Research Article

Assessment of Colored Light and Pheromone Traps Efficacy on Controlling *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in Tomato Crop

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Abstract | *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a polyphagous pest of many economic crops including tomato crop, causing significant losses to the quantity and quality of tomatoes. Pheromone and light traps provide key information regarding the population status of *H. armigera* that can be used for its integrated management. Hence, a study was initiated at Department of Entomology, Sindh Agriculture University, Tando Jam to evaluate the impact of different colored light traps (yellow, blue, green, red, and white) and pheromone traps installed in a tomato field, district Shaheed Benazir Abad. All traps were installed at a density of four traps per acre. Weekly data was collected to document the capture of *H. armigera* moths in traps and their larval infestation on fruits, with ten plants randomly selected per replication. Stepwise regression and correlation analysis also were used to determine the association of weekly mean *H. armigera* adults captured in various traps with temperature, relative humidity, and wind velocity. Results indicated that since the transplantation of tomatoes into the field, significantly higher numbers of female and male moths were captured in pheromone and yellow-colored light traps, respectively. Conversely, red-colored light traps were found to be the least effective in capturing moths. Overall, the highest (43.38±2.16 adults per trap) and lowest (5.31±0.35 adults per trap) moth captures were recorded in pheromone and red colored light traps, respectively. The highest per week adults attracted in yellow, white, blue, and green colored lights traps were 26.70±1.64, 17.15±1.13, 16.46±0.99, and 13.89±0.98 adults per trap, respectively. Plots utilizing red-colored light traps exhibited a notably higher mean weekly infestation of *H. armigera*, whereas plots employing yellow-colored light traps and pheromone traps demonstrated the lowest infestation levels. A significantly higher, positive, and strong correlation of mean number of *H. armigera* captured was recorded in different traps with its weekly mean larval infestation on tomatoes. Correlation and regression result also confirmed a significant, negative and weak effect of temperature (minimum and maximum) on weekly mean number of adults captured in different types of traps evaluated in the study, whereas relative humidity exhibited a positive and significant but weak relationship with the adults captured. Therefore, our study suggests that pheromone along with yellow-colored light traps should be included in integrated management of *H. armigera*, not only to monitor its population but also help in its mass trapping to reduce losses in tomato crop.

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Introduction

Tomato, *Solanum lycopersicum* Linnaeus is one of the most important vegetables that is considered a key ingredient for humans due to its specific nutritive and economic value (Raiola *et al*., 2014; Khokhar and Rolania, 2022). During 2022, tomatoes were cultivated on 4.918 million hectares with production of 186.108 million tons globally, as both the area under cultivation and production of tomato declined as compared to 2021. A similar pattern was observed in Pakistan, where both the area cultivated with tomatoes and its production exhibited a declining trend in 2022, with figures standing at 66,697 hectares and 792,938 tons, respectively (FAOSTAT, 2024). Various factors contribute to the decreased production of tomatoes worldwide, particularly in Pakistan with insect pests and diseases as key factors to reduce their quantity and quality (Ochilo *et al*., 2018). Among insect pests, *Helicoverpa armigera* (Hübner), commonly known as tomato fruit borer is considered as a serious, globally distributed, and polyphagous pest of tomatoes that cause significant losses to quantity and quality of tomatoes (Krinski and Godoy, 2015; Pratissoli *et al*., 2015; Queriroz-Santos *et al*., 2018). Besides tomato, it causes huge losses to cotton, tobacco, maize, chickpea, pigeon pea, and other important crops (Mironidis *et al*., 2013; Cunningham and Zalucki, 2014). If adequate and timely management practices are not followed, the yield losses in tomatoes can reach up to 88% (Wakil *et al*., 2010; Singh *et al*., 2017) as a single larvae of *H. armigera* is capable to damage up to 12 tomato fruits during its development (Hussain and Bilal, 2007).

Generally, synthetic insecticides are widely used for the management of *H. armigera* in tomatoes and other crops mainly because of their rapid action and easy availability (Rizvi and Jaffar, 2015; Carneiro *et al*., 2016; Bueno *et al*., 2017). However, it has developed resistance against many groups of insecticides used for its management (Bilal *et al*., 2018; Riaz *et al*., 2021). Therefore, an alternate integrated management strategy should be employed to manage noxious insect pests including *H. armigera* with greater chances of success (Riaz *et al*., 2021). However, timely decision making is key to success of any integrated strategy where the use of synthetic pheromone and light trap provides basic and authentic information regarding the population status of *H. armigera* in the field conditions (Shah *et al*., 2015; Ullah *et al*., 2015; Madhu *et al*., 2019). Accordingly, since the identification of sex pheromone of *H. armigera* (a mixture of (Z)-11-hexadecenal and (Z)-9-hexadecenal) (Zhang *et al*., 2012), numerous studies have found it comparatively more effective method to determine the population patterns in the field (Baker *et al*., 2011; Fite *et al*., 2020; Sehto *et al*., 2020). Besides pheromone traps, light traps are also considered among the cost-effective methods for monitoring of insects as individual insects have specific affection for specific light colors (Baker *et al*., 2011; Ullah *et al*., 2015). Therefore, the use of light and pheromone, alone or in combination, against damaging crop pests in a particular field not only provide authentic information regarding for its monitoring but can also reduce its population substantially when integrated with other control measures (Tarusikirwa *et al*., 2020; Desneux *et al*., 2022; Mangrio *et al*., 2023).

Therefore, given the escalating threat posed by *H. armigera* to tomatoes and the significance of light and pheromone traps in its early detection and monitoring, this study was conducted to evaluate the efficiency of synthetic pheromone and various colored light traps in controlling *H. armigera* infestation in a tomato field.

Materials and Methods

Tomato cultivation

Local Desi tomato variety was transplanted at a rate of 50 grams per acre with recommended 2- and 4-feet plant to plant and row to row distance, respectively. Standard agronomic practices were applied to all the treatments.

Pheromone traps

The delta type white colored pheromone traps (27cm length x 17cm width x 10.50cm height) having a removable sticky sheet at base were used in the study. The synthetic pheromone of *H. armigera* i.e., (Z)-11-hexadecenal and (Z)-9-hexadecenal (Shani Enterprises, Multan) was placed in the traps, which was replaced with a new synthetic pheromone after every four weeks to retain their effectiveness to attract *H. armigera* moths.

Light traps

Five colored (blue, green, red, white, and yellow) LED 12-watt power bulbs (Philips, Pakistan), powered with 12-volt DC (Direct Current) batteries were used in the study. These bulbs were recharged with solar plates, as individual light traps were placed inside a bucket that was coated with non-drying glue to ensnare moths attracted to the lights.

Experimental design, data collection, and analysis

All the traps were installed at a density of four traps/ acre in a tomato field in a randomized complete block design as four replications were used for each trap. The data collection on the number of moths attracted in the individual traps was started since the transplantation of tomatoes till harvesting on weekly basis. The number of males and females captured per traps were identified based on their distinguishing morphological characteristics. Ten randomly selected tomato plants per replication were also observed to count the number of healthy and damaged fruits. The percentage infestation of *H. armigera* was calculated using the formula:

$$\textit{Infestation \%} = (\textit{infested fruits}/\ \textit{total fruits}) \times 100$$

Analysis of Variance was used to analyze the collected data, whereas means with significant differences were separated using the Least Significant Difference (LSD) test. The weather data was collected from the Meteorological Department, Pakistan regarding temperature, relative humidity, wind velocity, and rainfall to examine their effect on the number of adults captured in different traps using stepwise regression and Pearson's correlation. Correlation was also used to establish a relationship between infestation of *H. armigera* larvae on tomato fruits with mean moths captured in various traps. Computer software STATISTIX 8.1 version was used for the data analysis.

Results

Mean attraction of H. armigera moths in pheromone and colored light traps

Figure 1 illustrates results regarding the mean number of *H. armigera* male moths attracted and captured in various colored and pheromone traps in a tomato field. The results confirmed a highly substantial ($F=11.98$, $P < 0.001$) difference among various traps to attract males over entire duration of study. It was noticed adult *H. armigera* males attracted to pheromone traps (3.75±0.85 adults per trap) during the first week after the transplanting of tomatoes in field, followed by yellow (1.25±0.25 adults per trap) and white (0.50±0.29 adults per trap) light trap during the 2nd week of the transplanting. Afterwards, an increasing trend was observed in the mean *H. armigera* male moths captured in various traps, especially pheromone traps. The red and blue colored light traps were found to be substantially the least attractive for the adult *H. armigera* males with maximum per week attraction of only 3.75±0.63 and 6.50±1.55 adults per trap, respectively. However, due to the specific nature of pheromone traps, they attracted maximum per week male adults (75.25±7.16 adults per trap) during 16th week after transplanting, followed by yellow (15.50±3.33 adults per trap), white (10.25±2.02 adults per trap), and green (7.75±1.55 adults per trap) colored light traps, mostly observed during the 14th and 12th week after tomato transplantation, respectively. Afterwards, the mean capture of adult males of *H. armigera* showed a declining trend in various types of traps.

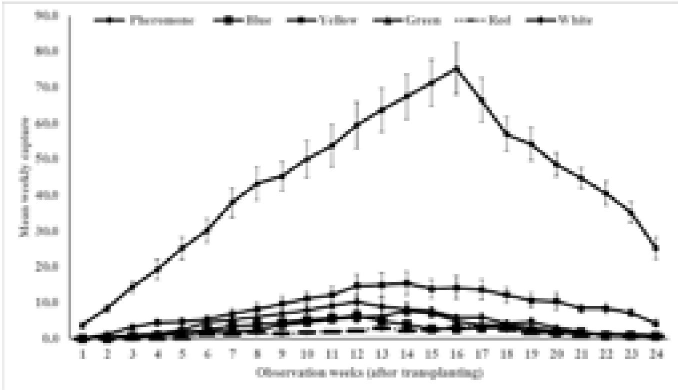

Figure 1: *Average weekly mean capture of Helicoverpa armigera males in pheromone and colored light traps in a tomato field (LSD = 5.9587, P < 0.05).*

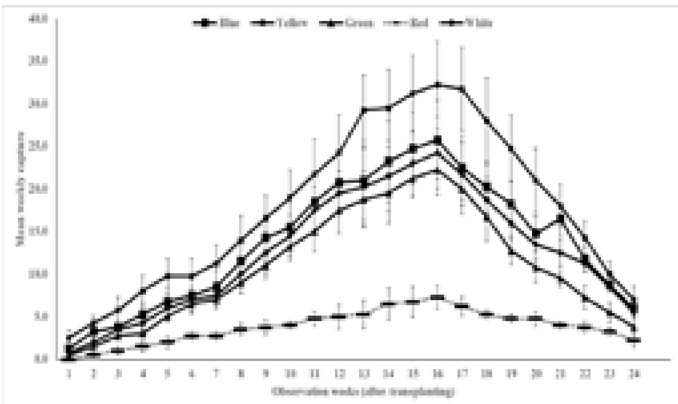

Figure 2: *Average weekly mean capture of Helicoverpa armigera females in various colored light traps in a tomato field (LSD = 6.0883, P < 0.05).*

Figure 2 illustrates the results regarding the weekly mean capture of adult females of *H. armigera* in different colored light traps. According to results, all the colored light traps were found attractive for the *H. armigera* females, however demonstrated a highly substantial (F = 2.90, P < 0.001) difference among them to attract the females. The mean number of females attracted in blue, yellow, green, and white during first week after tomato transplantation was recorded as 1.25±0.48, 2.50±0.87, 0.50±0.29, 0.75±0.25 adults per trap, respectively, whereas no adult female was captured in red colored traps. Afterwards, the number of adult females attracted in various colored light traps showed an increasing trend due to availability of more tomato fruits in the field. Thus, weekly maximum mean capture of *H. armigera* females (32.25±5.11 adults per trap) was recorded in yellow colored light traps during 16th week after tomato transplanting, followed by blue (25.75±4.61 adults per trap) and white (24.25±4.21 adults per trap) colored light traps, both observed during same 16th week of the transplantation. Moreover, the maximum mean capture in green and red colored light traps was recorded as 22.25±2.95 and 7.25±1.38 adults per trap, respectively. A declining trend in the mean capture of *H. armigera* females was recorded in different colored sticky traps towards the maturity of the tomato crop.

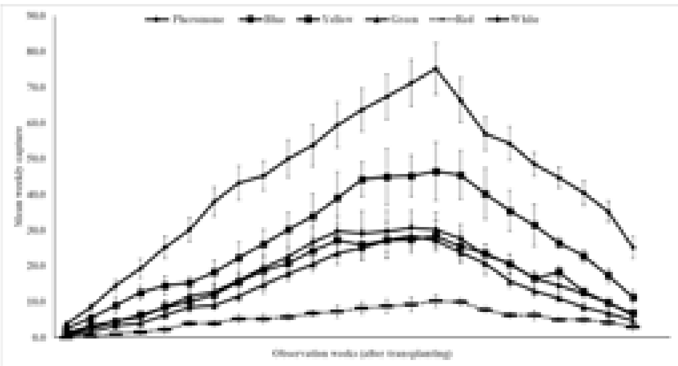

Figure 3: *Average weekly mean capture of Helicoverpa armigera (total) in pheromone and colored light traps in a tomato field (LSD = 9.1356, P < 0.05).*

The cumulative results regarding the mean weekly capture of total *H. armigera* adults (males and females) are given in Figure 3 that confirmed a highly substantial (F = 3.30, P < 0.001) variation in various traps to attract adults. Weekly, the maximum number of *H. armigera* adults were captured in pheromone traps (75.25±7.16 adults per trap), followed by yellow (46.50±8.05 adults per trap) and white (30.75±4.87 adults per trap) colored light traps. Moreover, the maximum weekly mean adults captured in green, blue, and red colored light traps were 28.50±3.80, 28.50±4.27, and 10.25±1.60 adults per trap, respectively, all mostly observed during 15th and 16th week after tomato transplantation. Thereafter, a decrease in the mean capture of *H. armigera* moths was recorded in all type of traps towards the maturity of tomato crop.

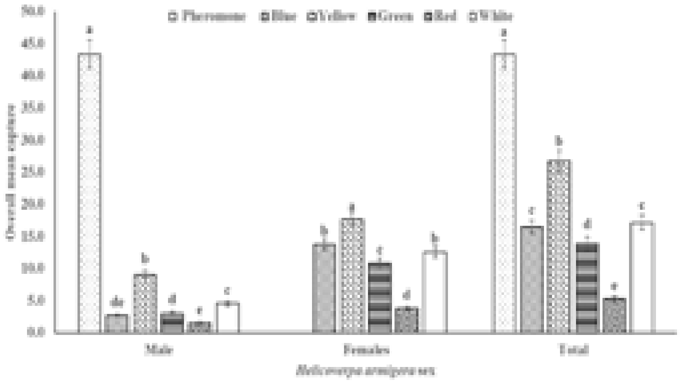

Figure 4: *Overall mean capture of Helicoverpa armigera (total) in pheromone and colored light traps in a tomato field. **Means with different letters are significantly different from each other against individual categories (LSD values Males = 1.2163, Females = 1.2428, Total = 1.8648, P < 0.05).*

Figure 4 illustrates the overall mean number of *H. armigera* males, females, and total (cumulative of males and females) captured in various traps used in the study. According to the results, overall, pheromone traps captured maximum number of males (43.38±2.16 adults per trap), whereas yellow colored light traps attracted maximum number of females (17.66±1.13 adults per trap). Moreover, yellow colored light traps also attracted substantial number of males (9.04±0.58 adults per trap), followed by white (4.57±0.38 adults per trap), green (3.05±0.27 adults per trap), and blue (2.70±0.23 adults per trap) colored light traps. Among all traps, red colored light traps attracted lowest number of males (1.50±0.14 adults per trap), females (3.81±0.26 adults per trap), and total (5.31±0.35 adults per trap) *H. armigera* adults. Cumulatively pheromone traps (43.38±2.16 adults per trap) were found to be most attractive with maximum capture of *H. armigera* adults, followed yellow (26.70±1.64 adults per trap), white (17.15±1.13 adults per trap), blue (16.46±0.99 adults per trap), and green (13.89±0.98 adults per trap) colored light traps. Thus, statistically, a highly substantial variation was observed among various traps to attract *H. armigera* females (F =218.16, P < 0.0001), males (F =1373.59, P < 0.0001), and total (F =383.78, P < 0.0001) adults

Weekly mean infestation of H. armigera on tomatoes

Figure 5 describes results regarding the weekly mean *H. armigera* infestation on fruits in various trap treatments used in the study and the same confirmed a highly substantial (F= 3.51, P < 0.001) variation among various treatments. Although, *H. armigera* catches in various traps was recorded during first week after the transplanting of tomato in field, but its first infestation on tomato fruits was recorded since their appearance in the crop during the fifth week of the transplantation. Accordingly, during the 5th week, the highest mean weekly infestation (3.50±0.78%) was observed in green light trap tomatoes, followed by 3.03±0.38, 2.10±0.31, 1.93±0.29, 1.30±0.16, and 1.18±0.16% infestation recorded in tomatoes grown with red, blue, white, pheromone, and yellow colored light traps, respectively. Afterwards, a rapid increase in the mean infestation of *H. armigera* was observed in red colored light traps treatment tomato fruits mainly because of the less capture of the adults, whereas level of infestation was comparatively low in yellow colored light trap and pheromone treatments. Thus, weekly the highest mean *H. armigera* infestation on fruits was recorded in red colored light tomato crop (37.18±3.43%) during 20th week after transplantation, followed by 30.10±3.03, 21.40±2.25, and 20.95±2.17% infestation observed in green, blue, and white colored light trap treatment tomatoes. Moreover, weekly the highest mean infestation of *H. armigera* in yellow colored light and pheromone traps was recorded as 15.48±1.66 and 17.35±2.35%, respectively observed during the 20th and 21st week after transplantation. Afterwards, a declining trend in the infestation of *H. armigera* on fruits in various treatments was observed towards the final harvesting of the tomato crop.

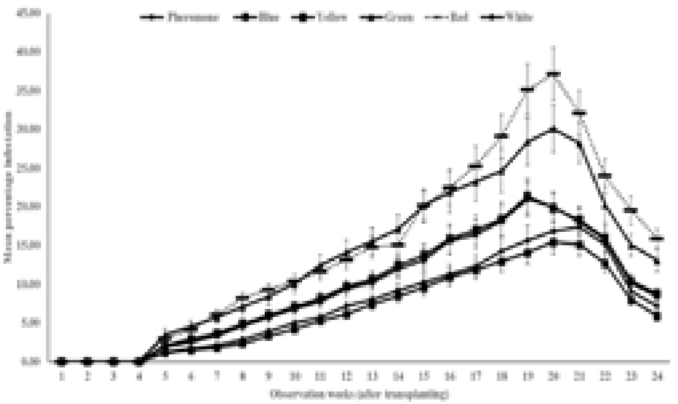

Figure 5: *Average weekly mean infestation of Helicoverpa armigera on tomato fruits (LSD = 3.7940, P < 0.05).*

Overall mean infestation of *H. armigera* in various treatment traps is given in Figure 6 that confirmed a highly substantial (F = 143.09, P < 0.001) variation among various treatments. The highest overall mean infestation of *H. armigera* on fruits was recorded in red colored light trap treatment (14.87±0.51%), followed by green light trap treatment (13.49±0.48%). Overall, significantly the lowest *H. armigera* infestation was noticed in yellow colored light (6.52±0.24%) and pheromone (7.35±0.29%) trap treatments. No significant difference in the mean infestation on tomato fruits was recorded between blue (9.48±0.33%) and white (9.21±0.33%) colored light trap treatments.

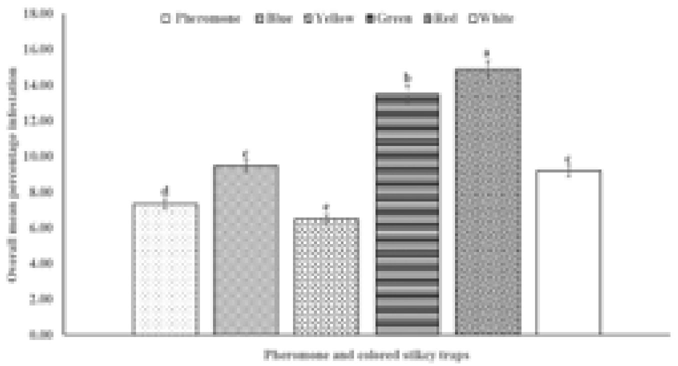

Figure 6: *Overall mean infestation of Helicoverpa armigera on tomato fruits. *Means with different letters are significantly different from each other (LSD = 0.7744, P < 0.05).*

Relationship of mean attraction of H. armigera in different traps with larval infestation and weather parameters

Table 1 demonstrates results for the correlation between mean *H. armigera* adults captured in various traps with its mean larval infestation on fruits. The results indicated that a highly substantial, positive, and strong relationship between the mean *H. armigera* infestation with adults captured in pheromone traps (r = 0.7690, P < 0.001) along with blue (r = 0.8157, P < 0.001), yellow (r = 0.8145, P < 0.001), green (r = 0.7748, P < 0.001), red (r = 0.8093, P < 0.001), and white (r = 0.7559, P < 0.001) colored light traps.

Table 1: *Pearson's correlation between mean capture of Helicoverpa armigera in pheromone and light traps with infestation of Helicoverpa armigera on tomato fruits.*

Type of trap	Mean infestation
Pheromone	r = 0.7690 P < 0.001
Blue	r = 0.8157 P < 0.001
Yellow	r = 0.8145 P < 0.001
Green	r = 0.7748 P < 0.001
Red	r = 0.8093 P < 0.001
White	r = 0.7559 P < 0.001

Table 2: *Pearson's correlation between mean capture of Helicoverpa armigera in pheromone and light traps with weather parameters.*

Weather parameter	*Helicoverpa armigera* sex		
	Male	Female	Total moths (Male + Female)
Minimum temperature	r = -0.2053 P < 0.001	r = -0.3476 P < 0.001	r = -0.3888 P < 0.001
Maximum Temperature	r = -0.2044 P < 0.001	r = -0.3413 P < 0.001	r = -0.3844 P < 0.001
Relative Humidity	r = 0.1309 P = 0.0016	r = 0.2329 P < 0.001	r = 0.2540 P < 0.001
Wind velocity	r = -0.0661 P = 0.1133	r = -0.1337 P = 0.0013	r = -0.1368 P = 0.0010

Moreover, the results regarding relationship of mean *H. armigera* adults captured in various trap treatments used in the study with various weather parameters are given in Table 2 confirmed that both minimum (r = - 0.2053, P < 0.001) and maximum (r = - 0.2044, P < 0.001) temperature showed a weak, significant but negative effect on weekly mean males captured in various traps, whereas effect of relative humidity was weak, significant, and positive (r = 0.1309, P = 0.0016). No considerable role of wind velocity (r = - 0.0661, P = 0.1133) was observed on the performance of various colored light traps to attract *H. armigera* males. Similarly, female mean capture of *H. armigera* was significantly affected by minimum temperature (r = - 0.3476, P < 0.001), maximum temperature (r = - 0.3413, P < 0.001), relative humidity (r = 0.2329, P < 0.001), and wind velocity (r = - 0.1337, P = 0.0013). Like males and females, minimum (r = - 0.3888, P < 0.001) and maximum (r = - 0.3844, P < 0.001) temperature elicited a negative, moderate, and highly significant effect on the overall mean *H. armigera* adults captured in different traps, whereas role of relative humidity (r = 0.2540, P < 0.001) was weak, positive but highly significant. The wind velocity (r = - 0.1368, P = 0.0010) illustrated a weak, negative, and significant effect on the mean capture of total *H. armigera* adults in various traps used in the study.

Stepwise regression model based on various weather conditions regulating the weekly mean *H. armigera* adults captured in different traps is given in Table 3. The results indicate that temperatures (minimum and maximum) along with relative humidity exhibited a significant role in weekly mean capture of *H. armigera* males and females, whereas no significant contribution of wind velocity was established in the regression model. Accordingly, the stepwise regression model calculated for *H. armigera* males was Y = 27.6813 (constant) – 0.5627 (maximum temperature), whereas R^2, adjusted R^2, and mean standard error (MSE) values were calculated as 0.0418, 0.0401, and 291.711, respectively. Moreover, the regression models for *H, armigera* females and total (cumulative males and females) were Y = 9.2667 (constant) + 0.4566 (maximum temperature) – 1.3747 (minimum temperature + 0.1973 (relative humidity) [R^2 = 0.1525, adjusted R^2 =0.1525, MSE = 76.693] and Y = 22.3075 (constant) + 0.7919 (maximum temperature) – 2.6543 (minimum temperature + 0.3767 (relative humidity) [R^2 = 0.1909, adjusted R^2 =0.1866, MSE = 255.173].

Table 3: *Stepwise regression models for the mean capture of Helicoverpa armigera in various traps with weather parameters.*

Helicoverpa armigera stage	Variable	Coefficient	Standard error	t value	P value	R^2	Adjusted R^2	MSE
Female	Constant	9.2667	3.5838	2.59	0.0100	0.1569	0.1525	76.693
	Maximum temperature	0.4566	0.1984	2.30	0.0217			
	Minimum temperature	-1.3747	0.2842	-4.84	0.001			
	Relative humidity	0.1973	0.0423	4.67	0.001			
Male	Constant	27.6813	3.4677	7.98	0.001	0.0418	0.0401	291.711
	Maximum temperature	-0.5627	0.1125	-5.00	0.001			
Total	Constant	22.3075	6.5370	3.41	0.0007	0.1909	0.1866	255.173
	Maximum temperature	0.7919	0.3619	2.19	0.0291			
	Minimum temperature	-2.6543	0.5185	-5.12	0.001			
	Relative humidity	0.3767	0.0771	4.88	0.001			

Discussion

The pheromone and different colored light traps (blue, yellow, green, red, and white) evaluated were found efficient to attract adult *H. armigera,* however, they differ significantly in their attractiveness towards the moths. The highest number of *H. armigera* males (75.25±7.16 adults per trap per week) were attracted and captured in pheromone traps mainly because of their specific nature, whereas yellow, blue, and white colored light traps were found to be comparatively more attractive for the females than red colored light traps. Overall, minimum number of *H. armigera* females and males were attracted in red colored light traps. The effectiveness of light and pheromone traps has been highlighted not only help in the monitoring of various insect pests, but they can also be used for their mass trapping (Riaz *et al*., 2021). Pheromone traps of *H. armigera* aim to attract maximum number of males, resulting in lower chances of females being fertilized which in turn can lay unfertilized eggs, resulting in lower infestation of the pest (Shah *et al*., 2015). Moreover, the use of such attracting traps not only be cost effective but also less hazardous to non-target insects and the environment (Mazumder and Khalequzzaman, 2010; Madhu *et al*., 2019; Mazumder *et al*., 2019) and may result in sustainable pest control (Madhu *et al*., 2019). Accordingly, many studies were conducted to confirm the effectiveness of pheromone traps against *H. armigera* in different crops of economic importance (Abbas *et al*., 2020; Fite *et al*., 2020; Karakantza *et al*., 2023).

Ujjan *et al*. (2019) confirmed a significant role of height of pheromone traps in a chickpea field to attract *H. armigera* as maximum adults were captured in traps placed at 6 feet height than 2- and 4-feet height, whereas maximum attractiveness of adults towards pheromone traps was observed at the sunset time. A considerable number of *H. armigera* were captured in pheromone traps installed at different densities i.e., 30, 40, and 50 traps per hectare over two years period in a tomato field, where comparatively higher catches were recorded during the first year than second year (Shah *et al*., 2017). A two-years study in two regions of Tunisia i.e., Zaghouan and Takelsa showed that pheromone traps were able to determine population fluctuation patterns as significantly more moths were captured at Takelsa than Zaghouan (Cherif and Grissa-Lebdi, 2017).

The difference in the mean number of *H. armigera* adults captured in pheromone traps obtained in numerous studies may be attributed to color and design of the traps used as Karakantza *et al*. (2023) reported that stripped traps used in a cotton field captured significantly more moths than green and colored traps. Studies also identified the significant role of funnel-trap color, trap height, and pheromone formulations in the mean capture of *H. armigera* in pheromone trap installed in a cotton field (Karakasis *et al*., 2021). The study found that trap color and formulation have significant impact on the mean capture of moths as white colored trap captured more moths than green and stripped colored traps as Barrettine's pheromone lure attracted more adults than Russel and Trécé lures.

Besides, pheromone traps, light traps are also used as one of the effective tools in monitoring of *H. armigera* in a tomato field as the number of moths captured increased gradually and reached at peak during the month of October (ten weeks after transplanting) (Reddy *et al*., 2021). The studies of Shah *et al.* (2011) also found considerable number of *H. armigera* captured in pheromone and light traps where light traps attracted comparatively more adults than pheromone traps. However, comparatively more moths captured in pheromone traps in this study than various colored light traps evaluated. Reddy *et al*. (2021) also reported comparatively a large number of adults attracted and captured in light traps than pheromone traps as such differences may be attributed to behavior of the available species and relative number of sex present in the study area. However, Ballari *et al*. (2021) reported comparatively greater number of *H. armigera* adults captured in pheromone traps than light traps as the mean number increased with growth of crop and decreased towards maturity. Such findings supported our results, not only regarding the mean *H. armigera* adults attracted in various colored light and pheromone traps, but also correlation of mean capture with the mean infestation of tomatoes that increased with the availability of more fruits with the growth of crop (Ballari *et al*., 2021). Keszthelyi *et al.* (2016) studies showed that in comparison to government managed Hungarian light traps, field installed light and pheromone traps found to be more effective in determining the appearance and seasonal patterns of *H. armigera* during the maize cropping season. The potential of light traps in determining the outbreaks of *H. armigera* documented in Brazil that can be used to reduce the losses in the agricultural crops (Specht *et al*., 2021).

Wang *et al*. (2022) studied various phototactic behaviors of *Spodoptera frugiperda* and *H. armigera* and found that both the insects showed more phototactic rate towards blue than green, white and red colored lights as their response increased with increasing light intensity. Moreover, trapping distance of *H. armigera* towards the blue light traps was higher than *S. frugiperda*. These findings are in accordance with our results as yellow, blue colored light traps were observed to be more attractive for *H. armigera* adults.

It has also been reported that *H. armigera* adults captured in pheromone traps also corresponds to the number of larvae present in a tobacco field, hence with its infestation to the crop (Krsteska and Tashkoski, 2021). In a chickpea field, the mean number of *H. armigera* moths captured in pheromone traps were found to be significantly and positively correlated with the mean number of larvae found in the field, thus add to the infestation of the crop (Sonkar *et al*., 2012). Accordingly, the results of these studies supported the findings of this study as the infestation in tomato crop showed a strong, positive, and significant correlation with the mean number of moths captured in all traps (pheromone and light) used in the study. However, Pathania *et al*. (2009) based on their two-years study reported that larval infestation in tomatoes showed a positive and significant correlation with the mean number of moths captured in pheromone traps during 2004, but non-significant during 2005.

A significant and negative correlation of temperature (minimum and maximum) rainfall, and sunshine hours was recorded with the mean *H. armigera* adults captured in pheromone and light traps during the second-year study of Ballari *et al*. (2021), whereas relative humidity exhibited a significant and positive correlation, whereas during first year, except maximum temperature, remaining factors showed a positive effect on the mean capture of moths. Another study of Sonkar *et al*. (2012) also confirmed our results regarding relationship of mean number of *H. armigera* adults attracted in pheromone and various colored light traps as positive correlation was noticed with relative humidity, whereas maximum and minimum temperature exhibited as negative role. A negative correlation of the mean catches in pheromone traps with minimum temperature was reported by Pathania *et al*. (2009), whereas a positive correlation was found with the wind velocity. However, Reddy *et al*. (2021) reported that the mean *H. armigera* captured in both the traps showed a negative and significant correlation with relative humidity and rainfall, whereas a non-significant correlation with the temperature. These finding partially supports results of our study as gradual increase in all the traps was recorded with the growth of tomatoes, whereas role of relative humidity was positive and significant, but temperature and wind velocity exhibited a negative relationship with the mean capture in various traps.

Considering the key role of pheromone and light traps against *H. armigera* population monitoring and management, it has widely been used as a key component in various integrated management strategies against it (Abbas *et al*., 2020; Khokhar and Rolania, 2022).

Conclusion

Pheromone and all the colored light traps evaluated attracted *H. armigera* moths as significantly more male moths were captured in pheromone traps, whereas yellow colored light traps captured more female moths. Red colored light traps captured substantially the lowest number of *H. armigera* moths. A significant, positive, and strong correlation was recorded between the mean number of *H. armigera* moths captured with their larval infestation on tomato fruits. Temperature and relative humidity exhibited a negative and positive effect, respectively on the mean moth catches in various traps. Therefore, it is recommended that combined use of pheromone and yellow colored sticky traps in integrated management of *H. armigera* can help reduce its population and infestation in tomatoes.

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Novelty Statement

Besides pheromone and colored light traps were found effective to attract substantial number of *H.*

armigera moths (both males and females). Thus, the combined use of pheromone and yellow colored light traps in tomato fields not only helps in monitoring of *H. armigera* population but can also help in reducing its population and infestation when used in any integrated management program.

Author's Contribution

Ghulam Sarwar Kamboh, Arfan Ahmed Gilal and Lubna Bashir Rajput: Designed the study.
Ghulam Sarwar Kamboh: Conducted the experiments and wrote the initial draft.
Jamal-U-Ddin Hajano: Analyzed data.
Arfan Ahmed Gilal: Finalized the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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