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Technology Development for Optimal Trap Colors and Density Assessment against Rice Planthoppers

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Abstract Effective management of rice planthoppers, major pests affecting rice crops, necessitates optimal strategies for monitoring and controlling their populations. This study aimed to develop and evaluate technology to determine the most effective trap color and density to capture rice planthoppers. For five years (2019-2023), this research investigated the influence of different trap colors and densities on planthopper capture rates. The study utilized square-shaped sticky traps of five colors (White, Red, Green, Yellow, and Blue) installed at six densities (10, 15, 20, 25, 30, and 35 traps per acre) in rice fields. Traps were monitored weekly, and the captured planthoppers were counted. Studies from 2019 to 2023 revealed that as the number of traps increased, more rice planthoppers were captured on all trap colors, with Yellow Sticky Traps (YST) consistently catching the most. In 2019, YST captured 153.4 planthoppers at 10 traps per acre, increasing to 290.8 at 35 traps per acre, while Red Sticky Traps (RST) captured the least, from 32.6 to 68.6. This pattern persisted each year, with YST capturing the highest number of planthoppers at all densities: in 2020, captures ranged from 229.4 to 342.8; in 2021, from 286.4 to 388.6; in 2022, from 203.4 to 324.4; and in 2023, from 258.6 to 363.6. Green Sticky Traps (GST) and White Sticky Traps (WST) also performed well, while Blue Sticky Traps (BST) showed moderate effectiveness. RST remained the least effective but improved with higher densities. The study identified YST as the most effective color for capturing rice planthoppers, with increased trap density, leading to higher capture rates. These findings provided a basis for optimizing trap deployment in rice fields, contributing to more efficient pest management strategies.

Keywords Rice Planthoppers, Sticky Traps, Trap Color, Trap Density, Pest Management

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple foods, providing sustenance to over half of the global population [1]. However, rice production faces significant threats from various insect pests, among which planthoppers are particularly notorious [2]. Brown planthopper (*Nilaparvata lugens* Stål) and white-backed planthopper (*Sogatella furcifera* Horváth) are two major species that cause substantial damage to rice crops [3]. These pests not only directly feed on the plant sap, causing hopperburn and plant stunting, but also act as vectors for viral diseases, further exacerbating crop losses [4].

Traditional methods of controlling planthoppers have relied heavily on chemical insecticides [5]. While effective in the short term, these chemical controls pose several challenges, including developing insecticide resistance, resurgence of pest populations, negative impacts on non-target organisms, and environmental pollution [6,7]. Therefore, sustainable, and eco-friendly pest management strategies are imperative for long-term agricultural productivity and environmental health [8].

Among various Integrated Pest Management (IPM) strategies, sticky traps have emerged as promising tools for monitoring and controlling planthopper populations [9]. Sticky traps are advantageous because they are non-toxic, easy to use, and can be deployed to target specific pests based on their visual attraction to certain colors and densities [10]. However, the effectiveness of sticky traps is highly dependent on their color and density, which can influence the capture rates of the target pests [11,12,13].

Previous studies have shown that insect pests, including planthoppers, exhibit preferences for certain colors [14,15,16]. For instance, yellow and blue traps are particularly effective for many insect pests due to their high visual contrast against the green foliage of crops [10,17]. The density of traps, referring to the number of traps per unit area, also plays a crucial role in the effectiveness of pest capture and management [10,18]. Higher trap densities may increase the probability of intercepting pests, but they also involve greater costs and labor [19].

In rice ecosystems, optimizing the color and density of sticky traps could significantly enhance their efficiency in monitoring and controlling planthopper populations [9,20]. However, there is a need for region-specific studies to determine the optimal trap characteristics under local environmental conditions and pest dynamics.

The objective of this study was to systematically evaluate the effectiveness of different trap colors and densities in the context of rice planthopper management. The findings are expected to contribute to developing more effective and sustainable IPM strategies, reducing the reliance on chemical insecticides, and mitigating their associated risks.

2. Materials and Methods

2.1. Site Preparation

The experimental site at Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan was selected for its consistent agronomic conditions suitable for rice cultivation from 2019 to 2023. Standard agronomic practices, including tillage, sowing, and irrigation, were followed to ensure a healthy rice crop (*var.* Basmati 515) without applying insecticides to manage rice planthoppers.

2.2. Trap Setup

Square-shaped sticky traps were designed using weather-resistant durable materials to withstand field conditions. The trap surfaces were coated with a non-drying adhesive to ensure consistent trapping efficiency throughout the study period. The colors (White, Red, Green, Yellow, and Blue) were applied using high-quality dyes selected to reflect the intended wavelengths accurately, considering that many insects, including rice planthoppers, have vision extending into the ultraviolet range. These five distinct colors were chosen based on preliminary studies suggesting their potential attractiveness to rice planthoppers (Table 1).

Traps were installed at six different densities (10, 15, 20, 25, 30, and 35 traps per acre) to evaluate the influence of trap density on capture rates. Traps were placed at a height of 30-50 cm above the ground, aligning with the rice canopy where planthoppers are commonly found. Each density treatment was replicated three times, with traps evenly distributed across the field to minimize spatial bias.

Table 1. Comparison of trap colors based on wavelength, insect attractiveness, and versatility in insect pest management

Trap color	Wavelength	Attractiveness	Versatility
White	~400–700 nm	Moderately attractive to a variety of insect species	Highly versatile as a control color; visible in all conditions and good for comparisons
Red	~620–750 nm	Least attractive to most insects, including planthoppers	Mainly useful for testing color preferences, not for pest attraction
Green	~495–570 nm	Mimics foliage, making it somewhat attractive, though results may vary	Best in dense vegetation; useful for comparing natural vs. artificial colors
Yellow	~570–590 nm	Highly attractive to planthoppers due to its similarity to sunlight and healthy plants	Very versatile and effective across different insect species and environments
Blue	~450–495 nm	Moderately attractive, especially in open fields and for planthoppers	Works well in combination with other colors and offers good contrast with vegetation

2.3. Insecticide Use

Insecticides were not applied to the specific fields where the traps were installed, ensuring that the planthoppers in the experimental area were not directly exposed to chemical treatments. However, insecticides were applied in neighboring fields, which may have influenced insect movement or behavior. The absence of insecticides in the experimental field ensured that any behavioral interactions with the traps were unaffected by selective pressures within the experimental area, although regional insecticide use may have had some indirect impact.

2.4. Land Arrangement and Dimensions

The experimental plots were arranged so that each plot was assigned a specific trap color and density. Each plot was clearly demarcated and of uniform size, ensuring that comparisons could be made across treatments with minimal spatial interference. The dimensions of the plots were consistent across replicates, avoiding variations in trap performance due to plot size.

2.5. Trap Placement in Growing Season

The traps were placed during the peak active period of rice planthoppers, specifically from October to November. This timing was carefully chosen to coincide with the planthoppers' most active period in the rice fields, allowing for optimal capture rates and effective assessment of trap performance during the critical phases of the pest's life cycle.

2.6. Buffer Zones between Plots

Buffer land without any traps was maintained between the experimental plots to minimize the movement of planthoppers between adjacent areas. This setup ensured that the trapping effectiveness in one plot did not influence the insect populations or capture rates in neighboring plots.

2.7. Trap Monitoring

The traps were installed and remained in place throughout the active period of rice planthoppers, from October to November. Traps were monitored weekly, and the number of rice planthoppers captured on each trap was counted and recorded. Monitoring was conducted early in the morning to minimize disturbance and ensure accurate counts. To maintain consistent trapping efficiency, traps were replaced as needed if the adhesive lost effectiveness or if any damage occurred, ensuring reliable and accurate data collection throughout the planthopper's peak activity period. Data were meticulously recorded, noting the trap color, density, and the number of planthoppers captured.

2.8. Statistical Analysis

Data from each year (2019-2023) were compiled and organized into a comprehensive database. The data included the total number of planthoppers captured per trap color and density for each replication and year. The experiment was replicated three times per year for each treatment combination, ensuring sufficient statistical power. A mixed factorial ANOVA was employed, treating year as a within-group factor and trap color and density as between-group factors, to determine significant differences in planthopper captures among trap colors and densities. The significance level was set at $p < 0.05$.

The Least Significant Difference (LSD) post hoc test was used for pairwise comparisons to identify specific differences between trap colors and densities. Graphs illustrating the mean values of trapped planthoppers for each trap color and density were created using MS Excel, with error bars provided to indicate variability. Additionally, correlation graphs were developed to explore the relationship between trap density, color, and planthopper captures. These statistical analyses ensured a rigorous and comprehensive evaluation of the factors influencing planthopper trapping efficiency.

3. Results

Results obtained in 2019 showed that, as the trap density increased, the number of rice planthoppers captured also increased across all colors. Specifically, at 10 traps per acre, YST captured the most planthoppers (153.4), while RST captured the least (32.6). At 15 traps per acre, YST again captured the most (185.8), and RST the least (48.0). This trend continued with higher densities, with YST consistently capturing the highest number of planthoppers: 216.0 at 20 traps per acre, 237.4 at 25 traps per acre, 264.2 at 30 traps per acre, and 290.8 at 35 traps per acre. GST and WST also performed well, particularly at higher densities, while BST showed moderate effectiveness. RST remained the least effective, despite some improvement with increased density. Overall, YST proved to be the most effective in capturing rice planthoppers, highlighting their potential for effective pest management (Fig 1a).

Results obtained in 2020 showed that, as the trap density increased, the number of rice planthoppers captured also increased across all colors. Specifically, at 10 traps per acre, YST captured the most planthoppers (229.4), while RST captured the least (68.6). At 15 traps per acre, YST again captured the most (251.2), and RST the least (88.4). This trend continued with higher densities, with YST consistently capturing the highest number of planthoppers: 295.2 at 20 traps per acre, 317.8 at 25 traps per acre, 326.2 at 30 traps per acre, and 342.8 at 35 traps per acre. GST and WST also performed well, particularly at higher densities, while BST showed moderate effectiveness. RST remained the least effective, despite some improvement with increased density. Overall, YST proved to be the most effective in capturing rice planthoppers, highlighting their potential for effective pest management (Fig 1b).

Results obtained in 2021 showed that, as the trap density increased, the number of rice planthoppers captured also increased across all colors. Specifically, at 10 traps per acre, YST captured the most planthoppers (286.4), while RST captured the least (104.0). At 15 traps per acre, YST again captured the most (304.6), and RST the least (128.6). This trend continued with higher densities, with YST consistently capturing the highest number of planthoppers: 328.2 at 20 traps per acre, 340.8 at 25 traps per acre, 361.2 at 30 traps per acre, and 388.6 at 35 traps per acre. GST and WST also performed well, particularly at higher densities, while BST showed moderate effectiveness. RST remained the least effective, despite some improvement with increased density. Overall, YST proved to be the most effective in capturing rice planthoppers, highlighting their potential for effective pest management (Fig 1c).

Results obtained in 2022 showed that, as the trap density increased, the number of rice planthoppers captured also increased across all colors. Specifically, at 10 traps per acre, YST captured the most planthoppers (203.4), while RST captured the least (51.0). At 15 traps per acre, YST again captured the most (227.8), and RST the least (62.6). This trend continued with higher densities, with YST consistently capturing the highest number of planthoppers: 249.2 at 20 traps per acre, 275.8 at 25 traps per acre, 301.6 at 30 traps per acre, and 324.4 at 35 traps per acre. GST and WST also performed well, particularly at higher densities, while BST showed moderate effectiveness. RST remained the least effective, despite some improvement with increased density. Overall, YST proved to be the most effective in capturing rice planthoppers, highlighting their potential for effective pest management (Fig 1d).

Results obtained in 2023 showed that, as the trap density increased, the number of rice planthoppers captured also increased across all colors. Specifically, at 10 traps per acre, YST captured the most planthoppers (258.6), while RST captured the least (84.4). At 15 traps per acre, YST again captured the most (283.0), and RST the least (103.6). This trend continued with higher densities, with YST consistently capturing the highest number of planthoppers: 307.2 at 20 traps per acre, 324.0 at 25 traps per acre, 348.0 at 30 traps per acre, and 363.6 at 35 traps per acre. GST and WST also performed well, particularly at higher densities, while BST showed moderate effectiveness. RST remained the least effective, despite some improvement with increased density. Overall, YST proved to be the most effective in capturing rice planthoppers, highlighting their potential for effective pest management (Fig 1e).

The graphical representation in Figure 2 and the correlation coefficients in Table 2 provided a comprehensive understanding of the relationship between trap densities and their effectiveness in capturing rice planthoppers for different trap colors over the years 2019 to 2023. The graphs consistently showed a positive correlation between trap density and the number of rice planthoppers captured. This meant that as the number of traps per acre increased, the capture rate of rice planthoppers also increased. Among the different colors, YST consistently captured the highest number of rice planthoppers, followed by GST. WST and BST showed moderate effectiveness, while RST was the least effective but still showed improvement with increased density (Fig 2).

Table 2 presents the linear regression equations and the coefficients of determination (R^2) for each trap color across the five years. The equations indicated the relationship between trap density (x) and the number of trapped rice planthoppers (y). The high R^2 values, ranging from 0.949 to 0.999, indicated a strong linear relationship between trap density and rice planthoppers' capture rates for all trap colors. In 2019, the equations showed that YST had the highest slope (5.392x), indicating the highest increase in rice planthoppers captures with increasing trap density, and an R^2 of 0.997, reflecting a very strong correlation. In 2020, YST again showed a high slope (4.6549x) with an R^2 of 0.949, while GST also demonstrated a high capture rate with a slope of 4.8206x and an R^2 of 0.987. The trend continued in 2021, with YST having a slope of 3.9623x and an R^2 of 0.992, and GST showing a slope of 4.376x and an R^2 of 0.990. In 2022, YST had a slope of 4.8743x and an R^2 of 0.999, and GST had a slope of 5.5794x and an R^2 of 0.991, indicating exceptionally strong correlations. In 2023, YST maintained a high capture rate with a slope of 4.2103x and an R^2 of 0.995, while GST had a slope of 4.7771x and an R^2 of 0.986 (Table 2).

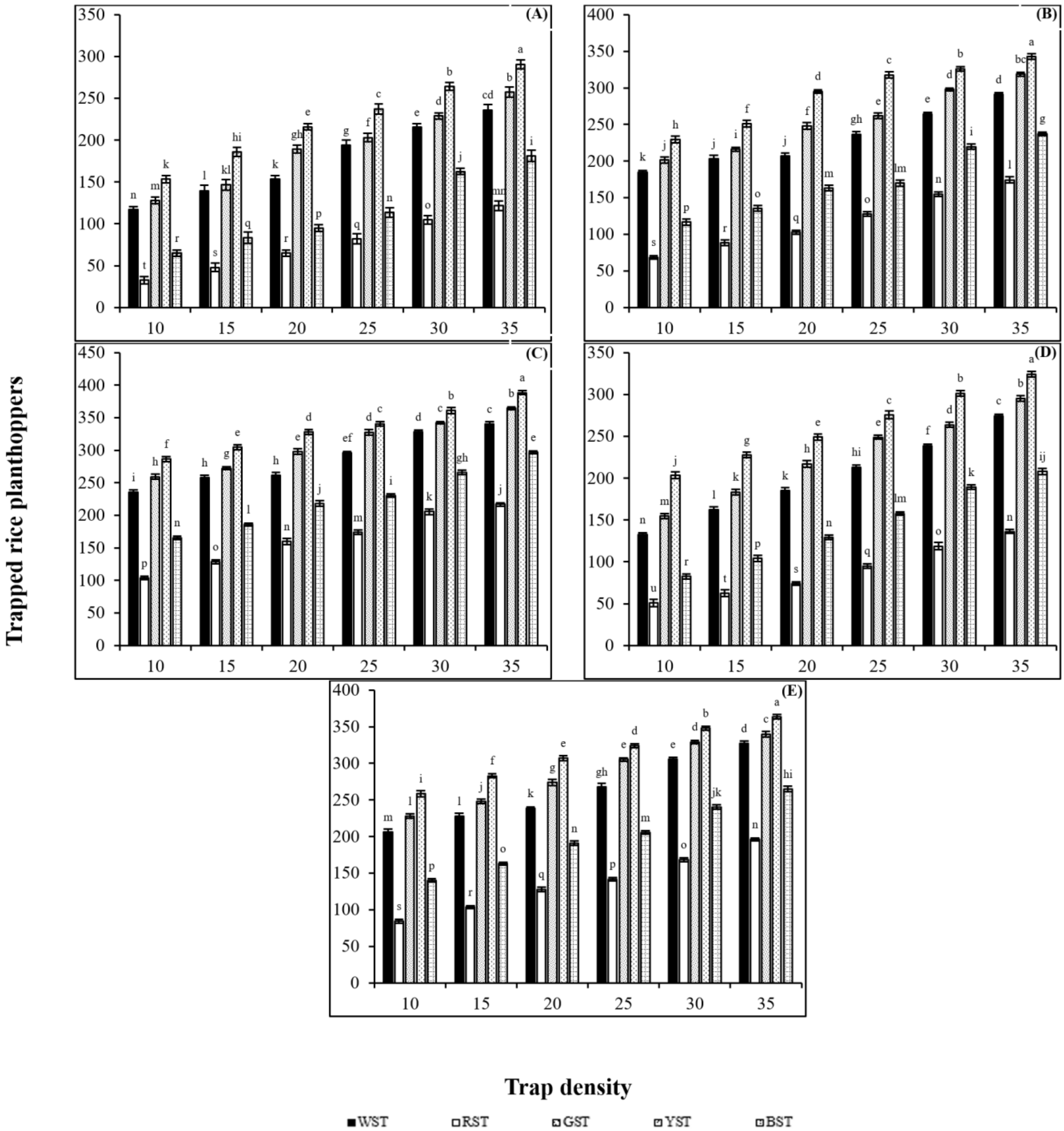

Figure 1. Effectiveness of different trap colors and trap densities in the context of rice planthopper management over the years 2019(A), 2020(B), 2021(C), 2022(D), and 2023(E)

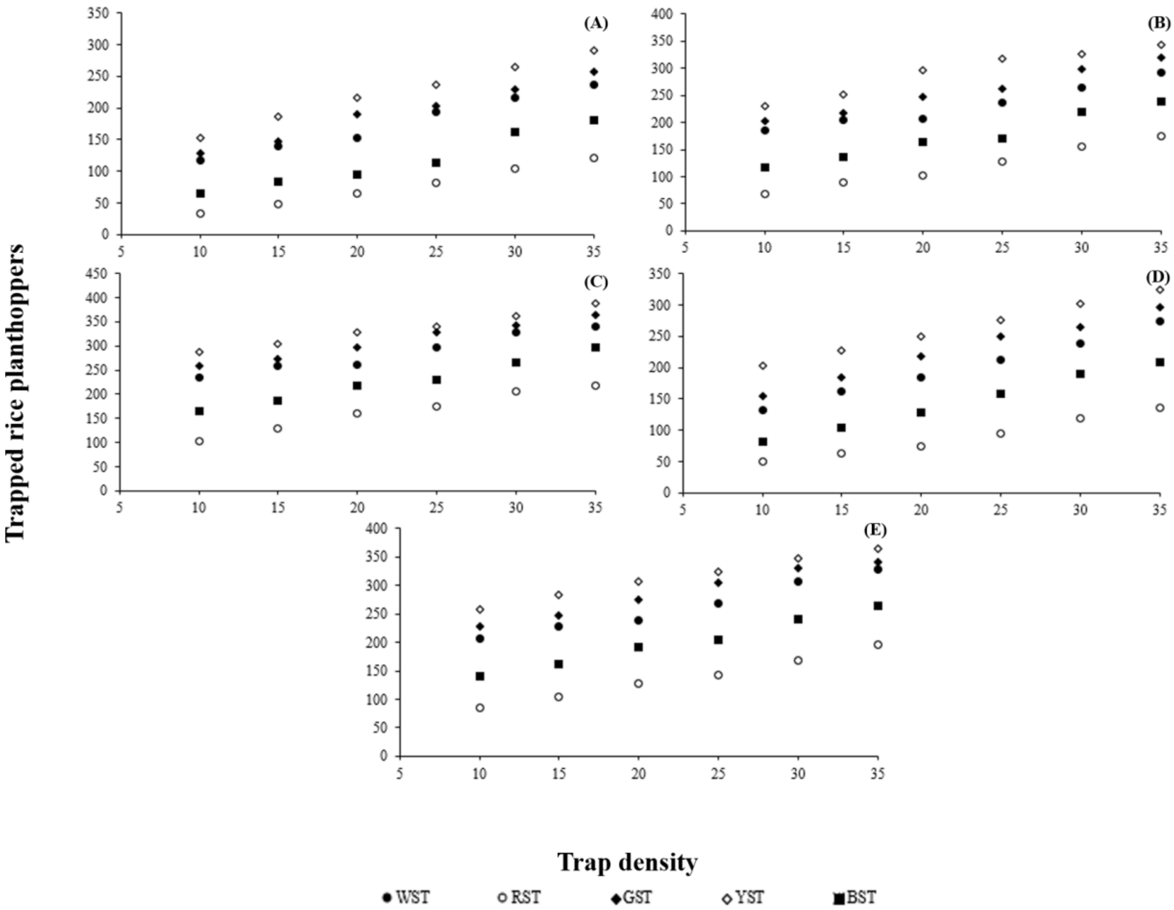

Figure 2. Graphical representation of correlation of different trap colors and trap densities in the context of rice planthopper management over the years 2019(A), 2020(B), 2021(C), 2022(D), and 2023(E)

Table 2. Correlation coefficients of different trap colors and trap densities in the context of rice planthopper management over different study years

Year	Trap color				
	WST	**RST**	**GST**	**YST**	**BST**
2019	y = 4.9383x + 64.922 R^2= 0.986	y = 3.6137x - 5.5752 R^2= 0.997	y = 5.1897x + 75.531 R^2= 0.987	y = 5.392x + 103.28 R^2= 0.997	y = 4.784x + 9.16 R^2= 0.951
2020	y = 4.2423x + 135.95 R^2= 0.962	y = 4.3063x + 22.642 R^2= 0.993	y = 4.8206x + 148.87 R^2= 0.987	y = 4.6549x + 189.03 R^2= 0.949	y = 4.9371x + 62.714 R^2= 0.966
2021	y = 4.3966x + 187.84 R^2= 0.964	y = 4.6343x + 60.629 R^2= 0.986	y = 4.376x + 212.31 R^2= 0.990	y = 3.9623x + 245.82 R^2= 0.992	y = 5.1909x + 110.41 R^2= 0.987
2022	y = 5.5337x + 76.558 R^2= 0.996	y = 3.5189x + 10.459 R^2= 0.982	y = 5.5794x + 101.73 R^2= 0.991	y = 4.8743x + 154.03 R^2= 0.999	y = 5.2091x + 27.994 R^2= 0.996
2023	y = 4.9634x + 150.56 R^2= 0.976	y = 4.3806x + 38.47 R^2= 0.992	y = 4.7771x + 179.91 R^2= 0.986	y = 4.2103x + 219.34 R^2= 0.995	y = 4.9726x + 88.884 R^2= 0.993

In 2019, WST trapped an average of 176.03 rice planthoppers, RST trapped 75.73, GST trapped 192.30, YST trapped 224.60, and BST trapped 116.80. In 2020, the number of trapped rice planthoppers increased across all traps, with WST capturing 231.40, RST capturing 119.53, GST capturing 257.33, YST capturing 293.77, and BST capturing 173.80. The trend continued in 2021, with WST trapping 286.77, RST trapping 164.90, GST trapping 310.77, YST trapping 334.97, and BST trapping 227.20. In 2022, the number of rice planthoppers trapped decreased slightly for most traps, with WST trapping 201.07, RST trapping 89.63, GST trapping 227.27, YST trapping 263.70, and BST trapping 145.20. However, in 2023, the numbers rose again, with WST trapping 262.23, RST trapping 137.03, GST trapping 287.40, YST trapping 314.07, and BST trapping 200.77. Throughout the years, GST consistently trapped the most rice planthoppers each year, with the highest count observed in 2021. In contrast, RST consistently trapped the fewest rice planthoppers each year. YST and BST also showed high effectiveness, second only to GST. WST showed moderate effectiveness throughout the years. GST appeared to be the most effective in trapping rice planthoppers across the years, followed by YST and BST. RST was the least effective. This data guided the optimal trap color selection for managing rice planthoppers (Fig 3).

In 2019, the number of trapped rice planthoppers ranged from 99.24 at a density of 10 traps per acre to 217.48 at a density of 35 traps per acre. In 2020, the numbers increased significantly, ranging from 160.28 at 10 traps per acre to 272.88 at 35 traps per acre. The trend continued in 2021, with even higher capture rates, ranging from 210.20 at 10 traps per acre to 321.52 at 35 traps per acre. In 2022, there was a slight decline in the number of captured rice planthoppers compared to 2021, but the numbers still showed an overall increase compared to 2019, with captures ranging from 124.8 at 10 traps per acre to 247.72 at 35 traps per acre. By 2023, the number of trapped rice planthoppers increased again, ranging from 183.44 at 10 traps per acre to 298.36 at 35 traps per acre. These results indicated a consistent increase in the number of trapped rice planthoppers with higher trap densities. The data also suggested year-to-year variations, likely due to improvements in trapping methods or environmental factors influencing rice planthopper populations (Fig 4).

In 2019, the number of trapped rice planthoppers was 157.1. This number increased significantly in 2020 to 215.2. The upward trend continued in 2021, where the number of trapped rice planthoppers peaked at 264.9. However, in 2022, there was a notable decrease, with 185.4 rice planthoppers trapped. The number rose again in 2023 to 240.3 (Fig 5).

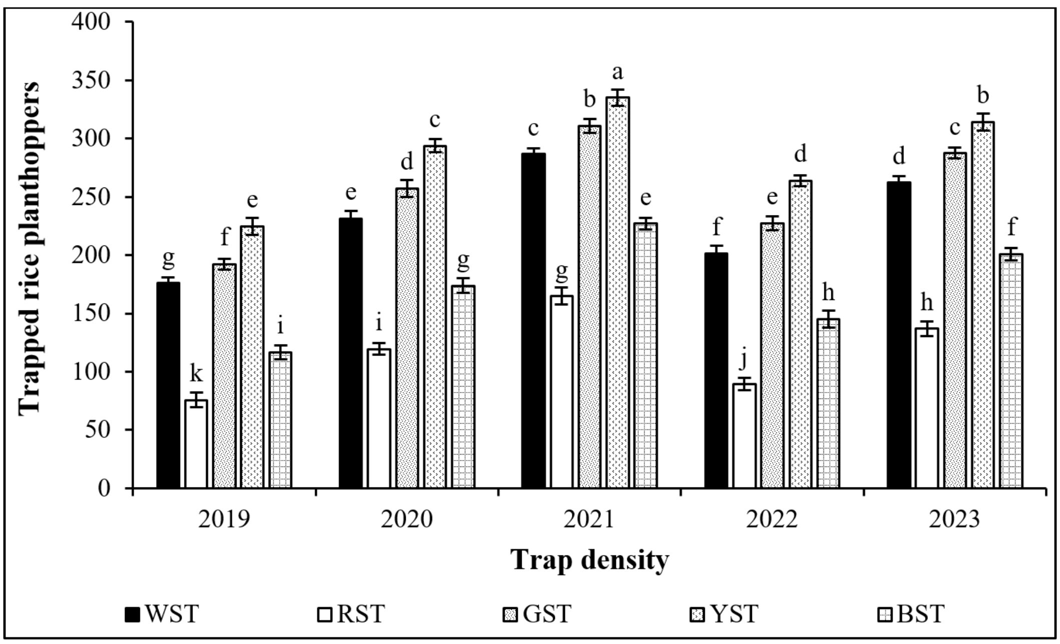

Figure 3. Effectiveness of different trap colors in the context of rice planthopper management over different study years

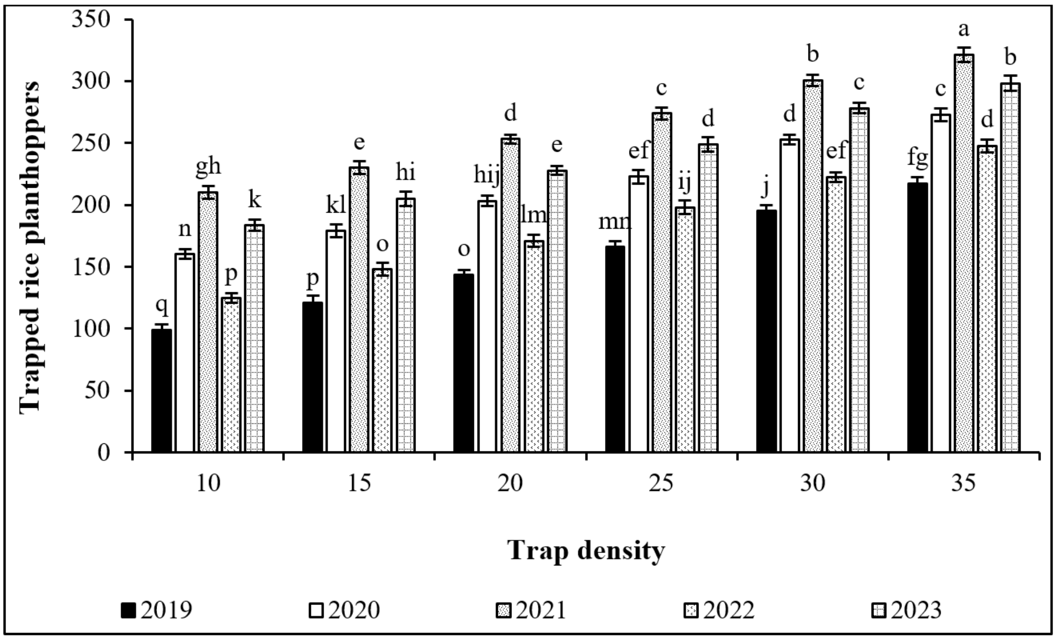

Figure 4. Effectiveness of different trap densities in the context of rice planthopper management over different study years

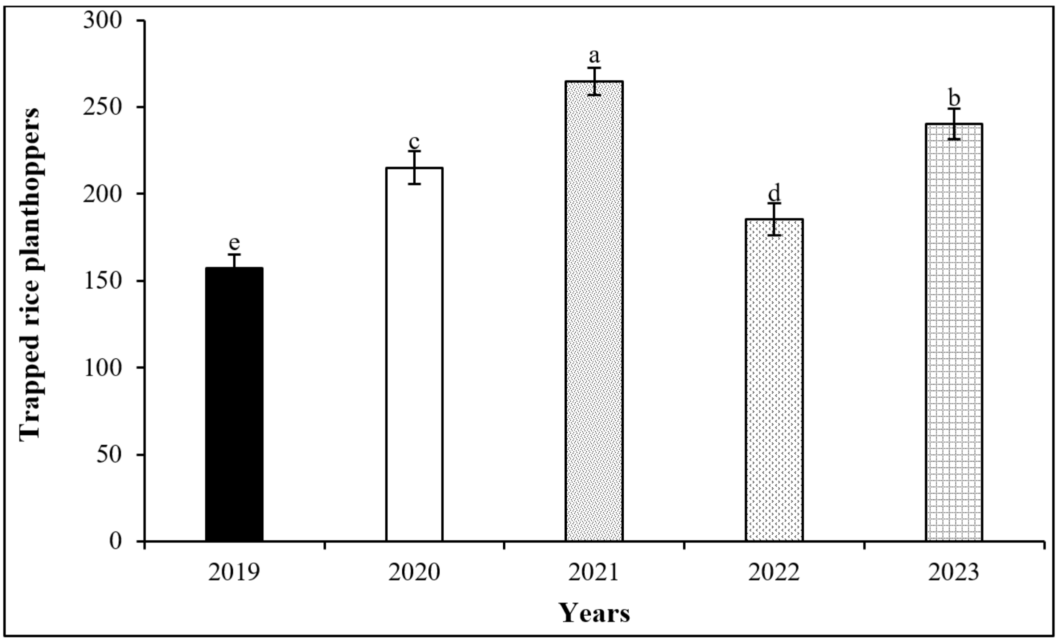

Figure 5. Rice planthopper trapped over different study years

At the lowest trap density of 10, the GST trap captured 194.28 rice planthoppers, and the YST trap captured 226.24, outperforming the BST (114.04), WST (175.28), and RST (68.12) traps. As density increased to 15, GST captured 213.4 and YST 250.48 planthoppers, still higher than BST (134.32), WST (198.32), and RST (86.24). At density 20, GST and YST continued to lead with captures of 245.32 and 279.16, respectively, compared to BST (159.4), WST (209.2), and RST (106). At density 25, GST and YST captured 269.4 and 299.16 planthoppers, while BST (175.44), WST (241.6), and RST (124.24) trailed. At density 30, GST and YST were most effective with captures of 292.44 and 320.24, surpassing BST (215.6), WST (270.72), and RST (150.52). Finally, at density 35, GST and YST captured 315.24 and 342.04 planthoppers, respectively, leading the BST (237.72), WST (293.88), and RST (169.08). The data consistently show GST and YST traps as the most effective at all densities (Fig 6).

The WST trapped 231.5 planthoppers. The RST trapped the fewest planthoppers, with a count of 117.4. The GST trapped 255 planthoppers. The YST trapped the highest number of planthoppers, with a count of 286.2. The BST trapped 172.8 planthoppers. (Fig 7).

At the lowest trap density of 10, the number of trapped rice planthoppers was 155.6. When the trap density increased to 15, the number of trapped rice planthoppers rose to 176.6. At a trap density of 20, the number of trapped rice planthoppers further increased to 199.8. As the trap density reached 25, the trapped rice planthoppers count rose to 222.0. With a further increase in trap density to 30, the number of trapped rice planthoppers continued to grow, reaching 249.9. At the highest trap density of 35, the number of trapped rice planthoppers peaked at 271.6 (Fig 8).

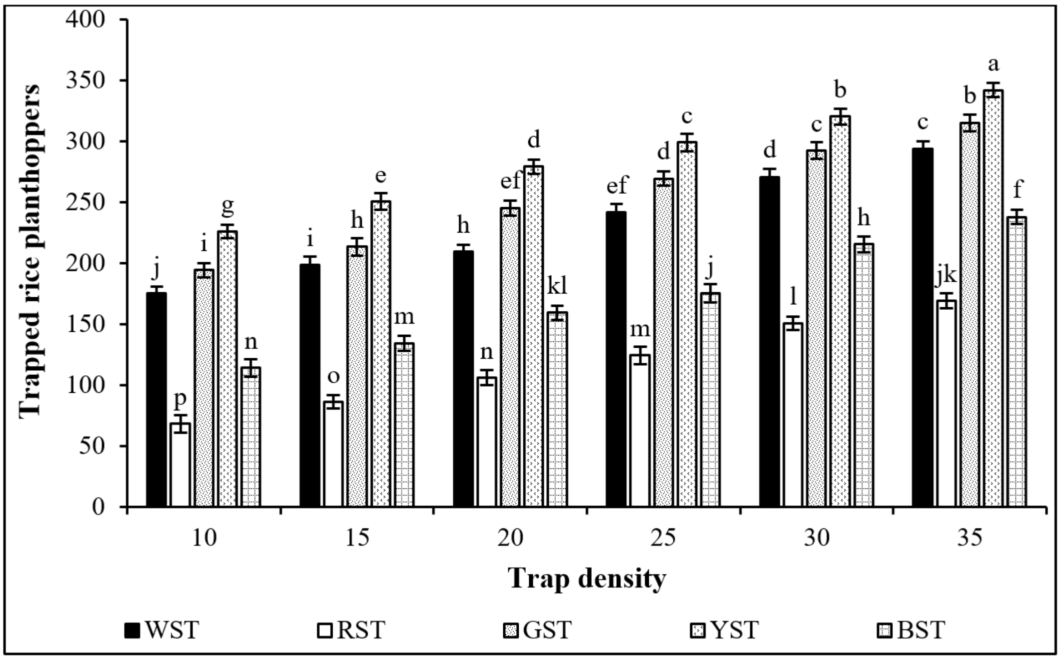

Figure 6. Effectiveness of different trap colors and densities in the context of rice planthopper management over the whole study period

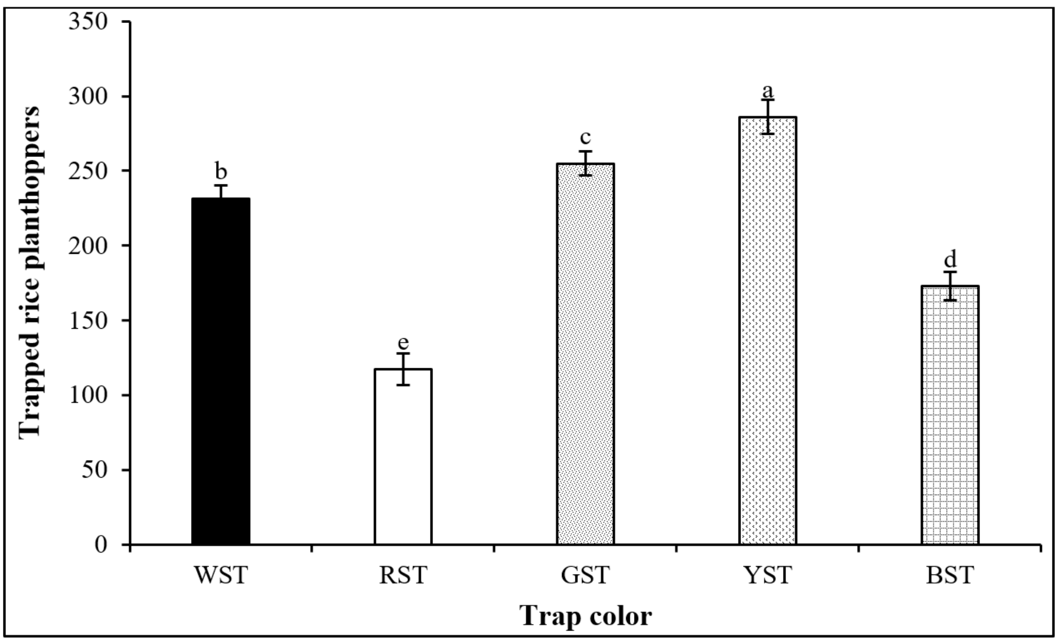

Figure 7. Effectiveness of different trap colors in the context of rice planthopper management over the whole study period

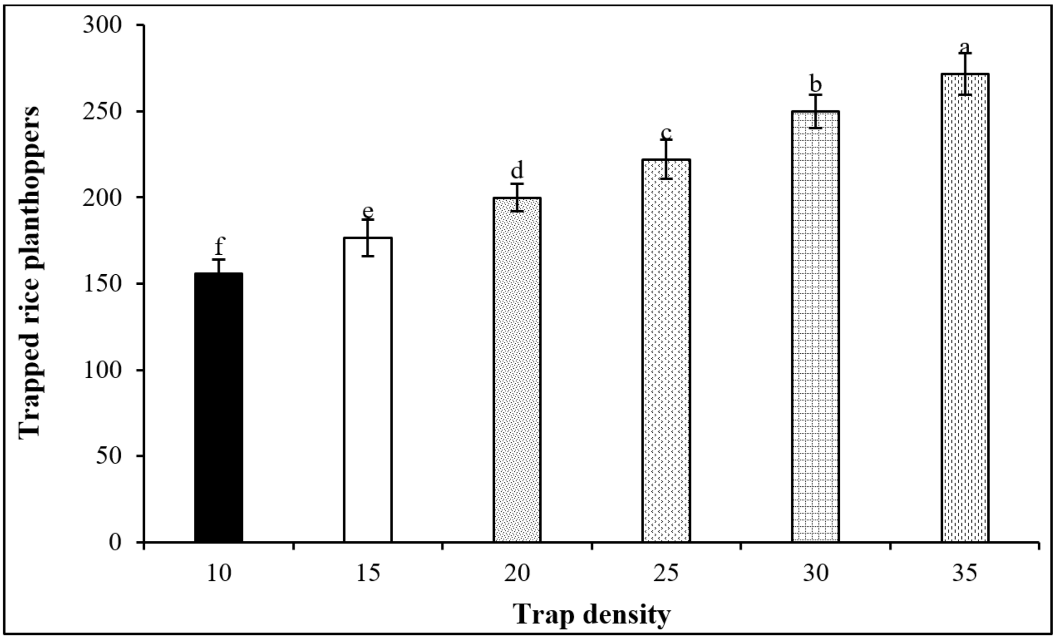

Figure 8. Effectiveness of different trap densities in the context of rice planthopper management over the whole study period

4. Discussion

The study examined the effectiveness of different trap colors and densities in capturing rice planthoppers over five years, with significant findings regarding the impact of these variables on trap efficacy. The key results consistently demonstrated that YST was the most effective in capturing rice planthoppers across all densities and years. Specifically, at increased trap densities, YST captured the highest number of rice planthoppers, with capture rates rising proportionally with trap density. Conversely, RST consistently showed the lowest capture rates, despite some improvement with increased density. These findings align with the hypothesis that both trap color and density are crucial in optimizing pest management.

The results indicate that trap density plays a crucial role in increasing capture rates, with higher densities leading to more effective pest management. The linear relationship observed between trap density and capture rates supports the hypothesis that a greater number of traps results in higher capture rates of rice planthoppers. This is consistent with previous research that has highlighted the importance of trap density in pest control [10,21,22]. Additionally, the superior performance of YST can be attributed to its color's attractiveness to rice planthoppers. Yellow is known to attract a wide range of insects, which may be due to its resemblance to certain natural attractants [10,23,24,25].

The persistent low capture rates of RST suggest that this color is less appealing to rice planthoppers. This finding is consistent with earlier studies indicating variability in trap effectiveness based on color [26,27]. The justification for the high effectiveness of YST lies in its high visibility and attractiveness to the target pests. This highlights the importance of selecting the right trap color for effective pest management and aligns with the broader understanding of insect behavior and attraction [28].

The implications of these findings are significant for pest management practices in rice cultivation. The demonstrated efficacy of YST suggests that incorporating yellow traps into pest management strategies could enhance the control of rice planthoppers and potentially reduce reliance on chemical insecticides. This supports sustainable agricultural practices by promoting environmentally friendly pest management solutions [29,30]. Additionally, the results emphasize the importance of trap density in optimizing pest control, which can aid in designing more effective monitoring and control systems for rice planthoppers.

The results of the current study align with and expand upon previous research on the use of sticky traps in insect pest management, particularly in rice and other agricultural systems. The superior efficacy of YST for capturing rice planthoppers, as demonstrated in this study, corroborates findings from various agroecosystems, where the spectral sensitivity of pests often favors yellow over other colors due to its attractant properties.

The preference of rice planthoppers for YST is consistent with research demonstrating the heightened effectiveness of YST for capturing aphids and whiteflies in tomato crops, aligning with the optical preferences of insects in the Hemiptera order, including planthoppers, suggesting that yellow wavelengths act as visual stimuli due to the insects' attraction to high-contrast, brightly colored surfaces [31]. This is further supported by studies that observed efficacy of YST in controlling *Bemisia tabaci*, where trap covers reduced non-target species captures but still concluded that yellow traps offer the highest attraction efficiency across various taxa of hemipteran pests [32].

YST have also been found effective in controlling thrips populations, particularly *Scirtothrips dorsalis*, in mango agroecosystems [33]. Although white traps were more effective for some thrips species, yellow traps remained the most efficient for managing thrips that share behavioral traits with rice planthoppers. This cross-ecosystem applicability of yellow traps emphasizes their utility as a universal tool for capturing herbivorous pests, particularly in monocot systems such as rice, where planthoppers present a critical threat to yield and quality.

Our findings regarding the positive correlation between trap density and capture rates align with research conducted on various trap colors and densities in cucurbitaceous crops, where increasing the number of traps per unit area significantly enhanced capture efficiency [34]. This mirrors our study's results, where increasing the density of YST from 25 to 30 traps per acre led to a significant increase in planthopper captures. These findings underscore the need to optimize trap density relative to pest pressure for maximal control, a crucial aspect of IPM programs.

Similar conclusions were drawn from studies using YST for monitoring *N. lugens*, where traps demonstrated superior capture rates compared to visual counting methods, further validating the reliability of YST for pest monitoring, especially in high-density populations [35]. The linear relationship between trap density and planthopper captures observed in our study further supports the notion that strategic trap deployment can significantly enhance pest management outcomes in rice systems.

Research has shown that combining YST with minimal insecticide application can reduce pest populations while minimizing chemical use, a finding that supports the role of trap-based monitoring in sustainable pest management systems [36]. This synergistic approach highlights the value of traps not only for monitoring but also as a primary control method, especially when integrated with targeted chemical interventions. Our study’s findings align with this perspective, showing that increased trap density enhances pest capture while potentially reducing reliance on insecticides, contributing to more environmentally friendly pest control methods in rice ecosystems.

The study's strengths include its longitudinal design, providing robust data over multiple years, and the comprehensive evaluation of various trap colors and densities. Adoption of statistical analyses such as ANOVA and regression enhances the validity of the results and offers a detailed understanding of the relationships between trap variables and capture rates. However, the study's focus on a single site in Punjab, Pakistan, may limit the generalizability of the findings to other regions or climatic conditions. Additionally, potential variations in rice planthopper populations due to environmental factors or agricultural practices beyond trap color and density were not accounted for.

Future research should consider examining the effectiveness of trap colors and densities in diverse geographic locations and under varying environmental conditions to assess the generalizability of these findings. Investigating the interaction between trap color and other attractants, such as pheromones or plant-based lures, could provide further insights into optimizing trap designs. Studying the long-term impact of increased trap densities on rice planthopper populations and crop yields could also offer valuable information on these pest management strategies' practical applications and sustainability. Expanding research to include other pest species and crops could enhance the applicability of these findings to broader agricultural contexts.

5. Conclusions

This study demonstrated that YST was the most effective for capturing rice planthoppers among the five colors tested, with GST also showing high effectiveness. Increasing trap density consistently enhanced capture rates across all trap colors, with a strong positive correlation observed between density and planthopper captures. Over the five years, YST maintained superior performance, making it the optimal choice for monitoring and controlling rice planthoppers. The findings highlighted the importance of trap color and density in developing effective pest management strategies, with YST providing a reliable solution for managing rice planthopper populations in rice fields. Future research could refine trap designs and explore additional color combinations to enhance pest control measures.

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