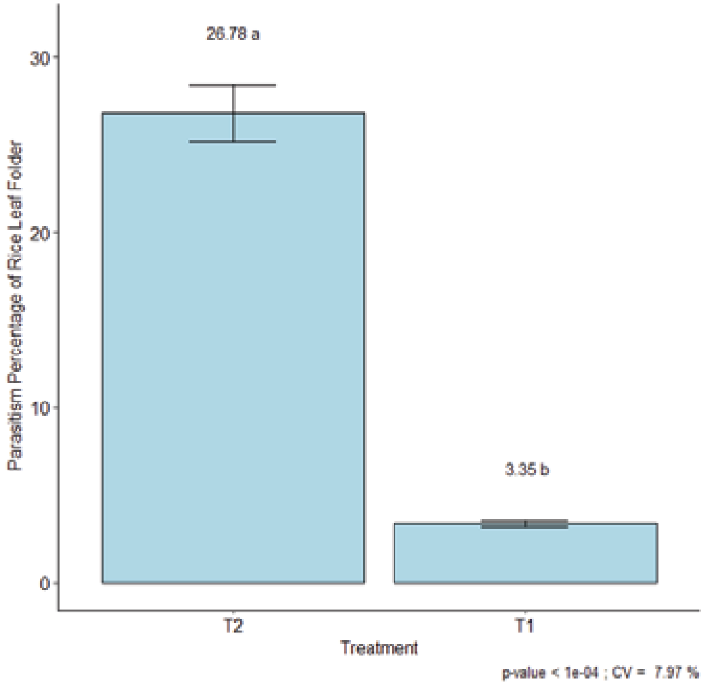

Fig. 3. Larval parasitism percentage of rice leaffolder during T. Aman season from 2021 to 2024.

(**Legend:** T_1 = Farmers practice (prophylactic insecticides applied field), T_2 = Researcher practice ("rational/need based" use of insecticides).

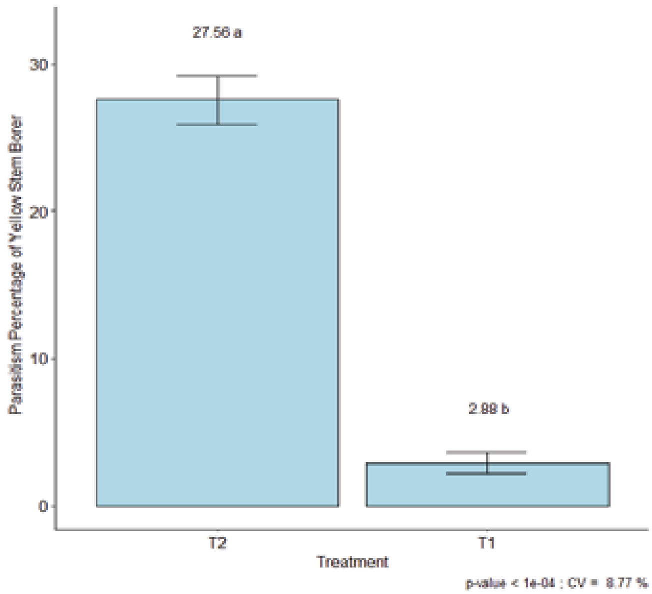

Fig. 4. Egg parasitism percentage of yellow stem borer during T. Aman season from 2021 to 2024.

(**Legend:** T_1 = Farmers practice (prophylactic insecticides applied field), T_2 = Researcher practice ("rational/need based" use of insecticides).

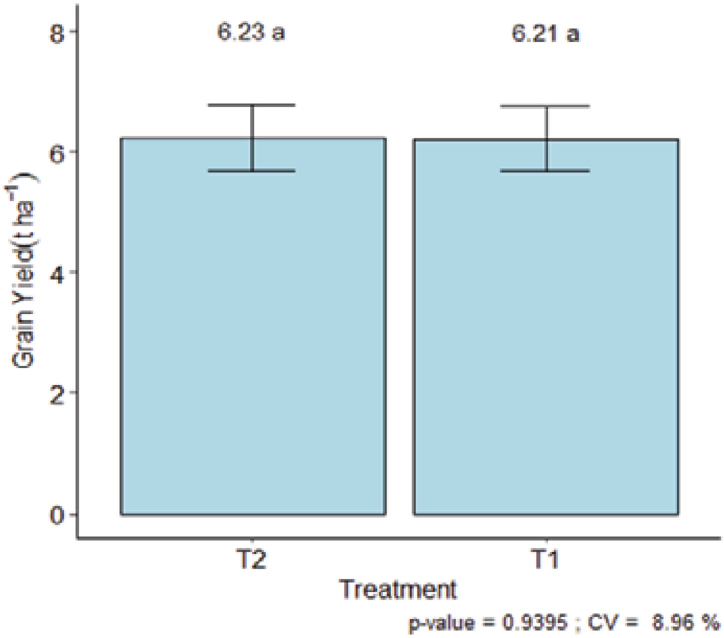

Fig. 5. Average grain yield of different treatments during T. Aman season from 2021 to 2024.

(**Legend:** T_1 = Farmers practice (prophylactic insecticides applied field), T_2 = Researcher practice ("rational/need based" use of insecticides).

4. Discussion

The presence of harmful insects and their natural enemies were observed in rice ecosystems throughout the cultivation process of rice. But the abundance of ups and downs based on the growth stage, availability of foods and disruption of ecosystem by application of insecticides. The natural enemy populations decrease due to indiscriminate applications of insecticides in rice fields which promotes pest outbreaks (Ali et al., 2019; Heong et al., 2015). In present study, we modified insecticide application (rational/need based insecticide application if damage reach to economic threshold level) which promotes biocontrol agents and naturally reduces pests populations and by maintaining no significant losses of rice yields. Prior to any insecticide application of both the treatments, statistically non-significant differences of insect pests and natural enemies in the all studied between the farmers practice (insecticide treatment) and researchers practice (rational use of insecticides) fields establishes a crucial baseline (Table 1 and 2). Our findings indicate that the initial pest and natural enemy pressure was comparable across both treatments at early stage of rice. The balance biodiversity of rice insect pests and their natural enemies observed at early stage of rice without insecticide application, thus helps to pest management naturally (Chaitanya et al., 2024; Chishi et al., 2025; Roy et al., 2024). After application of insecticide in farmers practice, initially observed significant reduction of both harmful and natural enemy. In addition, the results demonstrated that some pest species were more abundant in researcher practice plots after the 1st and 2nd application of insecticides (e.g., GLH, WLH, SHG, YSB, RB, RWM) while other species showed non-significant differences or mixed responses after repeated applications (3rd application) exhibited to specific responses and to temporal dynamics. Insecticide applications can result immediate reductions in susceptible insect pests but also cause trophic cascades (loss of natural enemies) and, in some cases, pesticide-induced pest resurgence via reduced predation, parasitism or sub-lethal stimulation of pest reproduction (Mu et al., 2016; Netra et al., 2024; Ye et al., 2024). Previous studies documented both acute and chronic forms of resurgence in rice planthoppers, mediated by loss of natural enemies, by physiological changes, specifically increased the levels of juvenile hormone and enhancement of fecundity in pest population after exposure to certain pesticides (Gao et al., 2025; Netra et al., 2024).

A consistent pattern was observed across all three insecticide applications (Tables 4, 6, and 8) and was the highest prevalence of natural enemies including spiders, damsel flies, dragonflies, ladybird beetles, parasitic wasps, green mirid bugs, and carabid beetles in the researcher practice plots. Conversely, natural enemy populations were significantly lower in the farmers' practice plots due to insecticide exposure. These findings align with earlier reports showing that insecticides suppress predator and parasitoid species more severely and persistently than they suppress pest populations (Zhang et al., 2017). The continuous high abundance of these predators and parasitoids species in the researcher practice plots highlights the destructive impact of the farmer's insecticide practice on biodiversity and balance ecosystem within the rice field. This phenomenon is well documented in recent studies, where broad-spectrum insecticides applications often cause severe mortality or behavioral disruption in beneficial arthropods, which are crucial for natural pest management (Ali et al., 2019; Bari et al., 2025; Chaitanya et al., 2024; Netra et al., 2024). Moreover, the survived natural enemies face delayed recolonization, and some species required long time to recover after application of insecticides. Moreover, the reduced or absence of the availability of predator or parasitoid species promotes to increase the pest population status even if a short-term knockdown of pests occurs immediately after spray (Ali et al., 2019, 2021; Bari et al., 2025). Natural enemies prey on adults, larvae, and eggs of harmful insects (Roy et al., 2024; Sathischandra et al., 2014). For example, hoppers such as BPH, WBPH, GLH, and SHG serve as prey for green mirid bugs (Islam and Catling, 2012; Roy et al., 2024). The eggs of GLH, SHG, YSB, RLR, BPH, and WBPH are parasitized by parasitic wasps, while ladybird beetles consume nymphs, eggs, and larvae of planthoppers and stem borers (Morshed et al., 2023; Roy et al., 2024). Carabid beetle preys on planthoppers, leafhoppers, stem borers, and root borers (Roy et al., 2024; Sathischandra et al., 2014). Spiders, being highly mobile, quickly colonize rice fields and efficiently predate on numerous pests, including nymphs of hoppers and moths of yellow stem borers and leaf folders (Morshed et al., 2023; Roy et al., 2024). Global estimates suggest that spiders collectively destroy 400–800 million tons of insect pests annually (Nyffeler and Birkhofer, 2017). Resurgence commonly occurs when insecticide application eliminates a greater proportion of natural enemies than target pests, enabling surviving pests to reproduce unchecked, resulting in secondary pest outbreaks (Ali et al., 2019; Bari et al., 2025). The data on parasitism rates strongly supports the effectiveness of biological control in the researcher practice plots. The significantly higher parasitism percentages for brown plant hopper (18.5%), rice leaf folder (29.08%), and yellow stem borer (29.08%) in the researcher practice (Fig. 2, 3, and 4) directly correlates with the highest prevalence of parasitoid, parasitic wasps in these fields (Tables 4, 6, and 8). This is a clear demonstration that insecticide applications severely compromise the natural pest management provided by parasitoids, which are highly susceptible to pesticide exposure (Abdel-Raheem, 2022; Gurr et al., 2003). The higher parasitism rates in the researcher practice plots indicate a robust natural mechanism for natural pest suppression (Ali et al., 2019; Bari et al., 2025). Importantly, grain yield did not differ significantly between the farmers' and researcher practice plots. Similar findings have been reported in previous studies, showing that insecticide-free fields maintain comparable yields to prophylactically sprayed fields (Ali et al., 2019; Bari et al., 2025).

Overall, the results demonstrate that routine insecticide applications disrupt ecological balance, reduce biodiversity, and weaken biological control without providing measurable yield benefits. In contrast, rational insecticide use based on economic threshold levels preserves beneficial arthropods while maintaining effective pest regulation and stable rice production.

5. Conclusion

At the initial stage of rice cultivation, the abundance of harmful insects and their natural enemies was identical across both management practices. However, following insecticide applications, the populations diverged significantly, harmful insects showed varied responses, while natural enemies experienced sharp declines. Field under the researcher practice maintained consistently higher levels of natural enemies, which were sufficient to keep pest populations below damaging levels and protect grain yield. This demonstrates that routine insecticide use in farmers' practice is ecologically detrimental and economically unnecessary, as it disrupts biodiversity without improving yield. These findings reinforce the importance of Integrated Pest Management (IPM) strategies emphasizing conservation of natural enemies, monitoring and threshold-guided management, and the use of selective, reduced-risk interventions when management is necessary. Adoption of such strategies can reduce pesticide dependence, enhance biodiversity, strengthen ecosystem services, and promote the long-term sustainability of rice production systems.

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