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Understanding the seasonal incidence of Fall armyworm, *Spodoptera frugiperda* (J E Smith, 1797) in maize in the Gird Region of Madhya Pradesh, India

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ABSTRACT

Effective pest management in maize requires a clear understanding of insect pest incidence to enable timely and targeted control measures. To address this concern, present research experiment was conducted at the Entomology Research Farm, College of Agriculture, Gwalior, M.P., during two consecutive years, i.e., Kharif 2021-22 and Kharif 2022-23, with the aim to assess the seasonal incidence of *S. frugiperda* in maize crop and its correlation with abiotic factors. The results revealed that the larval population of *S. frugiperda* was first observed in the 31st SMW and peaked in the 35th SMW during both 2021 and 2022. Furthermore, the lowest percentage of plant damage was also recorded in the 31st SMW during both years, with its peak at the 36th SMW, and thereafter, plant damage gradually decreased in the 44th SMW. The incidence of *S. frugiperda* demonstrated a significant positive correlation with minimum temperature (Min temp) during *Kharif* 2021 ($r = 0.823$, $p < 0.0001$*) and *Kharif* 2022 ($r = 0.781$, $p < 0.0010$*).

Keywords: Larval population, plant damage, abiotic factors, correlation, linear fit.

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INTRODUCTION

Maize, *Zea Mays* also known as corn, is a major annual cereal crop in the Poaceae family. Zea, an ancient Greek word, means “sustaining life,” while Mays, a Taino word, means “life giver.” It originated in South America and spread throughout the world. In India, maize is cultivated for multiple purposes, including human consumption, livestock and poultry feed, food processing, and the production of starch, dextrose, corn syrup, and corn oil. It is rich in B-complex vitamins such as B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), and B6 (pyridoxine), which contribute to the health of the hair, skin, digestion, heart, and brain. Additionally, maize contains vitamins A, C, and K, along with high levels of beta-carotene and selenium, which support thyroid health and immune system function. Compared to other cereals, maize has a higher protein and fat content (Kumar & Jhariya, 2013). In seventy developing countries, 53 of which grows more than 100,000 hectares of maize (Dowswell, 2019). In India, the average annual production of maize was 337.30 million tons, cultivated in 99.58 million ha of land, with average productivity of 3387 kg/ha (Anonymous, 2022). Among the maize growing states, Karnataka is the leading producer followed by Madhya Pradesh, Maharashtra, Tamil Nadu and West Bengal with the production of 52.20, 46.07, 35.85, 28.27 and 25.26 million tons respectively (Anonymous, 2022). In Madhya Pradesh, 14.00 million ha of the land area is under maize cultivation, which produces 46.07 million tons, and has a productivity of 3291 kg/ha (Anonymous, 2022). Despite a significant increase in the area under maize cultivation, productivity remains below the global average because of a number of biotic and abiotic constraints. Among them, biotic constraints being insect pests, which are known to significantly reduce yields (Ngoko et al, 2002). More than 250 insect species have been recorded on maize, both in the field and storage (Mathur, 1987). Fall Armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuiidae), is a highly migratory invasive pest native to tropical and subtropical areas of America (Sparks, 1979; Nagoshi et al, 2018; Early, González-Moreno, Murphy, & Day, 2018). The Fall Armyworm (FAW) has been documented to cause yield losses of up to 73% in maize across Latin America (Murua, Molina-Ochoa, & Coviella, 2006). It was first identified in São Tomé, Nigeria, Benin, and Togo Africa in 2016 (Goergen, Kumar, Sankung, Togola, & Tamo, 2016). In India, it was first reprted in May 2018 at the University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka (Sharanabasappa et al, 2018). It was also reported from other maize growing states of India viz., Andhra Pradesh, Tamil Nadu, Telangana, Maharashtra, Gujrat and several North-eastern states (Sharanabasappa et al, 2018; Swamy et al, 2018; Srikanth et al, 2018; Chormule et al, 2019). Due to its polyphagous nature, *S. frugiperda* damages a variety of crops, including maize, rice, sorghum, millet, sugarcane, vegetable crops, and cotton. In South India, the *S. frugiperda* infestation rate varied between 6.00% and 100% (Mallapur et al. 2018). It was estimated that the incidence of *S. frugiperda* would reduce maize production in India by 37000- 75000 tons (Suby et al. 2020). This insect poses significant challenges to maize cultivation, resulting in economic losses not just for individual farmers but also for the overall agricultural sector and regional economy. Monitoring the populations of pest throughout the growing season helps identify key periods of activity, enabling farmers to take preventive or curative actions at optimal times. Correlating pest incidence with abiotic factors, such as temperature, rainfall, or humidity, provides valuable understandings about the causes of pest outbreaks. The extent of damage caused by insect pest complexes depends on population trend in the field, which, in turn, are influenced by the dynamics of environmental factors (Isard, 2004). Identifying the relationship between these factors and insect pest population dynamics helps predict and prevent infestations. Therefore, the present research was conducted to study the seasonal incidence of *S. frugiperda* in maize crop.

MATERIAL AND METHODS

The present study was conducted at the Entomology Research Farm, College of Agriculture, Gwalior, M.P. (26°14' North and 78°15' East) during *Kharif* 2021 and *Kharif* 2022. The maize hybrid variety 'RMH 1899 Super' was sown with a plot size of 10m x 9m and a spacing of 60 cm between rows and 20 cm between plants. All recommended agronomic practices were followed, except for the plant protection measures.

To observe the seasonal incidence of *S. frugiperda*, the number of larvae was recorded on ten randomly selected plants at weekly intervals, starting from germination until harvest of the crop. The number of infested and healthy plants was recorded to determine the percentage of plant damage during each standard meteorological week. Data on abiotic factors *such as* maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, and rainfall were recorded from the meteorological observatory, College of Agriculture, Gwalior, M.P. Correlation and regression analyses of *S. frugiperda* infestation with weather parameters were performed using the JMP version 18.0.1 software.

RESULTS

During the *Kharif* seasons of 2021 and 2022, the presence of *S. frugiperda* was observed shortly after the crop emerged (Table 1). Incidence of *S. frugiperda* commenced during the 31st SMW, with an average population of 1.2 and 1.7 larvae per plant, while the lowest per cent plant damage (7.74% and 8.60%) caused by *S. frugiperda* was recorded during the same period in the respective years. The population of *S. frugiperda* larvae gradually increased up to the last week of August, at 45 days old crop, reaching its peak during 35th SMW, with an average population of 2.8 and 2.9 larvae per plant in the *Kharif* seasons of 2021 and 2022. As the number of *S. frugiperda* larvae increased, the percentage of plant damage also increased, reaching its peak during 36th SMW at 50 days of crop stage, with an average infestation rate of 65.48% and 69.48% for the two consecutive years. Subsequently, the population began to decline gradually, but persisted throughout the cropping season. At the end of the 44th SMW (first week of November), the minimum number of *S. frugiperda* larvae observed was 0.2 and 0.5 larvae per plant in both consecutive years. Correspondingly, the mean plant damage, 16.77% and 20.04%, respectively, was recorded during the same period in the *Kharif* seasons of 2021 and 2022.

Table 1. Seasonal incidence of *S. frugiperda* in maize during Kharif 2021 and Kharif 2022.

SMW	Kharif 2021		Kharif 2022	
	No. of Larvae/ plant	Plant damage (%)	No. of Larvae / plant	Plant damage (%)
31	1.2	7.74	1.7	8.60
32	1.9	14.50	1.8	10.64
33	2.2	20.80	1.9	14.46
34	2.6	28.39	2.6	28.62
35	2.8	45.16	2.9	52.26
36	2.2	65.48	2.4	69.48
37	1.8	56.45	1.7	58.20
38	1.6	48.71	1.6	46.26
39	1.3	40.32	1.5	37.65
40	1.3	33.87	1.3	32.22
41	1.2	25.81	1.1	28.82
42	0.8	25.48	1.0	26.60
43	0.5	23.23	0.8	25.66
44	0.2	16.77	0.5	20.04

Correlation studies indicated that different relationships were established between the larval populations and abiotic factors during Kharif 2021 and 2022 (Tables 2 and 3). A weak positive correlation was observed between maximum temperature (Max temp) and *S. frugiperda* larvae in both years; however, this correlation was not statistically significant. Moreover, a highly significant correlation was exhibited by the minimum temperature (Min temp), showing a strong positive correlation with *S. frugiperda* larvae, $r = 0.823$, $p < 0.000^*$ (2021), and $r = 0.781$, $p < 0.001^*$ (2022). Other abiotic factors viz morning relative humidity (Morning RH), evening relative humidity (Evening RH), rainfall, and evaporation were found to be statistically non-significant with respect to the larval population.

Table 2. Correlation and regression analysis between *S. frugiperda* larvae and abiotic factors during Kharif 2021.

Variable	Correlation Coefficient	Significance (p-value)	R-squared	Intercept	Slope
Max temperature	0.390	0.168	0.152	-2.551	0.125
Min temperature	0.823	0.000*	0.677	-1.767	0.142
Morning RH	-0.016	0.957	0.000	1.754	-0.003
Evening RH	0.313	0.276	0.098	0.104	0.022
Rainfall	0.114	0.698	0.013	1.461	0.002
Evaporation	-0.109	0.712	0.012	1.705	-0.032

*significant at p<0.05

Table 3. Correlation and regression analysis between *S. frugiperda* larvae and meteorological parameters during Kharif 2022.

Variable	Correlation Coefficient	Significance (p-value)	R-squared	Intercept	Slope
Max temperature	0.289	0.316	0.083	-2.796	0.136
Min temperature	0.781	0.001*	0.610	-1.412	0.135
Morning RH	-0.110	0.708	0.012	3.172	-0.017
Evening RH	0.430	0.124	0.185	-0.341	0.0314
Rainfall	0.308	0.284	0.094	1.437	0.004
Evaporation	-0.107	0.715	0.012	1.847	-0.057

*significant at p<0.05

The relationship between the number of *S. frugiperda* larvae during Kharif 2021 and 2022 and the min temperature is depicted in the scatter plots in Figs. 1 & 2. The slope of the regression line shows that for every 1°C increase in the Min temp, the number of *S. frugiperda* larvae is expected to increase by approximately 0.142 and 0.135, respectively. As the Min temp increased, the confidence and prediction intervals became wider, indicating that the predictions were less certain at higher temperatures. The R-squared values for the regression were 0.677 and 0.610, respectively, indicating that the Min temp accounted for approximately 67.7% and 61% of the variability in the number of *S. frugiperda* larvae during Kharif 2021 and Kharif 2022.

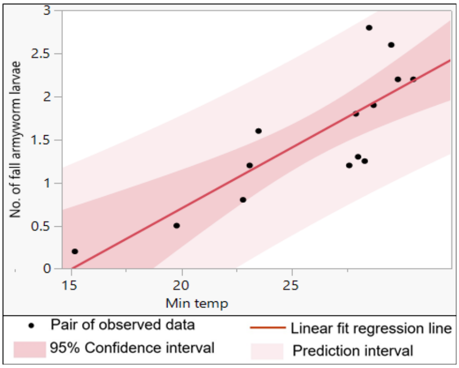

Figure 1. Bivariate fit of number of *S. frugiperda* larvae by minimum temperature during Kharif 2021.

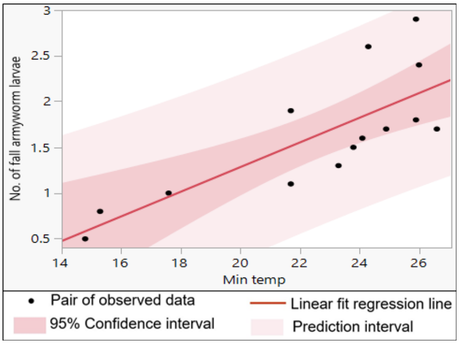

Figure 2. Bivariate fit of number of *S. frugiperda* larvae by minimum temperature during Kharif 2022.

CONCLUSIONS AND DISCUSSION

The results conclude that the infestation of *S. frugiperda* commenced at the early growth stage of crop with the highest larval population recorded during the first two months in both *Kharif* seasons of 2021 and 2022. However, population declined gradually at the end of the week but cumulative feeding caused significant damage. On the other hand, a more significant correlation appears to be exhibited by the Min temp, which indicated a strong positive correlation with *S. frugiperda* larvae, during *Kharif* seasons of both 2021 and 2022. As a result of this positive interaction, larval populations of *S. frugiperda* also tend to increase as the Min temp increased. The minimum temperature over a particular point may allow the pest to survive, resulting in an increase in population size during this season. These findings showed the significant need for early pest detection and appropriate control techniques to reduce crop losses. Implementing integrated pest management (IPM) strategies during the initial infestation period could successfully manage the impact of *S*. *frugiperda* on crop productivity.

The present study revealed that larval population of *S*. *frugiperda* was first recorded at the 31st SMW (15 days old crop) with the lowest plant damage recorded during the same period, with an average infestation rate of 7.74% and 8.60% for the Kharif seasons of 2021 and 2022. However, as the number of *S*. *frugiperda* larvae increased reached its peak in last week of August during the 35th SMW (45 days old crop), the percentage of plant damage also increased, and caused highest infestation during the 36th SMW (50 days old crop), with an average infestation rate of 65.48% and 69.48% for the two consecutive years. These findings are consistent with those of Kumari (2020), who noted that the larval population of *S*. *frugiperda* peaked in the last week of August before steadily declining until it reached its lowest point for the entire cropping season. In addition, Shylesha et al (2018) reported 9-62.5% plant infestation from various places surveyed; however, this is in complete agreement with the present findings. These findings are partially supported by Pradeep, Deshmukh, Sannathimmappa, Kalleshwaraswamy, & Firake (2022), who reported that FAW infestation started to appear gradually after the crop's emergence (8-10 days after sowing). The findings of Reddy, Kumari, Saha, & Singh (2020) are partially in line with the current results, which noted that during Kharif (2019), the incidence of *S*. *frugiperda* began in the first week of August in a 30 days old crop and peaked in the third week of August in a 45 days old crop. These variations in *S*. *frugiperda* emergence may have resulted from various growing seasons and variations in abiotic conditions present at the time of experimentation. The present results indicate that *S*. *frugiperda* in both years preferred the crop during the first two months after sowing. Due to the tender leaves and lack of cannibalism in the early instars, it was first found that there were more larvae per plant when the crop was in its early stages. These findings are consistent with Pradeep, Deshmukh, Sannathimmappa, Kalleshwaraswamy, & Firake (2022) and Deole & Paul (2018), who showed that the FAW larvae primarily favor soft maize leaves. This could be the result of a suitable climate, which favors an early *S*. *frugiperda* attack. *S*. *frugiperda* have the ability to quickly establish themselves on maize crops under such conditions, even at the beginning of the growing period. Anandhi et al (2020), reported a higher FAW population in Kharif (0.99-3.66 larvae/ plant), which is also consistent with the findings of the present results. In contrast to present results, Reddy, Kumari, Saha, & Singh (2020) recorded that *S. frugiperda* infestation peaked at 45 days of crop during Kharif. This could be due to the different sowing times and agro-climatic conditions in the different regions. The present results also indicate that, when the crop was in the late whorl stage as opposed to the early whorl stage in August, more percent of plant damage was recorded. This is similar to Pradeep, Deshmukh, Sannathimmappa, Kalleshwaraswamy, & Firake (2022), who found that FAW damage is more prevalent during vegetative growth stages (i.e., up to 9 weeks following emergence). The current findings reported that the population began to decline gradually but persisted throughout the cropping season. Similarly, Meagher & Nagoshi (2004) reported that the *S. frugiperda* population was present throughout the cropping season. The results also showed that the infestation gradually decreased, and the less mean plant damage, 16.77% and 20.04%

respectively, was recorded during the 44th SMW in the first week of November. This is partially in line with Kumar, Yasodha, & Justin (2020), who noted that during the *Kharif* season, *S. frugiperda* incidence peaked during the second fortnight of July 2019 and reached its lowest point during the second fortnight of October 2019. This may be due to the different agro-climatic conditions and sowing seasons.

The correlation analysis reveals that the larval population of *S. frugiperda* was influenced by minimum temperature, indicating a significant positive relationship in both the study years. The scientific evidence supports the current findings as reported by Pragya, Das, & Kakade (2022), who reported that minimum temperature had a largely favorable impact on fall armyworm larvae populations, which does not correspond with what is said about maximum temperature and evaporation. Similarly, Sidar, Deole, Yadu, & Ganguli (2015) discovered a significant but negative correlation between the cob borer larval population and minimum temperature (r= -0.44). In opposition to the current investigations, Kumar, Yasodha, & Justin (2020) reported that the incidence of *S. frugiperda* during Kharif and Rabi showed a significant negative relationship with relative humidity (r= -0.67) and rainfall (r= -0.82) as well as a significant positive correlation with maximum temperatures (r= 0.72). Anandhi et al (2020) also found that *S. frugiperda* incidence was significant and positively correlated with maximum temperature at all locations, minimum temperatures exhibited no significant relationship and rainfall from had a negative and significant correlation, which goes against the current finding.

AUTHOR CONTRIBUTION STATEMENT

[1]S.S. and [2]N.S.B. conceived, designed research and conducted experiments. [1]S.S, [3]N, [4]N.Y. and [5]S.S. contributed to analytical tools. [1]S.S., [6]S.S. and [7]N.T. wrote the manuscript. All authors have read and approved the manuscript.

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