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Assessment of larval population and damage potential of fall armyworm (*Spodoptera frugiperda*) in maize (*Zea mays*) ecosystem

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ABSTRACT

A study was carried out to assess the larval incidence and leaf damage potential of fall armyworm, *Spodoptera frugiperda* (J E Smith) in maize (*Zea mays* L.) agroecosystem during rainy (*kharif*) season of 2022 and 2023 at Banda district of Uttar Pradesh. The larval population first appeared in 33rd standard meteorological week (SMW), with initial counts of 0.10 and 0.28 larvae/plant in 2022 and 2023, respectively. The population peaked at 6.92 larvae/plant in 38th SMW during 2022 and 4.83 larvae/plant in 37th SMW during 2023. The leaf damage was also varied from 0.37–60.16% in 2022 and from 4.69–58.14% in 2023. Correlation analysis indicated a strong positive correlation between larval population and leaf damage, both influenced by abiotic weather parameters. In 2022, only rainfall showed a significant positive correlation with larval population. In contrast, during 2023, both larval population and leaf damage showed significant positive correlations with minimum temperature, maximum relative humidity and minimum relative humidity. Principal component analysis suggested that higher rainfall and relative humidity favour greater population growth and leaf damage in 2023 compared to 2022. The results of the regression analysis revealed that weather variables were more influenced in 2022 (R^2 = 58.7) than 2023 (R^2 = 41.5), showed 58.70% variability in fall armyworm larval population, where maximum temperature was most significant constant. Besides, other factors might also be responsible for a weaker model in 2023.

Keywords: Correlation, Larval population, Leaf damage, PCA, Weather variables

Maize (*Zea mays* L.), commonly known as corn, demonstrates remarkable adaptability to various agroclimatic conditions, making it a highly flexible crop. Due to its exceptional genetic yield potential among cereals, maize is recognised worldwide as the 'queen of cereals' (Jeyaraman 2017). Its composition includes approximately 72% starch, 10% protein and 4% fat (Ranum *et al.* 2014). Globally, maize is cultivated on 201.25 mha and producing approximately 1,220.54 mt of grain yield with an average productivity of 6.06 t/ha (USDA 2024). In India, it is majorly grown in Karnataka, Telangana, Bihar, Maharashtra, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Rajasthan, Uttar Pradesh and West Bengal; and has become the leading maize producer with a total area, production and average productivity of 10.04 mha, 33.62 mt and 3,349 kg/ha, respectively in 2020–21 (MOA 2023). Uttar Pradesh accounts for 8.3% of the total maize cultivated area in the country (Rakshit *et al.* 2019), which was 0.77 mha with 1.8 mt production and 2,331 kg/ha of average productivity (MOA 2022).

Among the maize production limiting factors, insect-pests play a significant role and invasive species pose a particularly severe threat to both ecological balance and economic viability (Evans *et al.* 2016). The fall armyworm (FAW) (*S. frugiperda* J E Smith, Noctuidae: Lepidoptera) is a devastating polyphagous pest (Baudron *et al.* 2019). In India, it was first noticed at Shivamoga district of Karnatakka in mid-May 2018 (Sharanabasappa *et al.* 2018), subsequently spread to other states and in Uttar Pradesh in 2019 (Padhee *et al.* 2019). From Banda district of Uttar Pradesh, it was first reported in 2020, where maize, finger millet and groundnut crops were severely affected (Pandey *et al.* 2022). Larvae feed on leaves, stems and reproductive structures (Tefera *et al.* 2019) and harvesting is often impossible due to the heavy toll caused by FAW larvae in cob production. Early instar larvae tend to be gregarious and scrape chlorophyll from one side of the leaf, leaving the opposite epidermal layer intact, resulting in characteristic 'window panes' on leaves (Tiwari *et al.* 2024). In the late instar stage, they cause extensive defoliation, often leaving of sawdust-like

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faecal matter (Abrahmas *et al.* 2017). The pest can be more destructive during the *kharif* season (June to August) as it feeds on large numbers of leaves and stems. Therefore, weather factors play crucial role in shaping geographical distribution, seasonal abundance, population size and severity of damage. It is predicted to cause 21–53% losses in annual maize production in the absence of control measures (Day *et al.* 2017). Accurately quantifying the relationship between pest activity and weather conditions is essential for predicting damage potential and improving integrated pest management (IPM) strategies (Seni and Naik 2018, Vennila *et al.* 2019, Seni 2020). Therefore, this study was carried out to investigate the population fluctuations trends and leaf damage potential of *S. frugiperda* on maize and their relationships with weather variables.

MATERIALS AND METHODS

Study area: The field experiment was conducted during the *kharif* seasons of 2022 and 2023 at College of Agriculture, Banda University of Agriculture and Technology, Banda (24˚53′–25˚55′ N, 80˚07′–81˚34′ E; at an elevation of 123 m amsl), Uttar Pradesh. The popular maize variety NMH-8399 was raised in 4th week of July with 60 cm × 35 cm plant spacing in 20 m × 10 m plot sized further divided in five blocks for observations.

Larval population and leaf damage assessment: The incidence of fall armyworm was assessed in terms of the larval population/plant and percent leaf damage by them. The larval counts were performed on a total of 100 tagged plants (20 from each block) arranged in a zig- zag pattern, started from a week after germination at weekly interval. The leaf damage caused by FAW was assessed in the same plot divided into five quadrants. In each quadrant, the total number of leaves and damaged leaves in five rows of 1 m length were counted and the percentage of leaf damage was determined and arranged it to a week basis.

Statistical analysis: The data on abiotic weather variables, viz. mean temperature (°C maximum and minimum), relative humidity (%, maximum and minimum) and total rainfall (mm), were collected from meteorological observatory for *kharif* 2022 and 2023 and arranged in a week basis. The simple correlation and regression analysis of larval population of FAW, leaf damage percentage with weather variables were determined separately for each year Fowler *et al.* (1998) and results were compared with the tabulated t-value (p=0.05). The regression equation was also derived by following formula suggested by Panse and Sukhatme (1954). The principal component analysis (PCA) was performed by using R statistical software.

RESULTS AND DISCUSSION

In 2022, the larval population and leaf damage first appeared at the early vegetative stage of the crops with 0.10 larvae/plant at the 33rd standard meteorological week (SMW) (2nd week of August) and peaked at 6.92 larvae/plant by the 38th SMW (3rd week of September) when the temperature and relative humidity ranged from 25.57–32.43ºC and 69.71–91.28%, respectively, with 100 mm of rainfall. The larval population temporarily decreased to 3.90 larvae/plant in the following week (39th SWM), reaching a second peak of 5.87 larvae/plant in the 40th SMW, and then declined steadily to 1.52 larvae/plant by the 44th SWM (Table 1).

Similarly, in 2023, the larval population first appeared in the 33rd SMW with 0.28 larvae/plant and peaked at 4.83 larvae/plant by the 37th SMW (2nd week of September), when the temperature and relative humidity ranged from 26.14–31.42°C and from 79.42–88.85%, respectively, with 57.50 mm of rainfall (Table 2). Afterward, the larval

Table 1 Larval population and percentage of leaf damage caused by fall armyworm during *kharif* 2022

Standard meteorological week	Mean larval population/plant	Leaf damage (%)	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
			Minimum	Maximum	Minimum	Maximum	
32nd	0.00	0.00	27.29	33.29	68.14	92.42	57.00
33rd	0.10	0.37	26.71	33.00	72.28	93.57	07.00
34th	1.32	1.73	25.86	31.71	77.14	94.57	56.00
35th	2.06	10.78	28.17	35.33	68.85	94.57	03.00
36th	3.25	23.78	27.14	37.29	62.28	92.71	00.50
37th	5.35	36.46	26.43	32.00	72.71	93.42	64.75
38th	6.92	60.16	25.57	32.43	69.71	91.28	100.00
39th	3.96	52.44	25.57	34.29	60.85	92.42	17.75
40th	5.87	55.93	25.29	33.71	56.71	92.14	56.00
41st	4.90	48.78	24.00	33.00	58.28	94.00	57.00
42nd	2.91	45.83	21.86	34.00	38.71	90.57	00.00
43rd	1.64	44.59	19.71	33.71	33.42	87.28	00.00
44th	1.52	37.62	19.00	33.57	35.85	89.14	00.00

population declined steadily to 0.28 larvae/plant by the 44th SMW. These findings are consistent with those of Reddy *et al.* (2020), who reported a similar peak infestation of *S. frugiperda* on 45-day old crops during the *kharif* season. These results are also consistent with those of Kumari (2020), Paul and Deole (2020) and Patel *et al.* (2020) who documented peak larval populations in either the third or fourth week of September. This finding corroborates the pattern of *S. frugiperda* infestation peaks observed in previous studies and highlights the consistency of peak infestation timing across different years and studies.

During *kharif* 2022, leaf damage caused by FAW first appeared in the 2nd week of August, initiated with 0.37% infestation. Infestation levels increased to 60.16% by the 38th SMW, coinciding with the crop's reproductive stage, decreased in the following week to 52.44%, and then slightly increased to 55.93% by the 40th SMW before declining to 37.62% by the 44th SMW. In 2023, leaf damage began at 4.69% during the 33rd SMW, rose steadily to 58.14% by the 37th SMW and then decreased to 5.68% by the 44th SMW. These findings are consistent with Patel *et al.* (2020), who also observed peak larval populations and maximum percent damage in the third week of September, followed by a decline. Among the years of experimentations, the infestations were comparatively higher (60.16%) in 2022 than the 2023. It may be due to higher rainfall and comparatively more rainy days in 2022 and these findings align with reports from several researchers (Baudron *et al.* 2019, Padhee and Prasanna 2019, Patel *et al.* 2020, Sunitha *et al.* 2021, Nivetha *et al.* 2022, Bakry and Abdel-Baky 2023) who reported leaf and plant infestations (53.33–70%) by FAW at various locations. This comparative analysis highlights the pattern of peak infestations during the reproductive stage of maize and corroborates findings from multiple studies on the extent of damage caused by fall armyworms in the *kharif* season.

Correlation analysis: A heatmap of the correlation between the *S. frugiperda* larval population and percent leaf damage with abiotic environmental factors was generated for each experimental year. In 2022, the larval population showed a significant positive correlation with rainfall (r = 0.57*), but a non-significant positive correlation with minimum temperature (r = 0.08), minimum relative humidity (r = 0.09) and maximum temperature (r = 0.06) as well as a non-significant negative correlation with maximum temperature (r = -0.10). However, in 2023, the larval population was significantly correlated with minimum temperature (r = 0.55*), minimum relative humidity (r = 0.56*) and maximum relative humidity (r = 0.61*), but showed non-significant correlation with maximum temperature and rainfall, with the highest value corresponding to maximum relative humidity (Fig. 1). These results indicate that low temperature and relative humidity (minimum and maximum) both favour larval population growth and increase the severity of FAW infestations during 2023. This variability in weather affecting FAW populations is consistent with previous findings (Meena *et al.* 2019, Kumar *et al.* 2020, Pasayat 2021, Sunitha *et al.* 2021, Muthukrishnan 2022), where mixed-type correlations have been observed due to season and location-specific weather variables (Lopez *et al.* 2019, Koffi *et al.* 2020). Such variability underscores the challenge of comparing results across different studies.

In 2022, percent leaf damage caused by FAW was negatively correlated with temperature and relative humidity, except for rainfall, which had the highest correlation value (r = 0.21); but all were not significant (Fig. 1). Also in *kharif* 2023, the percentage of leaf damage showed non-

Table 2 Larval population and percentage of leaf damage caused by fall armyworm during *kharif* 2023

Standard meteorological week	Mean larval population/plant	Leaf damage (%)	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
			Minimum	Maximum	Minimum	Maximum	
32nd	0.00	0.00	25.71	31.00	71.00	83.57	7.50
33rd	0.28	4.69	26.28	32.57	67.42	80.85	41.75
34th	2.71	32.81	26.57	31.28	77.28	82.14	35.00
35th	2.69	39.06	26.57	33.85	56.85	77.28	13.00
36th	1.64	48.58	25.71	31.57	74.57	86.00	80.00
37th	4.83	58.14	26.14	31.42	79.42	88.85	57.50
38th	2.30	36.61	26.00	32.42	73.71	84.85	00.00
39th	2.37	18.86	25.28	32.85	70.85	87.00	00.00
40th	1.89	14.32	23.57	32.28	56.71	78.85	00.00
41st	1.17	12.86	22.57	35.71	44.00	71.14	00.00
42nd	0.39	09.38	21.14	32.00	49.28	67.42	00.00
43rd	0.32	06.37	18.85	31.00	40.85	65.85	00.00
44th	0.28	05.68	18.00	31.28	50.85	72.14	00.00

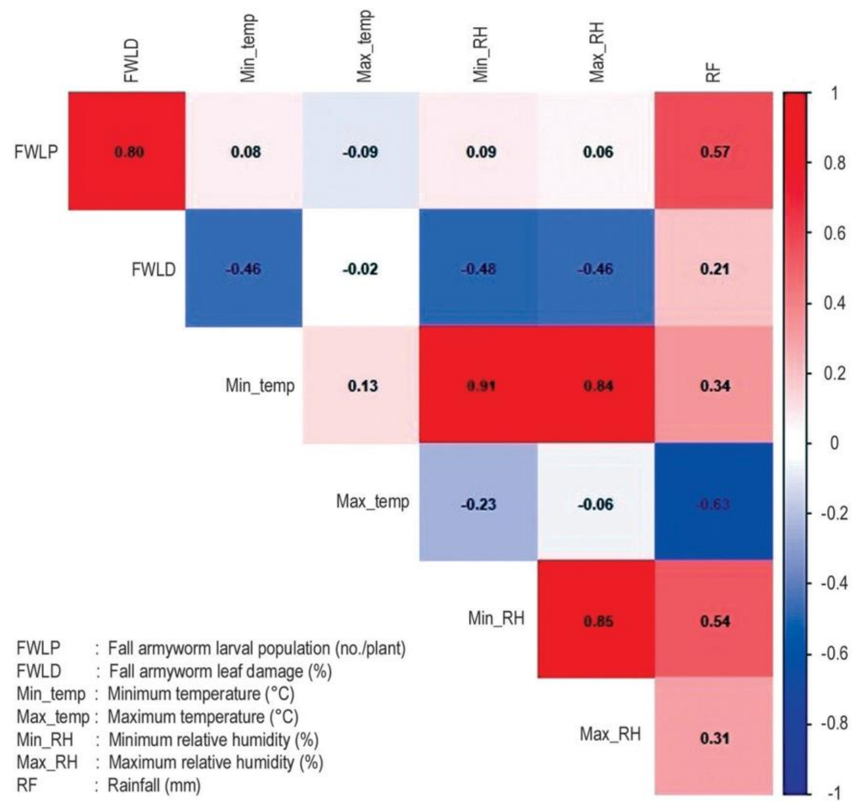
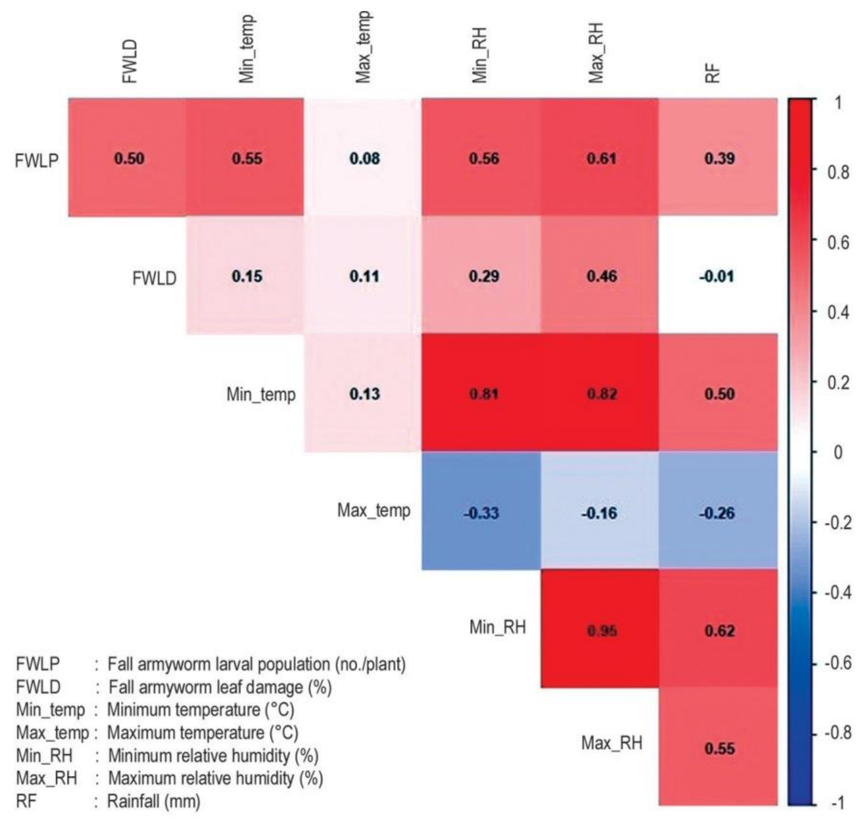


Fig. 1 Heatmap depicting the relationships of fall armyworm infestation with weather variables in *kharif* 2022.

significant correlations values, positive with temperatures and relative humidity, where maximum value (r = 0.46) associated with minimum relative humidity and negative and minimum value (r = -0.01) with rainfall (Fig. 2). The negative correlations with temperature are consistent with Pradeep *et al.* (2022) but differ from Patel *et al.* (2020), who reported positive correlations. The non-significant negative correlation with relative humidity in the present findings aligns with Patel *et al.* (2020) and Alam *et al.* (2022). A non-significant correlation with rainfall in both the years is consistent with the findings of Ahissou *et al.* (2022) and Haroli *et al.* (2023), who reported non-significant and variable correlations between fall armyworm infestation and rainfall. These results underscore the variability of weather impacts on pest infestations across different studies and locations and suggest that environmental factors may influence both larval population and leaf damage, although the direction and strength of these influences between the two years. It may be valuable to further investigate potential reasons for these differences, such as variations in pest resistance, changes in plant health, or broader climatic factors influencing these relationships.

Principal component analysis (PCA): The PCA biplot revealed a strong association between FAW infestation and meteorological variables. In *kharif* 2022, first two components accounted for 46.2% (Dim 1) and 31.8% (Dim 2) variations with a total of 78.0% variation (Fig. 3). A strong positive association between FAW larval population and leaf damage confirm that an increase in larval population leads to maximum leaf damage. A moderate association with rainfall and relative humidity suggested that moist weather condition may increase FAW development and feeding potential, however a opposite orientation of maximum temperature showed a negative influence on FAW. Also in *kharif* 2023, the PCA biplot explained a total of 78.1% variation, whereas the first principal component (Dim 1) accounts for a large proportion of variance (60.5%) and second component (Dim 2) for only



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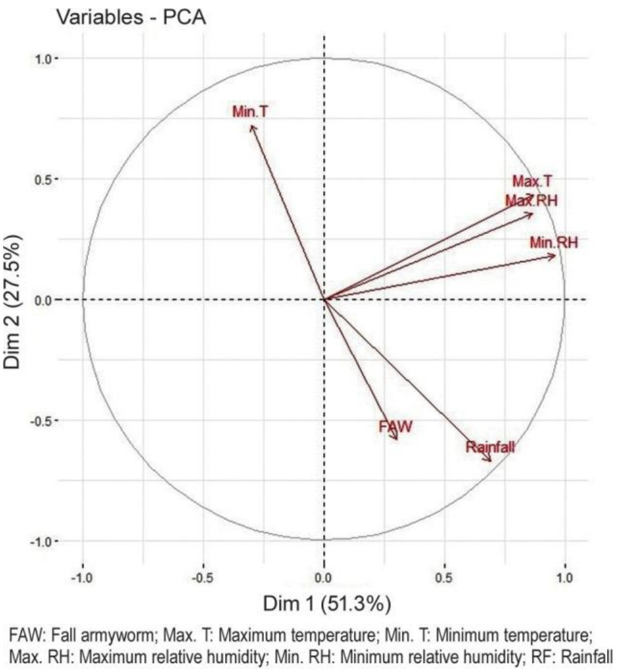

Fig. 3 PCA of fall armyworm with weather variables for the *kharif* 2022.

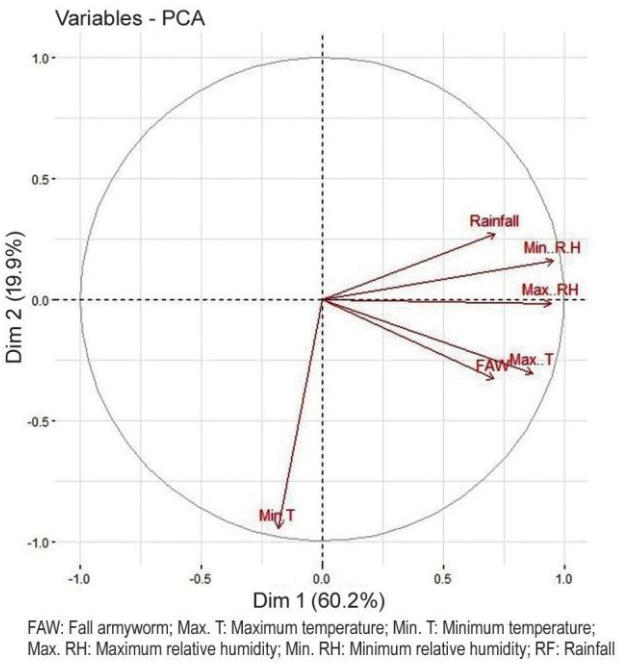

Fig. 4 PCA of fall armyworm with weather variables for the *kharif* 2023.

17.6% (Fig. 4). A close alignment of FAW larval population and leaf damage with rainfall, minimum temperature and relative humidity, indicates a strong influence of these factors in FAW infestation in 2023 which may have promoted greater larval population and leaf damage compared to 2022. The PCA study indicated that the incidence and damage potential of FAW varied by season. These findings align with those of López *et al.* (2019) and Koffi *et al.* (2020), who reported to year variation in FAW damage to maize crops.

Regression equation: The stepwise multiple regression equations described the relationship between the FAW larval population and weather parameters (Table 3). The results indicated that weather parameters explained a greater proportion of variation in FAW larval population in *kharif* 2022 (58.7%, $R^2 = 0.587$) than in 2023 (41.5%, $R^2 = 0.415$). In 2022, the regression coefficients showed that maximum temperature ($X_2 = 0.926$) exerted the strongest positive influence on larval population, followed by maximum relative humidity ($X_3 = 0.395$) and rainfall ($X_5 = 0.077$),

Table 3 Stepwise regression equation between the larval population of *S. frugiperda* and weather parameters

Year	Stepwise regression equations	R^2
2022	$Y = -57.27 + (-0.222)\ X_1 + (0.926)\ X_2 + (0.395)\ X_3 + (-0.072)\ X_4 + (0.077)\ X_5$	58.7
2023	$Y = -14.63 + (-0.048)\ X_1 + (0.296)\ X_2 + (0.075)\ X_3 + (0.029)\ X_4 + (0.006)\ X_5$	41.5

Significance level: p=0.05. X_1, Minimum temperature; X_2, Maximum temperature; X_3, Maximum RH; X_4, Minimum RH; X_5, Rainfall.

suggesting that these variables favoured the development and abundance of *S. frugiperda*, whereas minimum temperature and minimum relative humidity had negative effects. In *kharif* 2023, all weather variables had positive regression coefficients, with maximum temperature ($X_2 = 0.296$) again emerging as the most influential predictor among the variables, although their effects were comparatively weaker. These findings suggest that weather conditions played a more pronounced role in determining pest incidence in *kharif* 2022 than in 2023. The regression models for both years indicated that the maximum temperature and maximum relative humidity had stronger and consistent impact on FAW, although their effects varied by week, month, season and year. The variability in the impact of weather conditions might be due to year wise variations in region specific environmental conditions or other factors not included in regression model. These findings are consistent with those of Patel *et al.* (2020) who noted 49% of the variation in FAW larval populations by rainfall and Sunitha *et al.* (2021) who found 65% influence in FAW incidence by weather parameters. This underscores the need for further research to explore additional variables or interactions that might better explain the dynamics of larval populations and shifting behaviour of FAW on other host rather than maize.

This study found that *Spodoptera frugiperda* is a serious pest of maize during the *kharif* season, with infestation beginning in the 33rd SMW and peaking during the 37th–38th SMW. The highest larval populations (6.92 and 4.83 larvae/plant) and leaf damage (60.16% and 58.14%) were recorded in 2022 and 2023, respectively. Weather factors significantly influenced pest incidence, with rainfall being the main determinant in 2023. Correlation, PCA, and regression analyses confirmed that climatic variables substantially affected seasonal fluctuations in fall armyworm populations. The results indicated that mid-August to late September is the most critical period for fall armyworm infestation in maize, highlighting the importance of regular surveillance and weather-based forecasting for timely implementation of integrated pest management strategies and effective reduction of crop losses.

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