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# Seasonal Dynamics of *Spodoptera frugiperda* (J.E Smith) on Maize in the *Terai* Region of Uttarakhand

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***Abstract*:** The study on seasonal dynamics of *Spodoptera frugiperda* on maize was carried out at GBPUAT, Pantnagar during *kharif* 2023 and 2024. *Spodoptera frugiperda* population started appearing on maize at 28th and 31st SMW in 2023 and 2024, respectively, and persisted until crop maturity. The larval population reached the peak level of 3.08 larvae/plant in 33rd SMW during 2023 and 2.82 larvae/plant in 36th SMW during 2024 which declined thereafter. The plant damage ranged from 6.67-75.00% in 2023 and 5.00-80.00% in 2024. Pearson correlation revealed a significant and positive association of larval population with minimum temperature (r= 0.614 and r= 0.597) and evening relative humidity (r= 0.357 and r= 0.333) in year 2023 and 2024, respectively, while sunshine hours and rainfall showed negative effects. Principal component analysis confirmed minimum temperature and humidity as the key determinants of pest dynamics. These findings highlighted the significance of weather in *S. frugiperda* outbreaks and provide valuable insights for forecasting and long-term management strategies in maize cultivation.

***Keywords*:** Fall armyworm, Maize, Seasonal incidence, *Spodoptera frugiperda*

*Spodoptera frugiperda* (J.E Smith) (Lepidoptera: Noctuidae), commonly known as fall armyworm (FAW), has become a major invasive pest, inflicting severe damage on maize (*Zea mays* L.) worldwide. Originally from America, this highly polyphagous insect was first identified in Africa in year 2016 (Georgen et al., 2016) and has since expanded quickly throughout Asia, including diverse agro-climatic zones of India. It was first recorded in India during May 2018 in maize fields at the Agriculture College, Shivamogga, Karnataka (Sharanabasappa et al., 2018). Within just two years, it expanded across almost all maize-growing regions of the country (Suby et al., 2020, Naganna et al., 2020). In Pantnagar, it was detected for the first time in 2019, since then this pest is infesting maize in this region (Maurya et al., 2019).

FAW can infest maize at every stage of development, leading to significant yield reductions. Leaf feeding diminishes photosynthetic capacity, slows plant growth, disrupts reproduction, and ultimately reduces grain output (Chimweta et al., 2020). The early larvae scrape off chlorophyll, leaving a transparent silvery film that develops into elongated white streaks and pinholes. The later larval instars create characteristic "windowpanes" on leaves, leaving frass deposits around the funnel and upper leaves. In addition, the pest bores into stems, tassels, ears, and cobs, lowering grain quality and exposing cobs to secondary infections (Anjorin et al., 2022). This insect presents major challenges to maize production, causing financial harm not solely to farmers but also to broader agricultural sector and regional economy. Tracking pest populations throughout the growing season is essential to determine peak activity periods, allowing farmers to implement timely preventive or control measures. Examining the correlation between pest occurrence and meteorological factors such as temperature, rainfall, and humidity provides critical insights into the triggers of pest outbreaks. Understanding these relationships is key for predicting and managing infestations effectively. Therefore, studying the relation between these climatic variables and FAW incidence is vital for devising effective pest management practices. Hence, this research was done to analyze the impact of key meteorological parameters on FAW infestation and evaluate its damage potential in maize, thereby supporting timely forecasting and sustainable management of this invasive pest.

## MATERIAL AND METHODS

This research took place at the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Udham Singh Nagar, Uttarakhand, India (29° N latitude, 79° 3′ E longitude, 243.84 meter above mean sea level). The dynamics of *S. frugiperda* was studied on the maize (variety PCM-4) during *Kharif* season of 2023 and 2024. The crop was grown with spacing of 60 cm between rows and 25 cm between plants. Recommended agronomic practices were used to grow the crop. Throughout the experiment, no pesticide applications were made.

**Seasonal activity of FAW on maize plants:** Observations began two weeks after sowing and continued weekly until harvest. To monitor seasonal incidence of FAW, 60 maize plants (10 plants from each replicate within a plot size of 5 × 5 m²) were randomly selected each week. The larvae of FAW were identified by characteristic 'Y'-shaped mark on the larval head capsule, and four dark spots arranged in a square on the last abdominal segment (Prasanna et al., 2018, Capinera, 2020). As FAW larvae tend to conceal themselves within the midrib of maize leaves due to daytime temperature and light conditions, assessments were conducted in the early morning hours (6:00–9:00 a.m.). The number of larvae on 10 plants was recorded, and expressed as mean larval count per plant ± standard deviation (SD).

**Damage assessment:** Ten plants were chosen at random from each plot and observations on the number of plants damaged due to FAW were recorded. Plants showing visible signs of FAW damage were categorized as damaged, regardless of whether feeding larvae present or not. These observations were used for estimation of percent plant damage using the formula given by Murua et al. (2006).

**Plant damage (%)** = {Total number of damaged plants/Total number of plants observed} × 100

**Statistical analysis:** Weekly weather information was collected from the Department of Agrometeorology, Pantnagar (Fig. 1a & 1b). Regression and correlation analysis were done as per Snedecor and Cochran (1967).

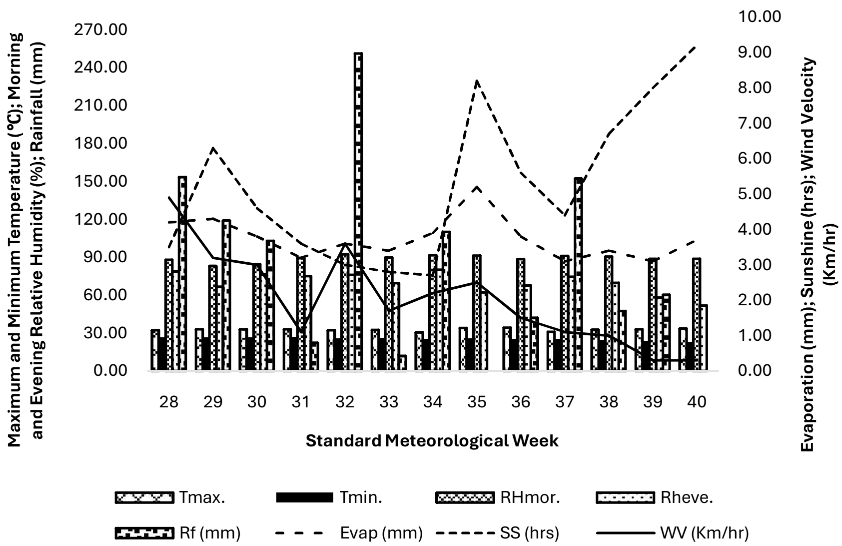


**Fig. 1a.** Weather data: Temperature (minimum and maximum) (°C), Morning and Evening Relative humidity (%), Rainfall (mm), Sunshine (hours), Wind velocity (km/hr) and Evaporation (mm) during the study duration of 2023

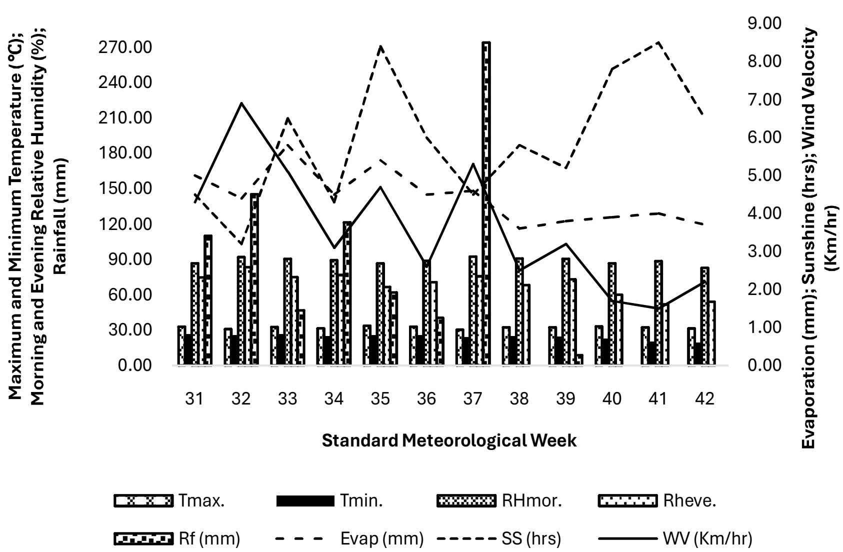


**Fig. 1b.** Weather data: Temperature (minimum and maximum) (°C), Morning and Evening Relative humidity (%), Rainfall (mm), Sunshine (hours), Wind velocity (km/hr) and Evaporation (mm) during the study duration of 2024

Pearson's correlation coefficient was applied to check the effect of weather parameters on FAW seasonal incidence. Additionally, principal component analysis (PCA) and regression models were employed to predict larval populations, with all analysis done with SPSS software (Version 20, SPSS Inc., Chicago, Illinois, USA).

## RESULTS AND DISCUSSION

**FAW seasonal incidence, damage percentage and their correlation with abiotic variables:** FAW infestation on maize was observed soon after germination, beginning in the 28th and 31st Standard Meteorological Weeks (SMW) during 2023 and 2024, respectively, and persisting until crop maturity (Fig. 2). Kumar et al. (2023) also observed larval activity from the 28th to the 40th SMW (second week of July to first week of October), with population ranging between 0.15 and 4.93 larvae per plant. Similarly, Ganavi and Kulkarni (2024) noted larval activity from the last week of July (31st SMW) until the 41st SMW, with a density of 0.85–2.25 larvae per plant. Suman et al. (2025) similarly observed that population of FAW larvae was first noticed in the 31st SMW and peaked in the 35th SMW in both 2021 and 2022.

The FAW population increased as crop growth progressed. The infestation followed distinct patterns across the two study years. In 2023, two peaks were evident: an initial peak of 2.80 larvae/plant in the 31st SMW, followed by a decline, and then a higher peak of 3.08 larvae/plant in the 33rd SMW (3rd week of August). After that, the population drastically decreased, reaching negligible levels towards the season's end. The research outcomes of Reddy et al. (2020) are partially in line with the current results, which noted that during *Kharif* 2019, the FAW incidence began in the 1st week of August in a 30 days old crop and peaked in the 3rd week of August in a 45 days old crop.

In 2024, the population exhibited a single peak. Populations remained low until the 33rd SMW, then increased steadily to reach 2.82 larvae/plant in the 36th SMW. After this there is a gradual decline in population but still remaining above 1.5 larvae/plant until the 38th SMW. Patil et al. (2024) recorded that larval incidence observed from 31st SMW *i.e.* 5th week of July, to the 43rd SMW *i.e.* 4th week of October with a peak incidence observed (4.05 larvae/ plant) during 39th SMW. While Dhuniya et al. (2025) noticed that the FAW incidence was initiated during 4th week of July (30th SMW), when there were 1.07 larvae/plant. Overall, the graph reveals a clear distinction in the FAW abundance patterns between the two years. Towards the late whorl stage, as the crop growth advances larval numbers declined, with only 1–2 larvae typically confined to the whorl. Rajisha et al. (2022) observed late larval stages were more commonly seen in late whorl stages, but 1st and 2nd larval instars were common in early plant stages, with roughly two to three larvae/plant. This reduction could be attributed to cannibalism, larval dispersal to nearby plants, and decreased preference for mature, tougher leaves by early instars. These observations agree with Deole and Paul (2018) and Pradeep et al. (2022), where FAW larvae preferentially feed on the tender leaves of maize. These findings also proved that phenology of the crop has a significant impact in FAW larval abundance. Durocher et al. (2021) also found that FAW larvae varied depending on the crop's phenological stage. Fall armyworm primarily acts as a defoliator and can cause mortality in young maize plants. Feeding in the whorl reduces the photosynthetic capacity of the crop, while ear feeding lowers grain quality and results in yield losses (Capinera 2020). The most acute damage was seen during the late whorl stage, when whorls predominantly harboured later instar larvae. As voracious feeders, they caused extensive injuries, with nearly 77% of the plant tissue

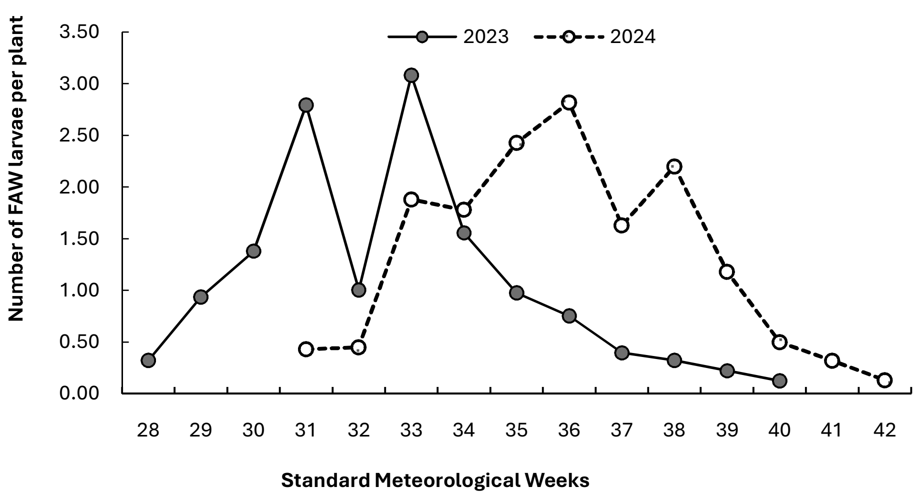


**Fig. 2.** Seasonal incidence of FAW larvae during 2023 and 2024

consumed during the final instar (Day et al., 2017, Flanders et al., 2017).

The percent of damaged plants closely followed larval population trends (Fig. 3). In 2023, damage began in the second week of July *i.e.* 28$^{th}$ SMW and continued until the first week of October (40$^{th}$ SMW), ranging from 6.67 to 75.0%. In 2024, infestation started slightly later, from the 1$^{st}$ week of August, and extended until the 3$^{rd}$ week of October, with damage varying between 5.0 and 80.0%. Peak infestation occurred in the 33$^{rd}$ SMW of 2023 (75.0%) and the 38$^{th}$ SMW of 2024 (80.0%). Patel et al. (2020) also documented FAW damage ranging from 10% to 81.66% between the 31$^{st}$ and 40$^{th}$ SMWs, and Kumar et al. (2023) recorded infestation levels between 9.3% and 79.1% from 28$^{th}$ to 40$^{th}$ SMW (2$^{nd}$ week of July to 1$^{st}$ week of October). Suman et al. (2025) reported that highest infestation occurred during the 36$^{th}$ SMW (50 days old crop), with an average infestation rate of 65.48 and 69.48% for the two consecutive years (2021 and 2022). Overall, the highest damage coincided with the vegetative growth phase, highlighting FAW's preference for younger maize tissues. As the crop transitioned to the reproductive stage, the percentage of infested plants declined markedly. This preference for tender foliage is consistent with earlier studies (Dhar et al., 2019), which demonstrated that larvae favour younger leaves due to their softer tissues, whereas older leaves, with thicker and tougher cell walls, are less palatable to defoliators (Perez et al., 2014, Bhusal and Bhattarai, 2019). However, damage occurs at all phases of crop growth. It was also reported that FAW is capable of damaging all growth stages of maize, however, damage is more severe in vegetative stage (Georgen et al., 2016, Deole and Paul, 2018, Suby et al., 2020).

The correlation study showed that FAW incidence in maize was significantly influenced by weather conditions during the *kharif* seasons of 2023 and 2024. In 2023, the FAW population showed a substantial and positive association with minimum temperature (r = 0.614*) and a significant and negative association with sunshine hours (r =

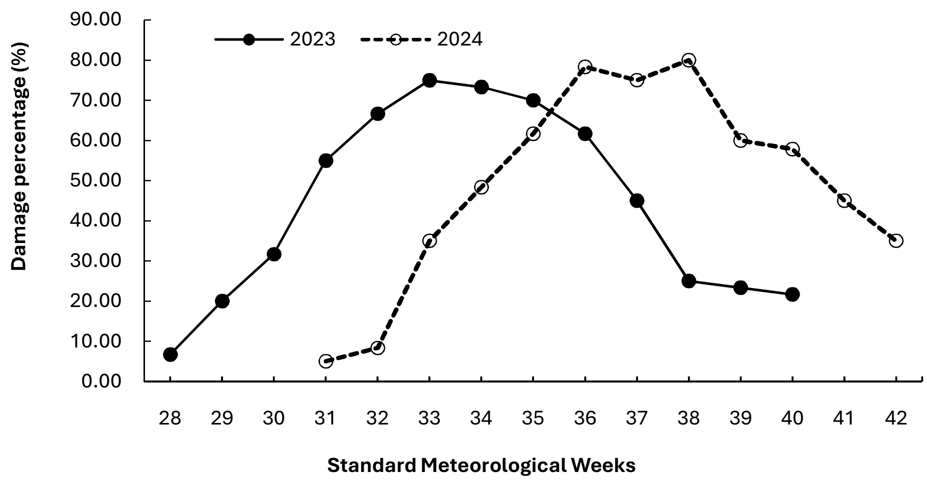


**Fig. 3.** Damage percentage of FAW larvae during 2023 and 2024

**Table 1.** Weather-based correlation matrix (Pearson's) for fall armyworm population in maize during *kharif* 2023

| Variables | PFAW | T (max.) | T (min.) | RH (mor.) | RH (eve.) | Rf | Evap. | SS |
|---|---|---|---|---|---|---|---|---|
| T (max.) | -0.105 | | | | | | | |
| T (min.) | 0.614$^{*}$ | -0.170 | | | | | | |
| RH (mor.) | 0.046 | -0.330 | -0.232 | | | | | |
| RH (eve.) | 0.357 | -0.631$^{*}$ | 0.733$^{**}$ | 0.114 | | | | |
| Rf | -0.236 | -0.557$^{*}$ | 0.285 | 0.059 | 0.596$^{*}$ | | | |
| Evap. | -0.123 | 0.354 | 0.231 | -0.151 | -0.089 | -0.089 | | |
| SS | -0.589$^{*}$ | 0.628$^{*}$ | -0.693$^{**}$ | -0.183 | -0.896$^{**}$ | -0.518 | 0.247 | |
| WV | 0.022 | -0.151 | 0.626$^{*}$ | -0.230 | 0.576$^{*}$ | 0.615$^{*}$ | 0.549 | -0.469 |

PFAW: FAW population per plant on Maize; T(max.): Temperature maximum (°C); T(min.): Temperature Minimum (°C); RH(mor.): Relative humidity morning (%); RH(eve.): Relative humidity evening (%); Rf: Rainfall (mm); Evap: Evaporation (mm); SS: Sunshine (hours); and WV: Wind velocity (km/h); NS: Non-significant. Correlation data is depicted in the table by bold digits

-0.589*). Maximum temperature, rainfall, and evaporation were adversely associated with larval population, whereas evening and morning relative humidity were positively associated. According to Barrios et al. (2019), the larval population of FAW was positively related with the relative humidity in maize ecosystem. The results suggest that minimum temperature and reduced sunshine hours provides favorable environment for FAW multiplication. These results are in line with previous findings by Patel et al. (2020), who found a negative relationship with rainfall, a non-significant positive association with morning humidity, and a significant and positive relation with minimum temperature. Deole and Paul (2018) also reported that FAW population had a negative non-significant relation with total rainfall.

In 2024, the FAW population had a strong and positive connection with the minimum temperature (r = 0.597*), indicating that higher night temperatures favoured pest incidence. Suman et al. (2025) also noticed that the incidence of FAW was significantly and positively related with the minimum temperature during *kharif* 2021 and 2022. Other abiotic factors *viz*., maximum temperature, morning and evening relative humidity, and evaporation were shown to have no statistical significance with respect to the larval population. Sunshine hours exhibited a weak and non-significant correlation, while rainfall and wind velocity had negligible influence on pest build-up. These findings differed notably from those of Kumar et al. (2020), who observed a negative association with rainfall and a positive but also a significant association with the highest temperature Comparable observations were made by Fonseca-Medrano et al. (2019) and Kumar et al. (2023), also observed that the pest showed a negative association with maximum temperature and sunshine hours while showing a strong positive association with humidity and minimum temperature. Overall, the findings proved that relative humidity and minimum temperature were the key weather parameters favouring the multiplication and persistence of FAW populations in maize, while excess sunshine and rainfall acted in the opposite direction.

**PCRA based predictions of FAW population in maize:** Eight abiotic variables were employed for Principal component regression analysis (PCRA) in attempt to group these associated parameters to the smallest feasible subgroups, indicating the percentage of variance. The principal component analysis (PCA) of abiotic variables influencing the population of FAW on maize during *kharif* season of 2023 are given in Table 3. The first principal component (PC1) explained 47.22% of the total variance, with strong contributions from minimum temperature, evening and morning relative humidity, rainfall, and wind velocity. This means that these variables collectively had the greatest impact on FAW population dynamics. The second principal component (PC2) accounted for an additional 24.54% of the variance, primarily contributed by maximum temperature, evaporation, and sunshine hours. Together, the first two components explained 71.76% of the total variation. Multiple regression equation was developed between the population of FAW and minimum temperature (Tmin.), relative humidity morning (RHmor.), relative humidity evening (RHeve.), rainfall (Rf), sunshine hours (SS) and wind velocity (WV) from PCA, and the correlation matrix for 2023.

FAW larval population per plant (2023) = 0.529(Tmin.) – 0.014(RHmor.) – 0.090(RHeve.) – 0.002(Rf) – 0.491(SS) – 0.168 (WV) ($P < 0.05$, $R = 0.95$, $R^2 = 0.89$).

The contribution of different weather variables in

**Table 3.** Principal components (PCs) with Eigen values and variances of *S. frugiperda* on maize during 2023

| Variables | Eigen value (%) | Variance | Cumulative variance (%) |
|---|---|---|---|
| $T_{min.}$, $RH_{mor.}$, $RH_{eve.}$, Rf, WV | 3.78 | 47.22 | 47.22 |
| $T_{max.}$, Evap., SS | 1.96 | 24.54 | 71.76 |

**Table 2.** Weather-based correlation matrix (Pearson's) for Fall armyworm population in maize during *kharif* 2024

| Variables | PFAW | T (max.) | T (min.) | RH (mor.) | RH (eve.) | Rf | Evap. | SS |
|---|---|---|---|---|---|---|---|---|
| T (max.) | 0.261 | | | | | | | |
| T (min.) | 0.597* | 0.210 | | | | | | |
| RH (mor.) | 0.338 | -0.409 | 0.513 | | | | | |
| RH (eve.) | 0.333 | -0.302 | 0.845** | 0.672* | | | | |
| Rf | 0.090 | -0.646* | 0.358 | 0.501 | 0.638* | | | |
| Evap. | 0.373 | 0.240 | 0.625* | 0.118 | 0.437 | 0.367 | | |
| SS | 0.048 | 0.641* | -0.441 | -0.497 | -0.808* | -0.625* | 0.011 | |
| WV | 0.104 | -0.367 | 0.614* | 0.504 | 0.784** | 0.699* | 0.610* | -0.563 |

PFAW: FAW population per plant on Maize; T(max.): Temperature maximum (°C); T(min.): Temperature Minimum (°C); RH(mor.): Relative humidity morning (%); RH(eve.): Relative humidity evening (%); Rf: Rainfall (mm); Evap: Evaporation (mm); SS: Sunshine (hours); and WV: Wind velocity (km/h); NS: Non-significant. Correlation data is depicted in the table by bold digits

**Table 4.** Principal components (PCs) with Eigen values and variances of *S. frugiperda* on maize during 2024

| Variables | Eigen value (%) | Variance | Cumulative variance (%) |
|---|---|---|---|
| $T_{min.}$, $RH_{mor.}$, $RH_{eve.}$, Rf, WV | 4.48 | 55.95 | 55.95 |
| $T_{max.}$, Evap., SS | 1.83 | 22.81 | 78.76 |

influencing FAW population during *kharif,* 2024. Indicated that first principal component (PC1) accounted for 55.95% of the total variance, with strongly influenced from minimum temperature, evening and morning relative humidity, rainfall, and wind velocity (Table 4). The second principal component (PC2) explained an additional 22.81% of the variance, primarily contributed by maximum temperature, evaporation, and sunshine hours. Together, PC1 and PC2 explained 78.76% of the total variation in FAW population with respect to weather factors, suggesting that minimum temperature and humidity-related variables were the most critical determinants. Thus, PCA results corroborate the correlation findings, emphasizing that humid conditions along with higher night temperature were optimal for FAW population buildup, while sunshine and evaporation played secondary but notable roles.

FAW larval population per plant (2024) = 1.128(Tmin.) – 0.175(RHmor.) – 0.012(RHeve.) – 0.005(Rf) – 0.935(SS) – 0.421 (WV) ($P < 0.05$, $R = 0.92$, $R^2 = 0.84$).

## CONCLUSION

Studies on the seasonal occurrence and abundance of insect pests is essential for the development of successful IPM programs. Seasonal dynamics of *S. frugiperda* across different meteorological weeks indicated that infestation begins shortly after crop emergence, typically 15–20 days after sowing. The number of larvae peaked in the 33rd SMW of 2023 and 2.82 per plant in the 36th SMW of 2024. Correlation analysis of larval populations with weather factors revealed a positive association with minimum temperature in both study years. The results suggest that fluctuations in FAW population is highly influenced by prevailing climatic conditions, as variations in larval abundance and crop damage were observed across both the years. The information obtained on incidence, damage patterns, and the significance of meteorological parameters provides key insights that can guide holistic and successful management measures against this invasive pest.

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