

Eco-Friendly Integrated Management of Rice Yellow Stem Borer, *Scirpophaga incertulas* in Sindh, Pakistan

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ABSTRACT

The yellow stem borer, *Scirpophaga incertulas* Walker is one of the most destructive insect pests of rice globally from the seedling stage to crop maturity. Synthetic insecticides have led to environmental pollution, resistance development and health concerns, emphasizing the need for eco-friendly alternatives. This study was conducted across major rice-growing districts of Sindh, Pakistan during 2022-2023 to evaluate the effectiveness of integrated, non-chemical, eco-friendly management practices (Mechanical, Cultural and Post-harvest cultural practices). Temperature positively but non-significantly ($r = -0.52$) correlated with the dead hearts percentage but white ears percentage had a significant negative correlation with temperature. Relative humidity exhibited a negative, but non-significant correlation with white ear incidence. Field observations, based on stubble dissection, confirmed that *S. incertulas* overwinters within rice stubbles from November to April, the highest seasonal male captures in sex pheromone traps were recorded in Larkana district during 2022. Whereas light traps attracted both sexes and recorded the highest overall catch from all districts. Moth activity declined in the second year (2023), resulting in reduced male captures in sex pheromone traps with significant difference ($DF=86$, $F=92.74$, $P=0.001$). Across both years, higher male captures were associated with lower egg fertility under laboratory conditions. In contrast, egg fertility increased significantly in chemical and control plots over consecutive years, with a clear distinction between eco-friendly practices and other treatments. Highest damage incidence was recorded in Larkana and Thatta during the first year but declined in the second year following the continuous application of cultural, post-harvest, and mechanical practices. Damage symptoms increased in insecticide-treated plots and control plots, providing clear evidence of resistance development caused by frequent and indiscriminate insecticide application. The *Brumus suturalis* found a voracious predator on the eggs and the larvae of *S. incertulas*. Integrated eco-friendly practices significantly reduced pest incidence and improved yield and profitability, offering a sustainable and economically viable alternative for rice farmers.

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Key words

Rice yellow stem borer, Population dynamics, Eco-friendly management practices, Cost-benefit ratio

INTRODUCTION

Rice, (*Oryza sativa* L.) is one of the most important food crops worldwide and serves as the primary staple for more than half of the global population (Solangi *et al.*, 2024). In Asia alone, approximately 90% of the human population depends on rice as their daily dietary staple (Rahimoon *et al.*, 2023; Shankar *et al.*, 2024). Rice productivity is significantly influenced by various biotic and abiotic factors (Saxena and Murty, 2014). Among the biotic factors, insect pests are a serious threat to rice crops globally.

Among insect pests, the rice stem borer complex is recognized as a major constraint, causing yield losses of up to 30% (Saleem *et al.*, 2014). The yellow stem borer, *Scirpophaga incertulas* (Walker) is the most prevalent and widely distributed species of the stem borer complex (Mahar *et al.*, 2025) and is present across all major rice-producing regions worldwide (Nyaupane, 2022). In Asia, it persists throughout the season within rice stubbles (Catling and Islam, 2015; Shankar *et al.*, 2024). Females oviposit in egg masses containing 50-200 eggs, typically deposited on leaves (Rahimoon *et al.*, 2021). The polyphagous larvae bore into rice stems, producing characteristic symptoms: "dead hearts" at the vegetative stage and "whiteheads" at the reproductive stage (Satpathi *et al.*, 2012). Damage caused by *S. incertulas* results in severe grain yield loss, ranging from 3% to 20% annually and reaching up to 60% under heavy infestation (Muralidharan *et al.*, 2006; Alfaro *et al.*, 2015). Synthetic insecticides have quick action against insect pests; however, their indiscriminate and prolonged use has created serious ecological and human

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health concerns, including pest resistance, environmental contamination, food poisoning, and grower health hazards (Khan *et al.*, 2010). Consequently, there is an urgent need to develop sustainable alternatives through integrated pest management (IPM). A successful IPM approach integrates mechanical, cultural, biological and when necessary, chemical control measures to suppress pest populations below economic thresholds (Arain *et al.*, 2025). Biological control forms a cornerstone of sustainable IPM, relying on natural enemies such as predators, parasitoids, and pathogens (Pathan *et al.*, 2023). These agents are often host-specific, environmentally safe, and economically viable, minimizing risks to non-target organisms and reducing pesticide residues (Solangi *et al.*, 2013). Among the most effective predators are the *Coccinella septempunctata* (Linnaeus), *Brumus suturalis* (Fabricius), *Coccinella transversalis*, and *Chrysoperla carnea* (Stephens), which are important regulators of soft-bodied insect pests in Pakistan and worldwide (Baloach *et al.*, 2020). In pyralid moths, chemical cues such as sex pheromones and host plant volatiles play a significant role in feeding and reproduction (Pophof *et al.*, 2005). Sex pheromones are effective tools for mating disruption, surveillance and mass trapping (Chen *et al.*, 2014; Solangi *et al.*, 2024). Similarly, visual trapping methods such as sticky colored traps have proven useful for monitoring pest populations in cropping systems (Gencsoylu, 2018; Arain *et al.*, 2025). Yellow sticky traps are widely used for moth monitoring and control in rice crop (Satia *et al.*, 2023; Mahar *et al.*, 2025; Arain *et al.*, 2025), though their long-term efficacy across multiple growing seasons remains uncertain. Yellow water pan traps are also effective tools for managing *S. incertulas* (Mahar *et al.*, 2025) and are valued for their simplicity and efficiency in capturing flying insects (Map Biocontrol, 2022; Solangi *et al.*, 2024). Light traps are also extensively used for monitoring nocturnal moths, capitalizing on their natural phototactic behavior (Longcore *et al.*, 2015; Chatterjee *et al.*, 2017). Given the importance of *S. incertulas* management, the present study was undertaken to evaluate the effectiveness of different eco-friendly IPM practices against *S. incertulas* under field conditions. Specifically, the research aimed to assess the efficiency of pheromone, light, and sticky traps in suppressing moth populations, to examine the relationship between moth capture and egg fertility, and to evaluate the predatory potential of natural enemies (*C. carnea*, *C. septempunctata*, *C. transversalis*, and *B. suturalis*). To our knowledge, this is the first comprehensive field study in Pakistan that simultaneously integrates trap-based suppression and predator activity for the sustainable management of the *S. incertulas*.

MATERIALS AND METHODS

Study site

The present study on the management of the *S. incertulas* was conducted over two consecutive years (2022-2023) across three major rice-growing ecological zones and four districts of Sindh province, Pakistan. The upper (Larkana district), central (Hyderabad district), and lower (Thatta and Badin districts), these districts were selected due to their distinct climatic conditions, representing diverse ecological zones for evaluating pest incidence and management strategies.

Seasonal abundance and abiotic factors analysis

In the preliminary phase, rice fields in the selected districts were surveyed to assess the population dynamics of *S. incertulas* and its relationship with key abiotic factors (temperature °C and relative humidity %). Light traps were installed in rice fields five weeks after transplantation to monitor adult moth activity throughout the cropping cycle in all four districts of Sindh. In addition to trap monitoring, visual observations were made by digging and splitting rice stubbles, which confirmed that *S. incertulas* overwintered within the stubbles during the off-season. The abiotic factors data was collected from the meteorological department of each district on monthly basis. The number of moths captured daily at each trap was recorded and subsequently correlated with prevailing average temperature °C and R.H%, to determine the influence of environmental factors on seasonal population fluctuations.

Experiment detail

The study was conducted using the rice variety Super Basmati, which was sown during the first week of July in both years (2022-2023). Approximately four weeks after sowing, the nursery seedlings were transplanted into the main experimental field to allow for proper establishment. The experiment was laid out in a randomized complete block design (RCBD) with four treatments as shown below and three replications per treatment. Each experimental plot measured 12×24 m (288 m²), with appropriate spacing between plots to minimize experimental error.

Yellow plastic plates (12×8 inches) were purchased and mounted on wooden stakes at a height of 3 ft. Each plate was coated with grease an adhesive material, which was replaced weekly to maintain stickiness, a total of seven sticky traps per hectare were installed with three replications (Arain *et al.*, 2025; Mahar *et al.*, 2025).

Light traps of the Jermy type were used, consisting of four components: A collecting chamber, a funnel-shaped lid, a light source, and a protective top cover against

rainfall. Standard 12-watt electric bulbs served as the light source, while potassium cyanide was used for killing captured moths. The traps were suspended at a height of approximately 3.5 ft with the support of iron rods, with six traps deployed per hectare (Hussain *et al.*, 2018).

Commercial pheromone traps and lures were procured from Zafar Shani Chemical Company, Multan. Six traps per hectare were installed on wooden stands. The pheromone blend consisted of two active components, (Z)-11-hexadecenal and (Z)-9-hexadecenal, prepared in methanol at a concentration of 50 µg/10 µL and loaded into rubber capsules for field deployment (Alfaro *et al.*, 2015; Solangi *et al.*, 2024).

Yellow water pans (15 inches in diameter, 18 inches in height) were filled with 10 liter of water mixed with 10mL of motor oil to reduce surface tension. Captured moths were submerged in oily water and collected weekly. Six traps per hectare were placed at ground level, and moths captured from each replication were counted and identified to assess trap effectiveness (Arafin *et al.*, 2025).

The traps were set up as follows: T₁ (Mechanical control) Light traps, sex pheromone traps, yellow sticky traps and yellow water pan traps.

T₂ (Cultural control): Early planting, synchronized planting, removal of egg masses before transplanting, maintenance of plant spacing, avoidance of excessive nitrogen fertilization and the use of resistant varieties + post harvest cultural practices (PHCP) (Deep ploughing, removing of stubbles, weeds, and bunds). Recommended agronomic practices were followed throughout the crop cycle, these included early planting (transplanting by 15th June), synchronized planting, and maintenance of plant spacing (20 × 20 cm) (Mondal and Puteh, 2013). Prior to transplanting, nursery seedlings were carefully inspected for egg masses of *S. incertulas*. Egg masses attached to leaves were manually removed by handpicking and destroyed to prevent their transfer to the main field. In cases of heavy infestation, infested leaf portions were pruned and discarded outside the field. After harvest, deep ploughing with a moldboard plough was conducted in all four locations to destroy overwintering larvae in stubbles. Fields were kept clean by removing stubbles, weeds, and bunds and left fallow until the next transplanting.

T₃ (Chemical control): treated with Fipronil G 0.2% at 15 kg/h. The incidence of *S. incertulas* was monitored in terms of adult activity, egg masses, dead hearts, and whiteheads. Observations were made weekly from one month after transplanting until harvest. For each plot (12m×24m) 10 hills were randomly examined at tillering and panicle stages (Katel *et al.*, 2023).

T₄ (Untreated): Without management practices.

Evaluation of crop damage

Treatment effects were evaluated by monitoring *S. incertulas* populations and assessing crop damage symptoms, specifically dead hearts and whiteheads. For damage appraisal, 100 rice plants were randomly selected from each replication, including control plots. Symptoms were confirmed by dissecting stems and tillers to verify larval feeding. Assessments were conducted from September to November during the rice season. Dead heart (%) and white ear head (%) incidence were calculated using the standard formulas of Onate (1965).

$$\text{DH or WE \%} = \frac{\text{Number of DH or WE}}{\text{Number of total tillers}} \times 100$$

Where, DH is dead heart in rice crop. WE is white ears of rice crop.

Identification of male and female adults

All moths captured in the trapping devices were collected and transported to the laboratory for sex identification. Morphological identification was conducted following published keys and confirmed with the assistance of well renowned taxonomist Prof. Dr. Imran Khatri. Female moths were distinguished by their pale-yellow to light-brown forewings, each marked with a single black spot. Females measured approximately 13 mm in body length with a wingspan of 32 mm and males were smaller, grey to light brown in coloration, and characterized by two rows of small spots near the apex of each forewing (Rahimoon *et al.*, 2023).

Evaluation of egg fertility under laboratory conditions

Rice leaves bearing egg masses were clipped and wrapped at the base with moist cotton to maintain freshness until hatching. Egg masses collected from different treatments were incubated under controlled laboratory conditions (28 ± 2 °C, 60% relative humidity) at the Department of Plant Protection, SAU, Tandojam. Fertility was assessed by distinguishing fertile and infertile eggs, and the percentage of fertile eggs was calculated using the standard formula:

$$\text{Fertility rate \%} = \frac{\text{Number of fertile eggs}}{\text{Number of eggs kept in the cages}} \times 100$$

Feeding potential of predators on *S. incertulas* under laboratory conditions

The feeding potential of *C. septempunctata*, *B. suturalis*, *C. transversalis*, and *C. carnea*, was evaluated against eggs and larval stages of the *S. incertulas*. Different developmental stages of the predators were collected from the field and maintained in the biological control laboratory. Predator larvae were reared individually in Petri dishes, while adults were kept in rearing cages.

Egg masses and larvae of *S. incertulas* were collected from the Latif Experimental Farm, SAU, Tandojam. Egg masses were carefully separated and counted under a stereomicroscope. Equal numbers of eggs and larvae were offered daily to individual predators from larval to adult stage. Each prey density (eggs and larvae) was replicated three times. Predator consumption was recorded after 24 hours and monitored daily for 10 consecutive days. For *C. carnea*, neonates and first to third instar larvae were placed individually in glass jars (7×3 cm). Different larval instars of *S. incertulas* were provided daily as prey, and the number of individuals consumed per day was recorded for each predator instar.

Cost-benefit ratio analysis

Grain yield per plot and the associated production costs for each management practice were recorded across all replications. The benefit-cost ratio (BCR) was calculated following the method described by Solangi *et al.* (2024).

$$BCR = N_r / G_e$$

Where BCR is the benefit-cost ratio, N_r is net returns/ha, and G_e indicates gross expenditure/ha.

Data analysis

Average values for adult moth catches, crop damage incidence (%), and grain yield per plot were subjected to one-way analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at $P < 0.05$. In addition, a generalized linear mixed-effects model (GLMM) was employed to evaluate the effects of treatments. Statistical analyses were conducted using SPSS software (version 21; IBM SPSS Statistics, Chicago, IL, USA), applying the mixed models procedure for GLMM.

RESULTS

Relationship of population with abiotic factors

Results revealed that *S. incertulas* overwinter

occurred from late November to early March under low temperature (20 °C) and high RH (80%). Activity resumed in late April and continued until November, adapting to abiotic conditions. Population buildup increased from May (90.41±9.25 individuals) and remained high throughout the rice-growing season in Hyderabad. Peak populations (175.58 ± 19.25 at 43°C and 70% RH) were recorded during July in Thatta followed by Larkana (186.18 ± 19.52 at 39.5 °C and 67% RH), with similar trends in Badin. Overall, highest population densities were observed at 35-41 °C, showing significant variation ($df = 275$, $F = 31.7$, $P < 0.002$). Also, pest activity closely aligned with abiotic factors and crop phenology from nursery to harvest (Fig. 1).

The correlation studies between the incidence of *S. incertulas* and relative humidity (RH) revealed that the dead hearts (%) and white ear heads (%) had a significant negative correlation with average relative humidity in the district Thatta. Whereas RH (%) from other districts significantly and positively correlated with dead heart %. A positive non-significant (-0.52*) correlation with an average temperature was observed with dead hearts % in the district Thatta. However, the white ears % had a significant negative correlation with average temperature, and average RH was observed with a negative non-significant correlation with the white ears % (Table I).

Impact of different trapping devices on the population of rice yellow stem borer 2022-23

Pheromone trap

The maximum (472.36±19.58) adults were captured from Larkana district during the first year (2022) and minimum (23.10±4.12) were captured in the second year (2023). The significant differences ($df=9$, $F=19.63$; $P < 0.003$) were observed in the first-second year captured population. Subsequently, variation was seen in different trapping devices ($df= 3$; $F=06.29$, $P < 0.009$).

Table I. Correlation matrix between mean population of rice borer in four districts of Sindh and abiotic factors (2022-2023).

Year	Damage symptoms	A biotic factor							
		Temperature				Relative humidity			
		Larkana	Hyderabad	Badin	Thatta	Larkana	Hyderabad	Badin	Thatta
2022	Dead heart (%)	0.55*	-0.50	-0.51	-0.52*	-0.49	0.61*	0.65*	0.69**
	White ear heads (%)	-0.41	-0.56	-0.53	-0.49	-0.41	0.50	0.56	0.70**
2023	Dead heart (%)	0.57*	-0.52	-0.50	-0.54*	-0.50	0.59*	0.66*	0.71**
	White ear heads (%)	-0.43	-0.58	-0.51	-0.47	-0.50	0.52	0.60	0.73**

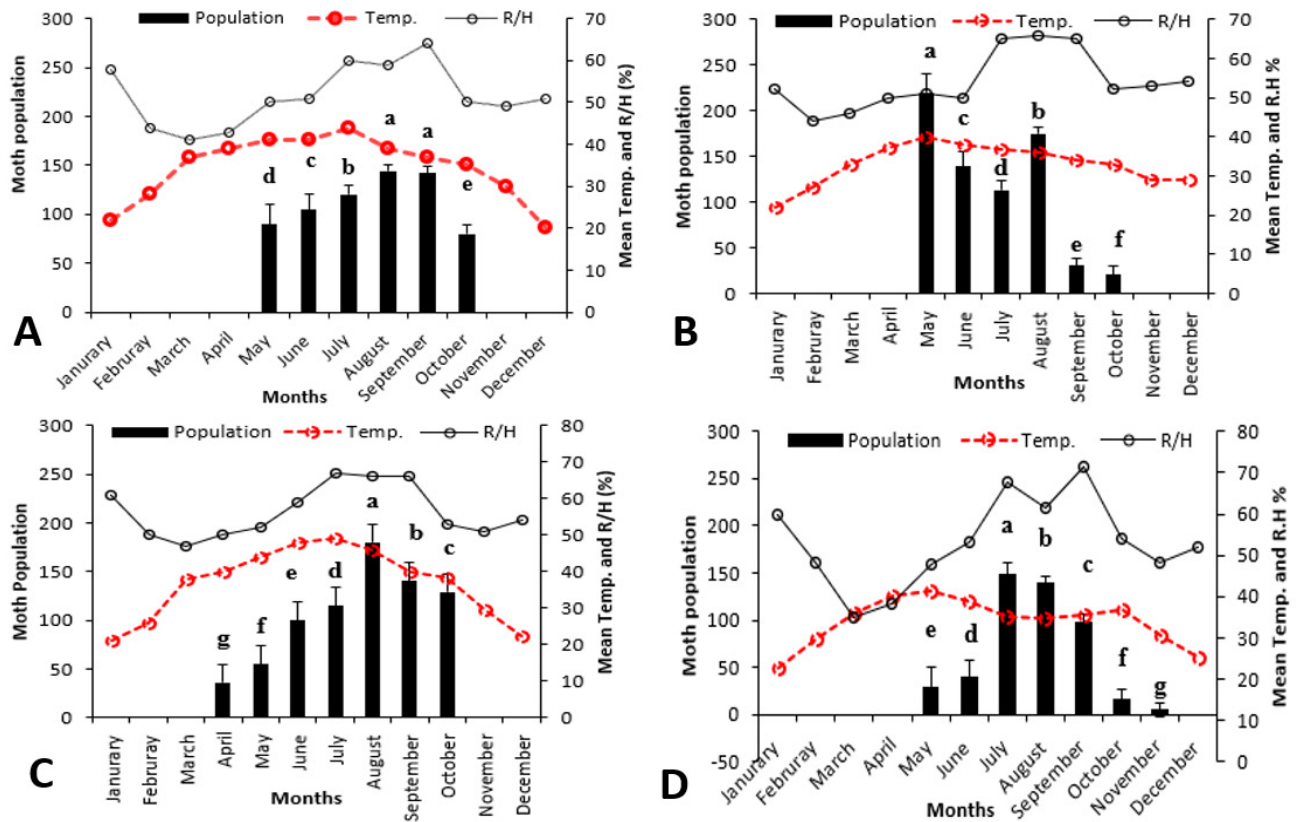


Fig. 1. Seasonal activity pattern of *S. incertulas* and its relationship with abiotic factors in Hyderabad (A), Thatta (B), Larkano (C) and Badin (D) district.

Light trap

The light trap effectively attracted adults of both sexes, the highest population (730.20 ± 21.18) recorded during the first year (2022); however, adult activity declined significantly ($df = 86$; $F = 92.29$, $P < 0.001$) in the second year (2023), the lowest population (49.36 ± 3.16) was captured in the Larkana district.

Sticky traps

Sticky traps also attracted adult populations, the highest number (131.36 ± 4.19) recorded during the first year (2022) and the lowest (10.36 ± 1.20) during the second year (2023). Statistical analysis revealed a significant difference between years and among districts ($df = 93$, $F = 100.9$, $P < 0.001$).

Water pan trap

Water pan trap attracted 54.14 ± 5.47 adults during the first year (2022) and minimum (1.41 ± 0.78) adults were captured during the second year with significant difference ($df = 55$, $F = 23.1$, $P < 0.008$). Overall, results revealed that moth activity was significantly decreased from

all locations on each trap as compared to the first year, which is a remarkable impact of continuous application of mechanical traps on population incidence of rice borer (Table II).

Impact of post-harvest and continuous application of eco-friendly practices on the population resurgence next year (2023) cropping season

Weekly average egg masses

The post-harvest practices, including removal of rice stubbles, deep ploughing, and field sanitation prior to transplanting, effectively reduced egg mass density (1.01 ± 0.10) and suppressed population build-up and pest resurgence compared with the first year. Furthermore, increased moth capture during the second year (2023) was associated with reduced oviposition rates. In contrast, significantly higher egg mass densities were recorded in chemical (10.14 ± 3.15) and untreated control plots (19.52 ± 5.14). Overall, statistical analysis revealed a significant difference in average egg masses between the first and second years across districts ($df = 71$, $F = 42.3$, $P < 0.004$) (Table III).

Table II. Overall seasonal captured adult population of *S. incertulas* after installation of different trap devices in the different locations during 2022-23.

Year	Mechanical tools (Traps)	Mean adult males captured				Mean adults female captured			
		Larkana	Hyderabad	Badin	Thatta	Larkana	Hyderabad	Badin	Thatta
2022	Pheromone	421.36 ± 19.58 d	390 ± 15.66 e	300.25 ± 22.6 f	389.20 ± 14.58 e	51.56 ± 7.36 n	39.25 ± 5.14 p	22.36 ± 3.19 q	61.20 ± 6.58 m
	Light	520.19 ± 20.58 a	506.98 ± 22.69 b	478.5 ± 18.9 c	436.14 ± 20.36 cd	225.5 ± 15.2 g	210.25 ± 10.26 h	236.14 ± 11.29 i	199.25 ± 5.36 j
	Sticky	89.25 ± 8.36 k	70.12 ± 7.25 l	20.28 ± 5.68 q	16.14 ± 4.12 q	42.14 ± 4.14 p	30.25 ± 5.41 pq	10.58 ± 3.25 r	21.14 ± 3.47 q
	Water pan	52.14 ± 5.47 n	40.25 ± 7.12 p	60.58 ± 6.47 m	70.14 ± 10.25 l o	02.14 ± 0.88 s	00 ± 00	3.89 ± 01.02 st	00 ± 00
2023	Pheromone	19.10 ± 4.12 q	10.58 ± 3.25 r	19 ± 2.14 q	23.14 ± 3.85 q	04 ± 1.02 t	2.41 ± 0.75 s	00 ± 00	00 ± 00
	Light	43.36±3.16p	19.52±4.58q	20.36±4.56q	11.69±2.14 r	6.10±2.58s	10.47±1.59r	20.10±3.14q	17.85±2.58q
	Sticky	5.26 ± 1.20 s	9.14 ± 2.58 r	00 ± 00	2.78 ± 1.52 s	5.12 ± 2.81	9.25 ± 3.33 r	10.87 ± 4.58r	00 ± 00
	Water pan	1.41±0.78st	4.20 ± 1.20 s	2.10 ± 0.89 t	00 ± 00	00 ± 00	1.58 ± 0.52 s	3.01 ± 0.90 t	00 ± 00

*Different alphabetical letters indicate the significant differences between the treatments.

Table III. Weekly average egg mass from different locations during 2022-23.

Practices	Egg masses (2022)				Egg masses (2023)			
	Larkana	Hyderabad	Badin	Thatta	Larkana	Hyderabad	Badin	Thatta
Cultural	9.20 ± 2.03 cd	8.58 ± 1.25d	6.14 ± 1.30 f	8.14 ± 2.58 d	2.14 ± 0.99 i	1.58 ± 0.52 j	1.01 ± 0.10 l	3.14 ± 0.99 h
Mechanical	6.25 ± 1.12 ef	5.78 ± 1.99ef	3.14 ± 1.52 h	5.14 ± 1.01 g	1.75 ± 0.89 jk	1.25 ± 0.40 jk	1.47 ± 0.58 j	2.14 ± 1.20 i
Chemical	8.59 ± 2.45 d	6.49 ± 1.02f	7.14 ± 1.55 e	6.58 ± 2.00 f	9.49 ± 3.21 cd	9.58 ± 2.74cd	10.14 ± 3.1 5cb	8.11 ± 2.10 d
Un-treated	12.12 ± 3.77bc	9.45 ± 3.10	11.89 ± 4.20c	10.88 ± 4.69cb	14.25 ± 3.12ab	15.14 ± 0.00 b	19.52 ± 5.14 a	13.25 ± 4.52 b

*Different alphabetical letters indicate the significant differences between the treatments.

Table IV. Crop damage assessment caused by *S. incertulas* after installation of different trap devices in rice crop during 2022-23.

Year	Practices	Dead hearts (%)				White ear heads (%)			
		Larkana	Hyderabad	Badin	Thatta	Larkana	Hyderabad	Badin	Thatta
2022	Cultural	8.2	7.12	5.09	4.59	8.01	7.4	6.2	7.14
	Mechanical	4.9	5.2	4.2	6.8	5.20	10.12	9.10	8.12
	Chemical	11.7	9.1	12.5	13.2	10.1	8.52	10.17	9.20
	Un-treated	19	20.3	22.1	30.12	21.4	22.10	30.8	26.2
2023	Cultural	1.02	2.10	3.01	1.95	2.56	4.5	4	2.1
	Mechanical	2.09	1.89	2.08	2.01	2.78	1.84	2.09	3.14
	Chemical	10.69	19.25	20.5	11.5	12.14	21.52	16.71	11.47
	Un-treated	29.11	36.78	30.41	29.14	38.51	25.96	40.52	31.58

Crop damage assessment after application of different treatments 2023

Data from this trial demonstrated significant differences in crop infestation symptoms, including white ear and dead heart percentages, among all management practices ($df = 29$, $F=9.90$, $P< 0.005$). During the first-year trial, the maximum (8.2%) damage symptoms were recorded in the district Larkana, but it gradually decreased (1.02%) in the second year. The cultural practices and mechanical traps efficiently reduced the crop infestation during both years, but a notable impact was observed in the second year (2023). However, the damage symptoms increased from 9.1 to 19.25% and 20-36% in the insecticide and control plots, respectively, during both study years, which is clear evidence of insect resistance to the frequent, un-judicious, and excessive insecticide application in the study area (Table IV).

Effects of year, treatment, and location on the population incidence of the *S. incertulas*

The generalized linear mixed model (GLMM) model revealed a highly significant effect of year ($F = 33.26$, $P < 0.001$), indicating strong inter-annual variation in pest incidence. By contrast, the main effects of treatment ($F=1.3$, $P<0.26$) and location ($F=0.7$; $P <0.36$) were not significant, suggesting that population levels did not differ markedly among individual treatments or study sites when considered independently. However, significant interaction effects were observed. The year treatment interaction was significant ($F=32.36$; $P<0.001$), indicating that treatment effectiveness varied across years. Similarly, the year $\times$ location interaction ($F = 46.66$; $P<0.001$) demonstrated that pest incidence was influenced by site-specific climatic conditions depending on the year. The three-way interaction among year, treatment, and location was also highly significant ($F = 72.36$, $P < 0.0001$), confirming that pest dynamics were strongly shaped by combined temporal and spatial factors. These findings highlight that the population incidence of *S. incertulas* was more dependent on seasonal and ecological variability than on treatment effects alone (Table V).

Table V. Results of the generalized linear mixed model (GLMM) for the effects of treatments on the population incidence of yellow stem borer.

	df	F	P
Year	1,214	33.26	<0.001
Treatment	1,214	1.3	0.263
Location	1,214	0.7	0.365
Year x Treatment	1,214	32.36	<0.001
Year x Location	1,214	46.66	<0.001
Year $\times$ Treatment $\times$ Location	1,214	72.36	<0.0001

Significant P-value ($P<0.05$) are given in bold type in table.

Impact of moth capturing on egg fertility (%)

Egg fertility (%) showed a significant difference (df , 89, $F= 96.40$; $P<0.001$) between eco-friendly practices and other treatments. Maximum male capturing resulted in minimum egg fertility (%) under laboratory conditions during both years. Whereas the lowest egg fertility was recorded after the continuous application of sex pheromone and light traps, during the second year, egg fertility declined to a minimum range of 8.25–14.01%. In contrast, chemical plots exhibited a significant increase in egg fertility from 55.36% in the first year to 78.14% in the second year, with a similar increasing trend observed in the control plots across both years (Table VI).

Feeding potential of different predators on the different stages of rice borer

The feeding potential of different predators was assessed under laboratory conditions, and it was observed that the consumption rate mostly depends on the prey stages. Soft-bodied and creamy 1st instar of rice borer voraciously consumed by the 3rd, 4th larval instars and adults of each predator except *C. carnea* adult. As the rice borer stage increased, the consumption rate of predators decreased. Specifically, maximum borer eggs (203.58 ± 19.0) were consumed by *B. suturalis* adults, followed by *C. transversalis* (110.58 ± 16.36),

Table VI. Egg fertility (%) of different locations after application of different practices (2022-23).

Practices	Egg fertility (%) 2022				Egg fertility (%) 2023			
	Larkana	Hyderabad	Badin	Thatta	Larkana	Hyderabad	Badin	Thatta
Cultural	55.12	53.41	44.23	40.15	13.25	11.14	14.01	05.14
Mechanical	40.36	49.25	39.01	33.58	8.25	10.58	11.52	10.36
Chemical	63.25	70.25	55.36	61.45	78.36	76.47	73.41	79.25
Un-treated	80.14	79.01	81.36	44.25	82.85	84.25	86.36	84.89

Table VII. Feeding potential of different predators on rice borer under laboratory conditions.

Predators	Stages (Instar)	Rice borer stages					
		Eggs (n= 100)	1 st Instar (n= 100)	2 nd Instar (n= 200)	3 rd Instar (n= 200)	4 th Instar (n= 200)	5 th Instars (n= 200)
<i>C. septempunctata</i>	1 st	1.23±0.11	2.20±0.9	0	0	0	0
	2 nd	3.79±0.99	6.88±1	0	0	0	0
	3 rd	7.36±1.02	12.47±3.5	1.58±0.41	0	0	0
	4 th	29.14±3.25	55.89±6.8	40.25±9.3	0	0	0
	Male	60.25±6.14	69±9.1	36.25±8.1	32.58±8	0	0
	Female	101±8.14	120±11.02	130±10.5	69.51±9	0	0
<i>B. suturalis</i>	1 st	3.69±0.88	2.87±0.88	4.87±0.99	0	0	0
	2 nd	7.84±1.67	9.14±3.5	6.47±1.5	0	0	0
	3 rd	89.14±9.25	102.58±12	69.25±6.5	0	0	0
	4 th	120.14±10	145.8±14	110.0±10.2	10.02±2	0	0
	Male	203.58±19	158.14±16	201.14±12	18.69±4	0	0
	Female	158.47±9.2	210.58±20	189.14±16	15.63±5.3	0	0
<i>C. carnea</i>	1 st	1.14±0.21	00	0	0	0	0
	2 nd	5.69±1.99	2.36±0.25	0	0	0	0
	3 rd	9.25±2.5	4.85±1.2	0	0	0	0
	Adult	0	0	0	0	0	0
<i>C. transversalis</i>	1 st	3.47±1.2	2.41±0.3	0	0	0	0
	2 nd	7.14±2	3.47±1.2	0	0	0	0
	3 rd	14.20±4	80.14±8	70.36±8	0	0	0
	4 th	10.25±2.55	90.25±10	80.14±9	0	0	0
	Male	110.58±16	147.69±16	136.85±10.3	0	0	0
	Female	108.69±14	189.47±20	112.58±14.2	0	0	0

C. septempunctata (101±19.58), and *C. carnea* (9.25±2.59). Moreover, it was observed that the minimum eggs and larval stages were consumed by the *C. carnea* in 24 h. It was observed that the predator potential of the predator was higher in the younger instars than in the older ones. Also, there was a significant ($P < 0.001$) difference between the predatory potential regimes (Table VII).

Cost-benefit ratio analysis for management of rice yellow stem borer

There was a significant difference in the yield of the first and second year, after the installation of various trapping devices in rice fields. Results revealed that rice yield increased from the first year to the second year in all study areas after continuous application of eco-friendly practices. Thatta district, severely affected by borer, showed the highest (9236 kg/ha) yield, and earned maximum 2645.07 ha revenue. Similarly, significant differences in yield, net income, and cost/benefit ratio were recorded in the consecutive years (Table VIII).

Further, statistical analysis revealed that control plots and chemicals plots could not increase yield and cost-benefit ratio, which ultimately resulted in loss of grain yield and revenue deficit.

DISCUSSION

Rice yellow stem borer (*S. incertulas*) is one of the most destructive pest of rice, causing significant yield losses and posing a serious threat to sustainable rice production. Therefore, the development of eco-friendly and effective management strategies is essential to reduce reliance on synthetic insecticides and mitigate pest resurgence and resistance. Results of the current study demonstrated that the continuous application of cultural practices significantly reduced the *S. incertulas* incidence. Particularly, the number of egg masses declined from 9.20±1.36 in the first year to 2.01±0.99 in the second year, confirmed that cultural practices suppressed pest populations effectively these results align with the findings

Table VIII. Assessment of cost-benefit ratio for the management of *S. incertulas* during 2022-23 at different locations.

Area		Year 2022				Year 2023			
		Mechanical	Cultural	Chemical	Control	Mechanical	Cultural	Chemical	Control
Larkana	Yield (kg)	7900	7,000	2712	2000	9865	8,904	1560	1245
	Common cost	637.36	637.36	637.36	637.36	689.63	689.63	689.63	689.63
	Treatment cost	8.57	18.09	20.55	0	8.57	18.09	20.55	0
	Total cost	644.66	654.17	656.63	637.36	696.36	706.45	708.91	637.36
	Gross income	2858.59	2532.92	981.32	723.69	3569.61	3221.88	564.48	450.49
	Net income	2213.92	1878.74	324.68	87.60	2872.68	2515.42	-14.44	-5128
	C:B ratio	1:3.43	1:2.87	1:0.49	1:0.14	1:4.12	1:3.56	1: -0.20	1: -0.29
Hyderabad	Yield kg	6950	5,049	2200	1600	8693	7,652	1210	1001
	Common cost	637.36	637.36	637.36	637.36	689.63	689.63	689.63	689.63
	Treatment cost	8.57	18.09	20.55	0	8.57	18.09	20.55	0
	Total cost	644.66	654.17	656.63	637.36	696.93	706.45	708.91	637.36
	Gross income	2514.83	1826.96	796.03	578.95	3145.53	2768.85	437.83	362.20
	Net income	1870.17	1172.78	139.42	-57.13	2448.59	2062.39	-27.63	-29.63
	C:B ratio	1:2.90	1:1.79	1:0.21	1: -0.09	1:3.51	1:2.92	1: -0.38	1: -0.43
Thatta	Yield kg	6238	4,936	1936	2236	9236	7,825	1146	1136
	Common cost	637.36	637.36	637.36	637.36	689.63	689.63	689.63	689.63
	Treatment cost	8.57	18.09	20.55	0	8.57	18.09	20.55	0
	Total cost	644.66	654.17	656.63	637.36	696.93	706.45	708.91	637.36
	Gross income	2257.20	1786.07	700.53	809.09	3342.01	2831.45	414.67	411.05
	Net income	1612.53	1131.89	12131	173.10	2645.07	2124.99	-30.89	-36.25
	C:B ratio	1:2.50	1:1.73	1:0.07	1:0.27	1:3.80	1:3.01	1: -0.42	1: -0.35
Badin	Yield kg	7058	6,135	2158	1369	8936	7,869	1589	1469
	Common cost	637.36	637.36	637.36	637.36	689.63	689.63	689.63	689.63
	Treatment cost	8.57	18.09	20.55	0	8.57	18.09	20.55	0
	Total cost	644.66	654.17	656.63	637.36	696.93	706.45	708.91	637.36
	Gross income	2553.91	2219.93	780.86	495.36	3232.37	2847.37	574.67	531.55
	Net income	1909.25	1565.75	124.22	-14.06	2536.52	2140.91	-13.01	-104.53
	C:B ratio	1:2.96	1:2.39	1:0.19	1: -0.22	1:3.64	1:3.03	1: -0.19	1: -0.16

C:B ratio = Cost: Benefit ratio. Cost or revenue given in USD and One USD equal to 276.36 PKR.

of Kumar *et al.* (2023) which represents early rice sowing had the lowest borer population. Also, January *et al.* (2020) emphasized the importance of manipulating sowing dates and avoiding excessive application of nitrogenous fertilizers may reduce the *S. incertulas* occurrence in the rice field (January *et al.*, 2018b). Previous studies have reported that rice stem borer species commonly survive within residual rice stubbles (Kfir *et al.*, 2002; Togola *et al.*, 2020), consistent with this, the present study demonstrated that post-harvest practices, particularly the removal of stubbles from the previous season, significantly reduced the carryover of pest populations into the subsequent crop. As a result, infestation by *S. incertulas* in newly

transplanted fields was markedly suppressed. These findings agree with earlier reports by Kfir *et al.* (2002), Mohamed (2012), and Leonard and Rwegasira (2015), who also emphasized the importance of stubble management in limiting pest persistence and population build-up. Similarly, Kumar *et al.* (2023) suggested that ploughing down or burning of stubbles just after harvest of the rice crop was found to destroy substantial rice borer larval population. Remarkable results were found due to post-harvest cultural practices (PHCP) between two seasons in the current study, during the first year of the study 8.2% dead hearts were observed, but after post-harvest practices only 1.23% dead hearts were found during the next year

(2023), keeping the fields and bunds clean and destroying weeds effectively between two cropping cycle proved an effective eco-friendly management of *S. incertulas*. Results of the current study also revealed that light traps caught maximum seasonal borer population followed by sex pheromone traps, yellow sticky traps and yellow water pan traps, and significantly reduced the *S. incertulas* population outbreak in all study areas during both years. These results agreed with those previously used similar trapping devices against *S. incertulas* (Shankar *et al.*, 2024; Solangi *et al.*, 2024; Mahar *et al.*, 2025; Arain *et al.*, 2025). Light traps proved an effective tool for capturing adult rice yellow stem borers in rice fields during present study, thus significantly reducing moth populations and subsequent egg mass deposition, these findings also agreed with Lima *et al.* (2015). Light sources were found the most attractive source for attracting the noctuid moths, and during current study peak moth activity was observed from July-October months in the study area, similarly Kakde and Patel (2014) who observed the attraction of adults of rice yellow stem-borer from the 1st week of August to the last week of November. Sex pheromones traps also found an effective tool against borer population from September-November in all locations in the current study, results of Mahar *et al.* (2025); Witzgall *et al.* (2008) and Stelinski *et al.* (2013) are align with the results of current study. Sex pheromone traps disrupt the mating frequency of male and female, and a minimum (05.14%) egg fertility resulting in low frequency of damage symptoms in rice field indicating that pheromone traps significantly reduced both white ears and dead hearts caused by stem borer more efficiently than followed by light traps, this is because of the maximum number of adults caught by pheromone traps, these findings are agreed with Alfaro *et al.* (2015) and Chen *et al.* (2014) they confirmed that applications of pheromones traps reduced the damage symptoms (white ears and dead hearts) in the next year (2023) cropping season caused by *C. suppressalis* more proficiently than control plots. Similarly, Solangi *et al.* (2024) and Wang *et al.* (2011) used different sex pheromone dispensers with different densities to monitor and control the *C. suppressalis* in the rice fields. Subsequent and excessive insecticide application resulted in increased moth population, egg masses, and damage symptoms were observed across study sites, indicating possible insecticide resistance development and pest resurgence. These results agreed with Ge *et al.* (2025) the un-judicious, excessive and reliance on single formulation pesticide application developed resistance and reduced the field control efficiency against the *C. suppressalis*. In addition, we hypothesized that natural enemies may be effective against the rice borers and evaluated the feeding potential of different predators on the different larval

instars of the rice borers under laboratory conditions. Functional response analyses demonstrated that predation rates on borer eggs and larvae increased proportionally with prey density and stage. Among the tested species, the *B. suturalis* emerged as the most voracious predator, consuming significantly higher numbers of eggs and larvae than the other predators. These results are consistent with previous studies demonstrating that predator functional responses increase with prey density, thereby enhancing predation efficiency (Rahaman and Stouto, 2019), which supports the present findings. Moreover, higher abundance of natural enemies, particularly coccinellids and spiders, has been reported in rice ecosystems, contributing to effective biological control. In addition, cost-benefit analysis indicated that rice yield increased from the first to the second year across all study areas following the continuous implementation of eco-friendly practices. In contrast, both insecticide-treated and control plots exhibited reduced yield and economic returns. These findings agree with those reported by Solangi *et al.* (2024) and Shankar *et al.* (2024). These findings demonstrate that integrated eco-friendly practices provide sustainable, economical, and environmentally safe alternatives for rice stem borer management compared with insecticide-dependent approaches in rice ecosystems.

CONCLUSION

This study showed that rice yellow stem borer moth activity was strongly influenced by humid conditions and resumed after overwintering from late April to November. Larvae persisted in rice stubble, emphasizing the importance of post-harvest sanitation. During the first year, pheromone traps captured the most males, while light traps recorded the highest overall catch. In the second year, moth activity and damage symptoms (dead hearts and whiteheads) declined significantly across treatments, indicating the cumulative effectiveness of continuous eco-friendly practices. Whereas insecticide and control plots showed increasing damage, suggesting resistance development from indiscriminate pesticide use, also continuous trapping reduced egg fertility in the rice field. *C. septeimpunctata*, *C. transversalis* and *B. suturalis* voraciously feed early instars of rice borers under laboratory conditions. Overall, integrated eco-friendly (Light traps, pheromone traps and Cultural practices) management improved yield and profitability, producing the highest grain yield and revenue, and providing a sustainable alternative to insecticide-dependent approaches.

RECOMMENDATIONS

Current study provides valuable guidance for sustainable rice production through the integrated use of mechanical traps, post-harvest cultural practices, and the augmentation of natural enemies against the *S. incertulas*. The continuous application of these (Light traps, pheromone traps, Cultural and Post-Harvest Cultural Practices) eco-friendly measures significantly reduced stem borer incidence, while improving grain yield, gross and net returns, and the overall benefit-cost ratio in IPM demonstration plots. Adoption of such practices therefore proved to be not only economical but also environmentally safe and sustainable within the rice production system. It is further recommended that rice fields should not be left fallow or cultivated without proper ploughing, harvesting should be carried out approximately 20 cm above the soil surface to reduce pest residue.

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