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Research Article

Exploring the Utility of Light Traps for Early Detection and Management of Rice Insect Pests

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BA and AMS conceptualized the study and recorded the data. BA, AMS and MDG statistical analyzed the data. BA, MAF, MUS and AN wrote Introduction section of the manuscript. BA, AMS, MDG, THA and MAA wrote methodology section of the manuscript. BA, AMS, MDG, MAF, MAA and AN wrote results and discussion section of the manuscript. MI and MUS edited the format of the manuscript according to the format of this journal. The final manuscript was ultimately perused, scrutinized and approved for final submission by all the authors.

Keywords
Light traps, Rice insect pests, Early detection, Pest surveillance, Population dynamics, Pest management

Abstract | The study was aimed to evaluate the utility of light traps for early detection and management of rice insect pests (for preserving crop yields, preventing economic losses, and ensuring food security) by analyzing the population dynamics of rice insect pests, focusing on six species: *Scirpophaga innotata*, *Sesamia inferens*, *Scirpophaga incertulas*, *Cnaphalocrocis medinalis*, *Sogatella furcifera* and *Nilaparvata lugens*. Population data spanning four years (2019-2022) were collected through the use of light traps revealed distinct peak populations for each species at different times. *Scirpophaga innotata* exhibited a consistent peak population in September, with a significant increase from 2019 to 2020, followed by a decline from 2020 to 2021. However, a remarkable increase was observed from 2021 to 2022. *Sesamia inferens* displayed varying peak populations across the years, with a slight decrease from 2019 to 2020, a significant increase from 2020 to 2021, and a subsequent decline. *Scirpophaga incertulas* showed different peak populations at various times throughout the years, experiencing significant declines from 2019 to 2020 and from 2020 to 2021, followed by a decrease in 2022. *Cnaphalocrocis medinalis* demonstrated varying peak populations, experiencing a significant decrease from 2019 to 2020 and a subsequent decline from 2020 to 2021. Notably, *C. medinalis* was absent in 2022. *Sogatella furcifera* displayed different peak populations across the years, experiencing significant declines from 2019 to 2020, from 2020 to 2021, and from 2021 to 2022. *Nilaparvata lugens* exhibited varying peak populations, with a significant decrease from 2019 to 2020, a significant increase from 2020 to 2021, and a slight decrease from 2021 to 2022. These results offer important information about the time-related patterns of insect pests affecting rice. They provide a useful resource for safeguarding rice crops by enabling well-timed and effective pest control strategies based on the specific timing of each pest species. This underscores the significance of early identification using light traps in order to detect pests early on. Implementing timely pest control measures based on these observations can help protect rice crops from significant damage.

Novelty Statement | The novelty of this study lies in its investigation of the effectiveness of light traps for early detection and management of rice insect pests. By analyzing population data spanning multiple years, the study provides novel insights into the temporal dynamics of six specific insect species, highlighting their peak populations at different times. This research contributes to the understanding of pest population dynamics and emphasizes the significance of utilizing light traps for timely and effective pest management in rice crops.

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Introduction

Rice is a critical staple crop that serves as a primary food source for a significant portion of the global population

(Zhao *et al.*, 2017). In the 2021-22 crop year, about 520 million metric tons of rice were consumed worldwide, up from 437.18 million metric tons in the 2008-09 crop year. This shows the scale of its importance and reliance on rice crops. Rice is a primary source of nutrition for billions of people, and its production and consumption continue to increase to meet the growing demand (Statista, 2023).

However, the productivity and quality of rice crops are constantly threatened by a diverse array of insect pests (Sarwar, 2011). White rice stem borer, *Scirpophaga innotata* (Walker) (Lepidoptera: Pyralidae), pink rice stem borer, *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae), and yellow rice stem borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae). The boring larvae of these three borers result in dead hearts, whiteheads, and yield loss. Additionally, rice leaffolder, *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Pyralidae), whose larvae roll and tie leaves, contributes to a reduction in photosynthesis and plant vigor. Moreover, white backed planthopper, *Sogatella furcifera* (Horváth) (Hemiptera: Delphacidae), and brown planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae), through sap-feeding, cause hopperburn, yellowing, and stunted growth. These insect pests impose substantial damage through various mechanisms including direct feeding, disease transmission (Rice tungro disease, Rice grassy stunt, Rice ragged stunt and Rice yellow mottle virus), and the disruption of rice growth. These pests inflict substantial yield losses each year, posing significant challenges for farmers and jeopardizing the economic stability and food security of nations (Calicioglu *et al.*, 2019). Consequently, it is imperative to implement effective pest management strategies to mitigate the damage caused by these insects and sustainably enhance rice production (Alam *et al.*, 2016a).

Traditional approaches to managing insect pests in rice cultivation, encompassing scheduled spraying, threshold-based application, seed treatment, fogging, foliar sprays, non-selective pesticide use, insecticide mixtures, and emergency responses to pest outbreaks, have heavily relied on the extensive use of chemical pesticides, which have demonstrated some degree of effectiveness (McErlich and Boydston, 2014). However, the widespread and indiscriminate application of these chemicals has resulted in a multitude of adverse consequences (Ezeuko *et al.*, 2021). Firstly, it has led to environmental pollution (Anju *et al.*, 2010), contaminating soil (Kasture, 2017), water bodies (Sau *et al.*, 2022), and air resources (Anik *et al.*, 2021), thereby compromising the health of ecosystems (Dhama *et al.*, 2021) and non-target organisms (Stanley and Preetha, 2016). Moreover, the disruption of natural predator-prey relationships (Kalia and Gosal, 2011) and the reduction in biodiversity (Bayat *et al.*, 2019) have further exacerbated ecological imbalances (Kumar *et al.*, 2013). Furthermore, the overreliance on pesticides has contributed to the emergence of pesticide-resistant pest populations results from the selective pressure of pesticide use, overreliance on specific chemicals, lack of diversity in pest management strategies, and the natural adaptive evolution of pests (Kalia and Gosal, 2011), rendering certain chemicals ineffective and necessitating even higher pesticide usage (Dinham, 2003). These challenges underscore the urgent need for alternative approaches that are environmentally friendly, sustainable, and capable of facilitating early detection and effective management of rice insect pests (Alam *et al.*, 2016b).

In recent years, light traps have emerged as a promising tool in the field of insect pest management (Prasad and Prabhakar, 2012) that attract and capture insects by utilizing artificial light sources to mimic natural sources, exploiting the phototactic behavior of many insects. They are promising for insect pest management due to their effectiveness, cost-efficiency, and environmental friendliness, drawing insects towards the light through a combination of factors such as wavelength, intensity, and polarized light, ultimately aiding in monitoring, studying, and controlling insect populations. Exploiting the innate attraction of insects towards light sources, light traps utilize this behavioral characteristic to capture and monitor pest populations (Cardé and Elkinton, 1984). By strategically deploying light traps in rice fields, farmers and researchers can proactively detect the presence of insect pests at an early stage, enabling timely intervention and targeted management practices (Vennila *et al.*, 2016).

Light traps offer several advantages in the context of rice insect pest management (Qing *et al.*, 2020). Firstly, they provide an efficient means of monitoring pest populations (Nielsen *et al.*, 2013a), allowing farmers to gather valuable data on pest abundance (Prasad and Prabhakar, 2012), activity patterns (Kasap *et al.*, 2009), and seasonal variations (Fujita *et al.*, 2023). This information facilitates informed decision-making and the implementation of appropriate pest control measures. Secondly, light traps are environmentally friendly, as they do not involve the use of chemical pesticides. This mitigates the detrimental effects associated with conventional pesticide application, such as soil and water contamination, harm to beneficial organisms, and negative impacts on human health (Habel *et al.*, 2019). Additionally, light traps can attract a wide range of insect pests (Kim *et al.*, 2019), enabling comprehensive monitoring (Noskov *et al.*, 2021) and the development of targeted management strategies (Davies *et al.*, 2000).

The advantages of employing light traps for pest management are multifaceted and supported by empirical evidence. Noteworthy studies, such as Nielsen *et al.* (2013b), have showcased the precision of light traps in monitoring pest populations, offering insights into abundance, activity patterns, and seasonal fluctuations. Furthermore, these traps align with environmentally friendly practices by circumventing the need for chemical pesticides. This not only shields beneficial organisms and ecosystems but also fosters sustainable agricultural practices, underscoring the importance of exploring their potential for targeted management strategies (Habel *et al*., 2022).

This study bridges a significant gap in the existing literature by assessing the pragmatic utility of light traps for early detection and control of insect pests within the context of rice cultivation. By investigating the efficacy of light traps, the study contributes to the advancement of ecologically sound pest management strategies tailored for rice farming. This research's novelty lies in its potential to enhance rice productivity, reinforce food security, and promote sustainable pest management practices. The study thus positions itself as a crucial step forward in addressing the challenges of rice pest management while also offering valuable insights for future research and application.

The aim of this study was to investigate the effectiveness of light traps in the early detection and control of six species of insect pests (*Scirpophaga innotata*, *Sesamia inferens*, *Scirpophaga incertulas*, *Cnaphalocrocis medinalis*, *Sogatella furcifera*, and *Nilaparvata lugens*) in rice cultivation. With this objective in mind, a hypothesis was proposed, suggesting that the implementation of light traps in rice farming will make a significant contribution to detecting insect pests early on and managing them effectively. This, in turn, was expected to result in enhancing rice productivity, bolster food security, and promote environmentally friendly pest management practices in the realm of rice cultivation.

Materials and Methods

Study area and experimental design

The present investigations were conducted to explore and compare the light trap catches of insect pests affecting rice crops in the experimental area of the Rice Research Institute, Kala Shah Kaku (31.7213° N, 74.2700° E), Ministry of Agriculture, Government of Punjab, Pakistan. By monitoring the population dynamics and abundance of these pests over a four-year period (2019-22), valuable insights could be gained to enhance pest management strategies and crop protection measures.

Experimental procedures

Rice nursery seeding and transfer

The multi-varietal rice nursery was carefully seeded during the first week of June and subsequently transferred after one month. This timeframe allowed for proper establishment and growth of the rice plants before being exposed to potential insect infestations.

Adherence to standard recommendations

To ensure reliable results, all standard recommendations for plant production and plant protection were strictly followed throughout the experiment includes variety selection, water management, weed management and IPM. These recommendations encompassed a comprehensive set of practices aimed at optimizing plant growth and protecting the crops from pests.

Light trap placement

Light trap placement was strategically chosen within the experimental area historical pest incidence, identified hotspots, crop vulnerability, pest movement patterns, environmental factors, collaboration with local experts and considerations of crop variety susceptibility. This approach aimed to maximize the likelihood of capturing a representative sample of insect pests affecting rice crops.

Light trap calibration and maintenance

Data collection accuracy was ensured through regular calibration of the light trap and consistent maintenance of trapping equipment. Quality control measures included checking trap components, replacing killing bottles at predetermined intervals, and addressing any technical issues promptly.

Light trap design

Components of the light trap

The light trap used in the study consisted of four essential parts, each serving a specific function (Figure 1).

Collection bottle: The collection bottle, made of glass measuring 12.5 cm in height and 7.8 cm in width with a capacity of 475 ml, served as a containment chamber for the trapped insects, facilitating their subsequent identification and counting.

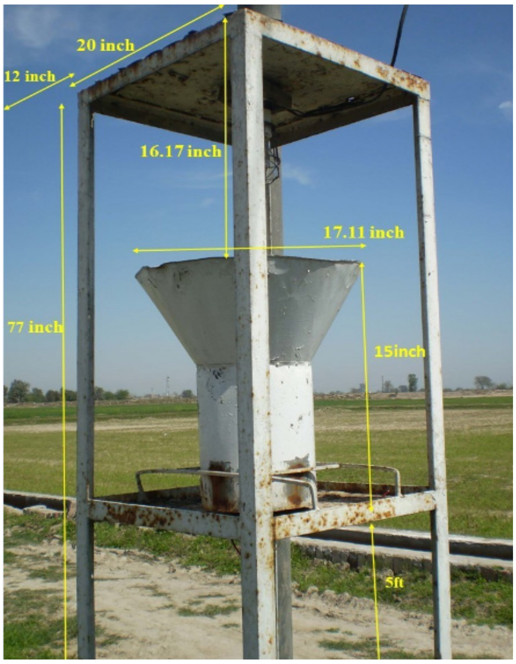

Figure 1: Schematic diagram of the light trap design.

Funnel-shaped lid: The funnel-shaped lid was strategically designed to direct the insects towards the collection bottle, increasing the trap's effectiveness.

Light source: A 100W incandescent bulb was utilized as the primary light source to attract insects towards the trap. This incandescent bulb emits a warm white light with a color temperature around 2700-3000K, producing a spectrum that is less attractive to insects compared to light sources with higher ultraviolet content.

Top lid: A top lid was employed to cover the light trap and safeguard it against unexpected rainfall, ensuring the integrity of the collected samples.

Use of potassium cyanide

To prevent any potential escape or interference of the trapped insects, potassium cyanide was used as a killing agent within the collection chamber. This method ensured that the collected insects remained intact and viable for subsequent identification and analysis.

Insect pest studied

Six species of insect pests including *Scirpophaga innotata*, *Sesamia inferens*, *Scirpophaga incertulas*, *Cnaphalocrocis medinalis*, *Sogatella furcifera*, and *Nilaparvata lugens* were studied. These species were known to be significant pests in rice cultivation and understanding their behavior and population dynamics was crucial for effective pest management in rice fields.

Comprehensive nocturnal insect monitoring using extended light traps

The light traps were deployed throughout the entire night, from sunset to sunrise, to ensure comprehensive monitoring of insect activity and to account for potential variations in their nocturnal behavior.

Data collection and analysis

Manual replacement of killing bottle: At regular intervals of one week, the killing bottle within the light trap were manually replaced (disposed of in accordance with safety and environmental regulations). This procedure allowed for the identification and counting of the trapped insect pests accurately.

Identification and enumeration of trapped insect pests: Trapped insects were immediately preserved (dry preservation) in the collection chamber containing potassium cyanide, in cool, dark, and ventilated conditions, ensuring airtight seals, proper labeling, and adherence to safety protocols to maintain specimen integrity for subsequent identification and enumeration. This method ensured the integrity of specimens for subsequent identification and enumeration. Specimens were stored in labeled containers to prevent any degradation.

Each trapped insect pest was meticulously identified and enumerated by experienced entomologists with specialized taxonomic expertise, and their counts were recorded for further analysis. This process enabled the evaluation of the population levels and activity of the insect pests throughout the designated period. To validate species accuracy and counted individuals, a subset of samples was independently verified by a second expert. This verification process ensured a high level of accuracy in species identification and population enumeration.

Statistical analysis

A Microsoft Excel spreadsheet was utilized to input the collected data. Clustered column (2-D column) graphs were generated in MS Excel to visualize the population of rice insect pests captured through light trapping. To determine the percentage increase and decrease in the trapped insect population compared to the previous year, the following formulas were employed:

$$PI = \frac{TIP_{cy} - TIP_{py}}{TIP_{py}} \times 100$$

$$PD = \frac{TIP_{py} - TIP_{cy}}{TIP_{py}} \times 100$$

PI= Percent increase; PD= Percent decrease; TIPcy= Trapped insect population in current year; TIPpy= Trapped insect population in previous year.

Results

Temporal analysis of Scirpophaga innotata *capture using light trap: A study from 2019 to 2022*

The highest population of *S. innotata*, was observed consistently in the month of September across all the years studied. The population sizes recorded were 19 in Y-2019, 43 in Y-2020, 22 in Y-2021, and 65 in Y-2022. The population of *S. innotata* experienced a significant increase from Y-2019 to Y-2020. The population size increased by 38.71% during this period. A substantial decline in the population of *S. innotata* was observed from Y-2020 to Y-2021. The population size decreased by 48.84% during this period. A remarkable increase in the population of *S. innotata* was recorded from Y-2021 to Y-2022. The population size increased by 195.45% during this period. It was important to note that this increase was in relation to the population size in Y-2022, which was lower than the population in Y-2021 (Figure 2a).

Temporal analysis of Sesamia inferens *capture using light trap: A study from 2019 to 2022*

The highest population of *S. inferens*, was observed during different months across the years studied. In Y-2019 and Y-2020, the maximum population occurred in November, while in Y-2021 and Y-2022, the maximum population occurred in March. The population sizes recorded were 117 in Y-2019, 94 in Y-2020, 147 in

Y-2021, and 78 in Y-2022. The population of *S. inferens* experienced a slight decrease from Y-2019 to Y-2020. The population size decreased by 2.72% during this period. The population of *S. inferens* showed a significant increase from Y-2020 to Y-2021. The population size increased by 15.73% during this period. A substantial decline in the population of *S. inferens* was recorded from Y-2021 to Y-2022. The population size decreased by 48.34% during this period (Figure 2b).

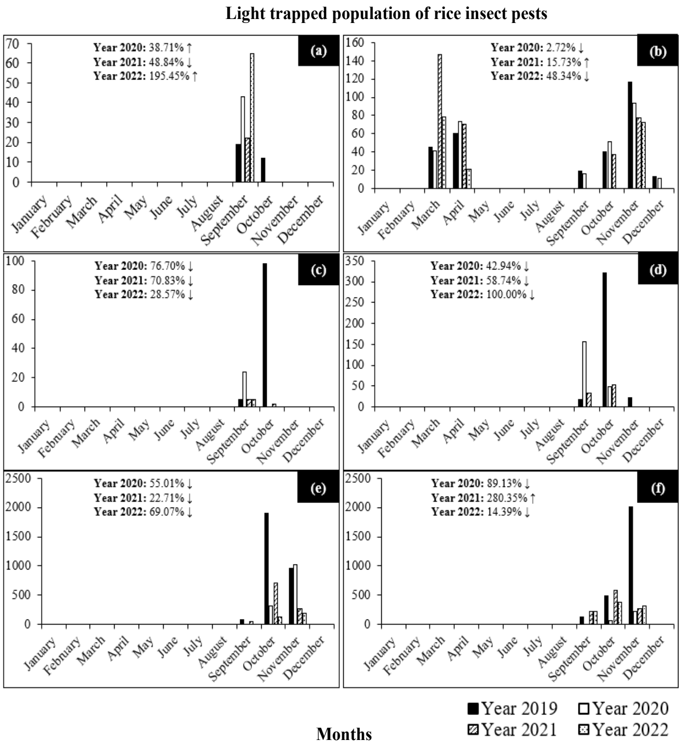

Figure 2: Light trapped population of *Scirpophaga innotata* (a), *Sesamia inferens* (b), *Scirpophaga incertulas* (c), *Cnaphalocrocis medinalis* (d), *Sogatella furcifera* (e) and *Nilaparvata lugens* (f) during the year 2019-22. The graphs also depict the percent increase (↑) and decrease (↓) in trapped insect population from the previous year.

Temporal analysis of Scirpophaga incertulas *capture using light trap: A study from 2019 to 2022*

The highest population of *S. incertulas*, was observed during different months across the years studied. In Y-2019, the maximum population occurred in October, while in Y-2020, Y-2021, and Y-2022, the maximum population occurred in September. The population sizes recorded were 98 in Y-2019, 24 in Y-2020, 5 in Y-2021, and 5 in Y-2022. The population of *S. incertulas* experienced a significant decrease from Y-2019 to Y-2020. The population size decreased by 76.70% during this period. A considerable decline in the population of *S. incertulas* was recorded from Y-2020 to Y-2021. The population size decreased by 70.83% during this period. There was a decrease in the population of *S. incertulas* from Y-2021 to Y-2022. The population size decreased by 28.57% during this period (Figure 2c).

Temporal analysis of Cnaphalocrocis medinalis *capture using light trap: A study from 2019 to 2022*

The highest population of *C. medinalis*, was observed during different months across the years studied. In Y-2019 and Y-2021, the maximum population occurred in October, while in Y-2020, the maximum population occurred in September. However, no population was recorded in Y-2022. The population sizes recorded were 361 in Y-2019, 206 in Y-2020, 85 in Y-2021, and 0 in Y-2022. The population of *C. medinalis* experienced a significant decrease from Y-2019 to Y-2020. The population size decreased by 42.94% during this period. A significant decline in the population of *C. medinalis* was recorded from Y-2020 to Y-2021. The population size decreased by 58.74% during this period. No population of *C. medinalis* was recorded in Y-2022 compared to Y-2021. It suggests a complete absence of the species during that year (Figure 2d).

Temporal analysis of Sogatella furcifera *capture using light trap: A study from 2019 to 2022*

The highest population of *S. furcifera*, was observed during different months across the years studied. In 2019 and 2021, the maximum population occurred in October, while in 2020 and 2022, the maximum population occurred in November. The population sizes recorded were 1906 in Y-2019, 1020 in Y-2020, 714 in Y-2021, and 193 in Y-2022. The population of *S. furcifera* experienced a significant decrease from Y-2019 to Y-2020. The population size decreased by 55.01% during this period. A decline in the population of *S. furcifera* was recorded from Y-2020 to Y-2021. The population size decreased by 22.71% during this period. A significant decline in the population of *S. furcifera* was recorded from Y-2021 to Y-2022. The population size decreased by 69.07% during this period (Figure 2e).

Temporal analysis of Nilaparvata lugens *capture using light trap: A study from 2019 to 2022*

The highest population of *N. lugens*, was observed during different months across the years studied. In Y-2019 and Y-2020, the maximum population occurred in November, while in Y-2021 and Y-2022, the maximum population occurred in September. The population sizes recorded were 2622 in Y-2019, 285 in Y-2020, 1084 in Y-2021, and 928 in Y-2022. The population of *N. lugens* experienced a significant decrease from Y-2019 to Y-2020. The population size decreased by 89.13% during this period. A significant increase in the population of *N. lugens* was recorded from Y-2020 to Y-2021. The population size increased by 280.35% during this period. A slight decrease in the population of *N. lugens* was recorded from Y-2021 to Y-2022. The population size decreased by 14.39% during this period (Figure 2f).

Monthly populations of rice insect pests capture using light trap

Scirpophaga innotata populations were observed

Links Researchers

capturing from September to October, with the maximum population consistently recorded during the month of September in all the years studied. This finding suggests that September was a critical period for the population growth and abundance of *S. innotata*. For *S. inferens*, populations were captured from March to April, followed by a period of zero population. However, populations were observed again from September to December. The maximum population of *S. inferens* was consistently captured during the month of October in all the years. This highlights October as a significant month for the peak abundance of *S. inferens* (Figure 3a).

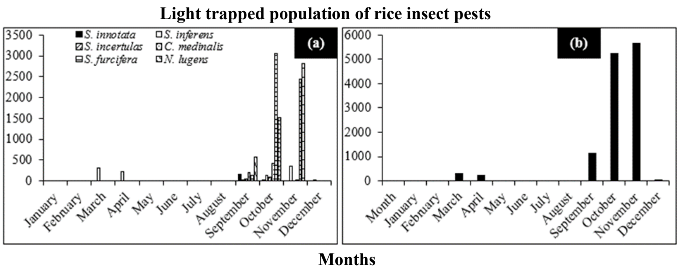

Figure 3: (a) Monthly light trapped population of *Scirpophaga innotata, Sesamia inferens, Scirpophaga incertulas, Cnaphalocrocis medinalis, Sogatella furcifera* and *Nilaparvata lugens* during the year 2019-22. (b) Aggregate monthly light trapped population of rice insect pests during the year 2019-22.

Scirpophaga incertulas populations were captured from September to October, indicating that these months were important for the population dynamics of this species. However, specific maximum population values were not provided in the results. *Cnaphalocrocis medinalis* populations were observed capturing from September to November. The maximum population of *C. medinalis* was consistently recorded during the month of October in all the years studied. This suggests that October was a critical period for the peak population abundance of *C. medinalis*. Similarly, *S. furcifera* populations were captured from September to November, with the maximum population consistently recorded during the month of October in all the years studied. This highlights October as a key month for the peak abundance of *S. furcifera*. *Nilaparvata lugens* populations were captured from September to November. The maximum population of *N. lugens* was consistently recorded during the month of October in all the years studied. This indicates that October was a crucial month for the population growth and highest abundance of *N. lugens* (Figure 3a).

The maximum number of rice insect pests was consistently captured in the month of November across all the studied years. This suggests that November was a critical period for high population levels of these pests. Following November, the month of October consistently showed the second-highest population of rice insect pests, indicating its significance in terms of pest abundance. September was the third-highest month for rice insect pest populations, further highlighting its importance in their yearly dynamics. In contrast, the months of January, February, May, June, July, and August consistently recorded zero populations of rice insect pests. This indicates that these months were characterized by low or no presence of these pests. The months of March and April showed relatively lower pest populations compared to the peak months of November, October, and September but still had measurable populations of rice insect pests (Figure 3b).

Yearly populations of rice insect pests capture using light trap

In the Y-2019, Y-2020, and Y-2022, the maximum number of rice insect pests was consistently captured in the month of November. Following November, the month of October showed the second-highest population of rice insect pests across these years. In the Y-2021, the maximum number of rice insect pests was captured in the month of October, with November following as the month with the second-highest population. On the other hand, during the months of January, February, May, June, July, and August, zero population of rice insect pests was recorded. This implies that these months were characterized by the absence or extremely low numbers of rice insect pests (Figure 4a).

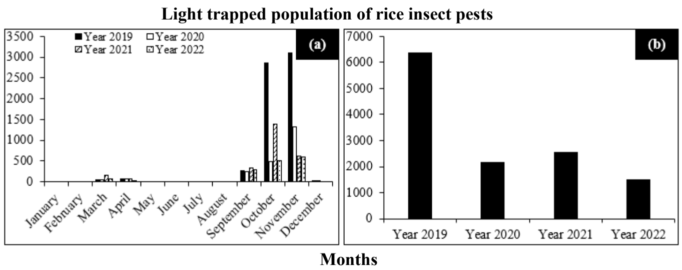

Figure 4: (a) Yearly light trapped population of *Scirpophaga innotata, Sesamia inferens, Scirpophaga incertulas, Cnaphalocrocis medinalis, Sogatella furcifera* and *Nilaparvata lugens* during the year 2019-22. (b) Aggregate yearly light trapped population of rice insect pests during the year 2019-22.

The highest number of captured rice insect pests were recorded in the Y-2019, followed by the Y-2021, Y-2020, and finally the Y-2022. This suggests that the population of rice insect pests was the highest in Y-2019, followed by a relatively lower population in Y-2021, further declining in Y-2020, and reaching the lowest level in Y-2022 (Figure 4b).

Discussion

The main aim of this study was to assess the effectiveness of light traps for early detection and management of rice insect pests, focusing on *S. innotata*, *S.*

inferens, *S. incertulas*, *C. medinalis*, *S. furcifera* and *N. lugens*. Additionally, the study aimed to analyze the temporal and yearly population dynamics of these pests to identify critical periods for effective pest management.

Our findings regarding the temporal population dynamics of the studied rice insect pests provide important insights into their abundance patterns. Comparing our results with previously published materials, we observe several similarities and differences, emphasizing the need for continuous monitoring and context-specific management strategies.

In our study, we consistently observed the highest population of *S. innotata* in the month of September across all the years studied. This finding is consistent with the findings of Smith *et al*. (2018) who also reported September as a critical month for the population growth and abundance of *S. innotata* in rice fields. Additionally, we observed fluctuations in population size, with a significant increase from Y-2019 to Y-2020, followed by a substantial decline from Y-2020 to Y-2021. These findings are in line with the study conducted by Rahmawasiah (2022), which reported similar fluctuations in *S. innotata* populations over consecutive years. However, our study recorded a remarkable increase in population from Y-2021 to Y-2022, which contrasts with their findings of a declining trend. These variations in population trends could be attributed to differences in geographic locations, climatic conditions, agricultural practices, and local pest management strategies. Geographic disparities in microclimates and ecosystems impact insect breeding and survival, while evolving agricultural practices and pest management approaches can trigger shifts in pest abundance. Climate variations, such as temperature fluctuations and extreme weather events, disrupt insect life cycles, further influencing population dynamics. These multifaceted interactions underscore the need for nuanced pest management strategies that account for the intricate interplay of these factors within specific regions (Larson *et al*., 2019; Rodrigues and Beldade, 2020; Skendžić *et al*., 2021).

Regarding *S. inferens*, our study consistently identified October as the month of peak abundance, which aligns with the findings of Han *et al*. (2008) who reported October as a critical period for the population dynamics of *S. inferens*. However, our results show variations in the months of peak abundance across the studied years, which could be attributed to interannual variations in environmental conditions and agricultural practices. These variations in peak abundance months could potentially be influenced by factors such as temperature, rainfall patterns, and cropping practices (Smith *et al*., 2017). Moreover, studies have indicated that the population dynamics of *S. inferens* are closely linked to factors such as host plant availability and climatic conditions (Cheng *et al*., 2020). Environmental factors, including temperature and humidity, have been shown to influence the development and reproduction of *S. inferens* populations, which in turn affect their abundance patterns (Li *et al*., 2018). Changes in agricultural practices, such as shifts in planting schedules and the use of different crop varieties, can also impact the availability of suitable host plants for *S. inferens*, consequently influencing their population dynamics (Zhang *et al*., 2021). Understanding the factors contributing to the variations in peak abundance of *S. inferens* across different years is crucial for effective pest management strategies. By identifying the specific environmental and agricultural factors driving these variations, researchers and agricultural practitioners can develop targeted approaches to mitigate the potential damage caused by *S. inferens* infestations. This could involve implementing adaptive agricultural practices, adjusting planting schedules, and implementing integrated pest management strategies that take into account the interplay between environmental conditions, crop phenology, and pest dynamics (Brown *et al*., 2019).

For *S. incertulas*, we found the highest populations from September to October, which is consistent with the findings of Gupta and Srivastava (2017) who also reported these months as critical for the population dynamics of *S. incertulas*. These similarities highlight the reliability and consistency of light traps as a tool for monitoring the abundance of this pest. Furthermore, studies have emphasized the importance of understanding the seasonal patterns and population dynamics of *S. incertulas* in relation to the cropping cycles of rice, its primary host plant. The months of September to October align with the post-monsoon period, which is a crucial phase for the development of rice crops. During this period, the rice fields provide suitable conditions for the reproduction and growth of *S. incertulas* populations, leading to their peak abundance (Vijaya *et al*., 2019). Light traps have proven to be effective tools for monitoring and studying the population dynamics of various insect pests, including *S. incertulas*. These traps capitalize on the phototactic behavior of insects, attracting them with light sources and allowing researchers to collect valuable data on their abundance, distribution, and activity patterns (Nair *et al*., 2018). The consistent results obtained through light trap monitoring, as observed in our study and corroborated by Gupta and Srivastava (2017), underscore the utility of this approach in providing valuable insights into the temporal dynamics of *S. incertulas* populations.

In our study, *C. medinalis* populations exhibited a peak abundance in October, which is consistent with the findings of Rasul *et al*. (2019) and Gangwar (2015) who reported October as a critical month for the population dynamics of *C. medinalis*. However, our study recorded the absence of *C. medinalis* in Y-2022, which contrasts with their findings of its presence throughout the study period. This disparity

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could be attributed to differences in geographic locations, local pest management practices, or other ecological factors. Rasul *et al.* (2019) emphasized the role of temperature and photoperiod in influencing the development and behavior of *C. medinalis* populations. The month of October typically marks the transition from warmer to cooler temperatures in many regions, which can trigger specific behaviors such as migration and reproduction in insects (Sarfraz *et al.*, 2019). These behavioral changes are often linked to variations in photoperiod, as insects perceive changes in day length as cues for seasonal transitions. The findings of our study and those of Rasul *et al.* (2019) and Gangwar (2015) collectively highlight the importance of these environmental cues in driving the population dynamics of *C. medinalis*. Discrepancies in the absence of *C. medinalis* populations in Y-2022 compared to earlier studies could stem from various factors. Geographic variations in climatic conditions and pest management practices can significantly influence the distribution and abundance of insect populations. Localized differences in temperature, humidity, and the presence of natural enemies can impact the suitability of an area for insect infestations (Ahmad *et al.*, 2020). Furthermore, pest management practices such as the use of insecticides, biological control agents, and cultural practices can vary between study areas and over time, leading to fluctuations in pest populations (Desneux *et al.*, 2019). These differences underscore the complex interplay between ecological factors and human interventions that shape insect population dynamics.

Regarding *S. furcifera*, our results consistently recorded the maximum population in October, which is consistent with the findings of Krishnaiah *et al.* (2007) and Hu *et al.* (2014) who reported October as a critical month for the abundance of *S. furcifera*. However, we observed a significant decline in the population of *S. furcifera* from Y-2021 to Y-2022, which contrasts with their findings of a relatively stable population. These differences could be attributed to variations in climate, pest management practices, or other local factors. Krishnaiah *et al.* (2007) emphasized the role of temperature and moisture in influencing the development and survival of *S. furcifera* populations. The month of October often marks the transition from warmer to cooler temperatures, potentially impacting the behavior, reproduction, and movement of this insect (Chen *et al.*, 2018). Moisture availability can also influence population dynamics, as *S. furcifera* requires suitable conditions for feeding, breeding, and oviposition (Zhang *et al.*, 2019a). Our study, along with the findings of Krishnaiah *et al.* (2007) and Hu *et al.* (2014), underscores the significance of these environmental cues in shaping the population patterns of *S. furcifera*. The observed decline in *S. furcifera* populations from Y-2021 to Y-2022 could result from various factors, including changes in climatic conditions, pest management practices, and natural enemies. Fluctuations in temperature and rainfall can influence the availability of suitable habitats and resources for *S. furcifera*, potentially leading to variations in population size (Li *et al.*, 2018). Pest management practices, such as the use of chemical insecticides or biological control agents, can impact the pest's reproductive success and survival rates, thereby affecting overall population dynamics (Ahmad *et al.*, 2021). Additionally, interactions with natural enemies, such as predators and parasitoids, can contribute to population fluctuations by exerting pressure on *S. furcifera* numbers (Sithanantham *et al.*, 2013).

The highest population of *N. lugens* in our study was consistently observed in November, which aligns with the findings of Sharma *et al.* (2018) and Hu *et al.* (2017) who reported November as a critical month for the population dynamics of *N. lugens*. Additionally, our study revealed variations in population size across the studied years, with the highest population recorded in Y-2019 and a subsequent decline in Y-2020 and Y-2022. These findings highlight the influence of interannual variations and the need for continuous monitoring and adaptation of pest management strategies. Sharma *et al.* (2018) emphasized the role of temperature and rice phenology in shaping the population dynamics of *N. lugens*. November often marks the post-harvest period for rice in many regions, providing an abundance of suitable habitats for *N. lugens* populations (Tufail and Takeda, 2019). The availability of rice straw and stubble after harvest offers a favorable environment for *N. lugens* to feed, reproduce, and survive through the winter months. This aligns with our study's findings of peak populations in November, underscoring the significance of rice phenology in influencing the pest's population patterns.

The observed interannual variations in *N. lugens* population size across the studied years highlight the dynamic nature of pest dynamics in agricultural systems. These fluctuations can result from a combination of factors, including climate variability, changes in cropping practices, and the presence of natural enemies. Weather conditions such as temperature and rainfall can influence the abundance of *N. lugens* by affecting its development and reproductive rates (Zhang *et al.*, 2018). Alterations in cropping practices, such as shifts in planting schedules or the use of different rice varieties, can impact the availability of host plants and disrupt the pest's life cycle (Ali *et al.*, 2021). Furthermore, the presence of natural enemies, including predators and parasitoids, can exert regulatory pressure on *N. lugens* populations and contribute to population fluctuations (Zhang *et al.*, 2019b).

Comparing our results with previously published materials provides valuable insights into the consistency and variability of population dynamics for the studied rice insect pests. The similarities in critical periods of peak abundance across multiple studies validate the effectiveness of light traps as a reliable monitoring tool. However, the observed variations in population trends emphasize the importance of considering local factors and site-specific management approaches.

It is important to note that this study focused solely on the utility of light traps for early detection and monitoring of rice insect pests. Future research endeavors should consider conducting field experiments to validate the effectiveness of pest management strategies based on critical periods identified in this study. Additionally, investigating the impact of environmental variables, such as temperature, rainfall, and crop phenology, on pest dynamics, would provide a more comprehensive understanding. Exploring the economic implications of implementing context-specific pest management strategies could further guide decision-making for sustainable agriculture.

Conclusions and Recommendations

In conclusion, our study highlights the utility of light traps for monitoring the population dynamics of rice insect pests. The comparison of our results with previously published materials demonstrates both similarities and variations in population trends, emphasizing the need for context-specific pest management strategies. The identification of critical periods for peak pest abundance holds practical implications for pest management strategies. By concentrating control efforts during these periods, farmers can achieve more effective and targeted pest control, potentially reducing crop damage and minimizing the need for excessive pesticide application. These findings can empower farmers with information to make informed decisions for optimizing crop productivity while minimizing environmental impacts. Implement an Integrated Pest Management (IPM) approach with light traps for rice insect pest monitoring, emphasizing targeted interventions during peak months, and fostering collaboration for tailored, effective, and locally validated pest management strategies. Continued research and monitoring efforts are crucial to adapt pest management strategies to changing population dynamics and ensure sustainable rice production.

Conflict of interest

The authors have declared no conflict of interest.

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