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Impact of Crop Phenology and Environmental Factors on Rice Leaf Folder Infestation in Middle Gangetic Plains of India

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Abstract: The present study was an attempt to examine the impact of crop growth stages and environmental factors on rice leaf folder infestation in middle Gangetic plains. Crop phenology was the most significant biotic factor influencing pest population density. Rice leaf folder infestation was highest during the crop's booting stage, with 11.15and 13.16 percent leaf damage per hill in *kharif* 2018-19 and 2019-20, respectively. During *kharif* 2018-19, the rice leaf folder infestation began in 31st SMW with 1.90 percent damaged leaves per hill and peaked at 38th SMW with 11.60 percent damaged leaves per hill In *kharif* 2019-20, pest infestation began in 31st SMW with 1.00 percent leaf damage per hill in the field and increased to a peak during the 39th SMW with 14.66± percent leaf damage per hill. The abiotic factors such as rainfall, morning relative humidity, average relative humidity and maximum temperature had a significant positive influence on rice leaf folder infestation. These findings could be used to create precise management strategies to keep pest infestation in the rice ecosystem below the economic threshold level.

Keywords: Rice, *Cnaphalocrocis medinalis*, Pest infestation, Crop phenology, Abiotic factors

In Asia's rice ecosystem, over 250 insect pests and 350 beneficial arthropod species have been recorded (Ali et al 2020). In India, out of more than 100 total insect pests, twenty insect pests species are considered economically important because they cause severe damage to rice production (Heinrichs et al 2017, Ali et al 2020). In the last two decades, rice crop yield losses have increased due to widespread outbreaks of certain insect pests of rice in the Indian subcontinent, among which rice leaf folder (*Cnaphalocrocis medinalis* Güenée) (Lepidoptera; Pyralidae) is the major one (Kumar et al 2023), which causes significant yield loss in India, China, and other Asian countries (Fahad et al 2021). Rice in yield losses of up to 20-30% in general (Sharma and Raju 2018) and under epidemic conditions yield losses can be up to 80% (Sachin et al 2023). Relied heavily on insecticides to manage rice insect pests, sometimes using indiscriminate doses of chemicals pesticides with similar modes of action, resulting in insecticide resistance, pest resurgence, outbreaks of secondary or minor insects, health hazards, environmental pollution, destruction of natural enemies and beneficial fauna of the rice ecosystem, and so on (Möhring et al 2020, Ali et al 2021).

The relationship between the insect pest and its host is an important factor in determining whether the insect develops and reproduces. On the other hand, the plant's susceptibility to insect attacks is determined by its chemical constituents and morphological features (Faruq et al 2018). Thus, selecting a stage-specific pest management strategy is an important step in pest management because pest-host interactions determine the species level of infestation and crop stage. Climate variables are also recognised as significant factors in the abundance and distribution of insects (Lantschner et al 2024). Regular observations of pest populations in the field useful to determine the incidence of insect pests in relation to several environmental factors such as rainfall, relative humidity, temperature, wind direction, and sunshine hour also helps to investigate the impact on the rise and fall of insect populations, as well as their survival, growth, multiplicative potential, and tritrophic interactions (Tomar 2010, Yang et al 2024). It is also useful in the development of prediction and forecasting models, which could help in a decision support system for plant infestation and pest dynamics is used to ensure timely pest management preparation and crop losses are avoided (Sharma et al 2018). With these considerations in mind designed study to show the incidence pattern of rice leaf folder in relation to crop growth stages and weather variables over two consecutive *kharif* seasons, 2018-19 and 2019-20.

MATERIAL AND METHODS

Pure seeds of the test variety (cv. Swarna sub-1) were procured from the University's Agricultural Research Farm (24° 56' N to 25° 35' N latitude and 82° 14' E to 83° 24' E longitude) and sown in nursery beds on the 5th and 9th of July in *kharif* 2018-19 and 2019-20, respectively. Twenty-one-day-old seedlings were transplanted at a rate of 2-3 seedlings per hill on a 50-square-meter plot in four replications. All recommended agronomic practises were implemented. Throughout the experiment, no plant protection measures were used for any of the insect pests.

Rice leaf folder infestation was recorded in unprotected plot at 7-day intervals beginning with the first occurrence or initiation of pest infestation and continuing until crop maturity. The observations were made by counting the number of damaged and total leaves on 10 randomly selected hills in each replication. Meteorological data (temperature, relative humidity, precipitation, wind speed, and sunshine time) were collected concurrently from the meteorological observatory at the Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi.

The effect of abiotic factors on rice leaf folder infestation was assessed using Pearson's correlation test. The same test was used to compare the infestation of rice leaf folder at the phenological stages of the plant (seedling, tillering, booting, flowering, and ripening) in both cropping years. Means were compared using Tukey's test ($p < 0.05$) using SPSS Pearson's correlation and Tukey tests (Version 27).

RESULTS AND DISCUSSION

Impact of crop phenology on the infestation of rice leaf folder: The phenological stages of rice plants had a significant impact on rice leaf folder infestation. During *kharif* 2018-19, larvae feeding on different stage plant leaves showed effects of crop growth stages (Table 1). All rice-growing stages had a significant impact on rice leaf folder damage. There were no damaged leaves found on the plant during its seedling stage. The crop's booting stage had the highest percentage of damaged leaves (11.15 percent per hill), followed by the tillering stage (6.95 percent per hill) and did not differ significantly from the flowering stage (6.86 percent per hill).

Table 1. Infestation of rice leaf folder during different phenological stages of rice (*Kharif* 2018-19 and 2019-20)

Phenological stage	Rice leaf folder infestation (% leaf damage)	
	Kharif 2018-2019	*Kharif* 2019-20
Seedling	0.00[c]	0.00[c]
Tillering	6.95[b]	7.66[b]
Booting	11.15[a]	13.16[a]
Flowering	6.86[b]	8.77[b]
Ripening	2.50[c]	1.83[c]
$F_{(4/15)}$	57.78	51.66

Mean followed by the same alphabets in columns were not statistically different by the Tukey test ($p < 0.05$)

The crop experienced the least damage during the ripening stage (2.50 % damaged leaves per hill). Similar results were observed in *kharif* 2019-20 and leaf damage caused by the rice leaf folder differed significantly along all rice growing stages (Table 1). The booting stage had the most damaged leaves (13.16percent per hill), followed by the flowering stage, which was not significantly different from the crop's tillering stage. The crop showed minimal damage during the ripening stage (1.83± percent damaged leaves per hill), with no damaging symptoms observed during the seedling stage.

The pest infestation began in rice fields during the early tillering stage, and the population was expected to grow gradually over generations. The highest infestation of rice leaf folder occurred during the crop's booting stage. The leaf folder infestation was more detrimental at the grain filling stage. Chakraborty and Deb (2011) also observed the most leaf folder damage during the crop's maximum tillering stage. The leaf folders consumed the majority of leaf mass when feeding on crop booting stage leaves. Previous studies reveal that the abundance of chemical compounds in leaves changes with the rice growth stage (Sun et al 2013), particularly, the nitrogen content was highest in the leaves of the plants during the tillering and booting stages (Chang et al 2018). The high nitrogen nutritional level of tillering and booting stage leaves, combined with increased consumption of these leaves by rice leaf folder larvae, may have contributed to their superior performance. Although secondary metabolites in rice change dramatically during development (Hu et al 2016). Sharma et al (2023) also observed that the tillering and booting stages of the rice crop are more susceptible to pest infestation. Thus, crop growth stages significantly influenced rice leaf folder infestation.

Impact of weather variables on the infestation of rice leaf folder: Rice leaf folder infestations ranged from 1.90 percent damaged leaves per in first week of August (31^{st} SMW) to 11.60 percent damaged leaves per in third week of September (38^{th} SMW) during *kharif* 2018-19 (Table 2). The rice leaf folder infestation began and reached its peak infestation after that, the percentage of damaged leaves steadily decreased, eventually reaching zero when the crop reached maturity (Figure 1). In *kharif* 2019–20, rice leaf folder infestations ranged from 1.00 percent damaged leaves per hill in the first week of August (31^{st} SMW) to 14.66 percent damaged leaves per hill in the fourth week of September (39^{th} SMW) (Table 3). The rice leaf folder infestation began and reached its peak, after that infestation gradually decreased and reached zero levels at the harvesting stage of the crop (Fig. 1). The incidence of the leaf folder was slightly higher during the second-year trial, which could be attributed to seasonal differences between years.

Earlier, studies on the rice leaf folder, *C. medinalis* revealed that the infestation began during the 31st SMW and reached peak infestation in the 37th SMW (Nirala et al 2015). However, Vanitha et al (2015) observed that the peak of rice leaf folder activity occurred between August and September, and then declined from October onward, whereas Rasul et al. (2019) confirmed that peak population of *C. medinalis* occurred during the fourth week of September. Shyamrao and Raghuraman (2019) also observed maximum damage at tillering stage. Chatterjee et al (2021) reported *C. medinalis* activity beginning in the second week of August and remaining low to moderate throughout the tillering stage. The infestation increased in October and peaked at the end of the month. The slight variation that could be attributed to location changes, but they confirm the similar seasonal occurrence pattern. These reports strongly support the current finding.

The correlation co-efficient study during *kharif* 2018-19 and 2019-20 (Table 4), the pooled data revealed that maximum temperature (r = 0.527), morning relative humidity (r = 0.465), average relative humidity (r = 0.541) all had significant positive relationship with *C. medinalis* infestation and evening relative humidity (r = 0.278), sunshine hours (r = 0.182) had non-significant positive relationship with *C. medinalis* infestation. While, rainfall had significant negative (r = - 0.501) and minimum temperature non-significant negative (r = - 0.255) association with the infestation of *C. medinalis.* Increase in leaf folder infestation was associated to rising temperatures and morning relative humidity. This could support the finding that warming conditions caused by global climate change have a significant impact on the abundance of

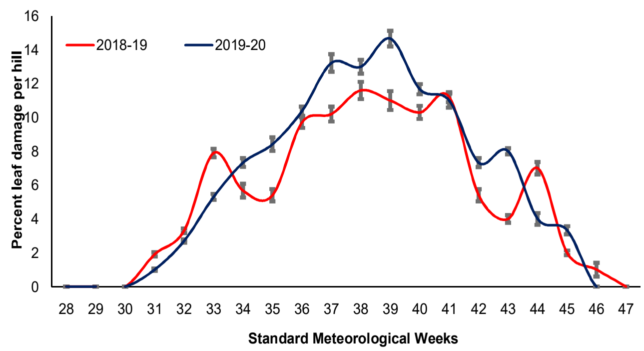

Fig. 1. Fluctuation of rice leaf folder infestation during *kharif* 2018-19 and 2019-20 (from 28th to 47th SMW). Standard errors are indicated (n = 10)

Table 2. Influence of abiotic factors on the rice leaf folder infestation during *kharif* 2018-2019

SMW	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
28	11.60	35.50	26.00	30.75	83.00	58.00	70.50	7.80	0.00±0.00
29	78.40	33.30	25.40	29.35	86.00	66.00	76.00	4.90	0.00±0.00
30	91.40	28.40	23.60	26.00	88.00	87.00	87.50	0.30	0.00±0.00
31	86.80	28.10	22.80	25.45	93.00	88.00	90.50	0.10	1.90±0.12
32	26.60	31.80	24.70	28.25	92.00	77.00	84.50	4.80	3.30±0.13
33	20.40	33.30	25.30	29.30	88.00	70.00	79.00	5.90	7.90±0.25
34	154.80	31.10	24.00	27.55	91.00	81.00	86.00	2.60	5.67±0.40
35	118.40	32.00	24.30	28.15	93.00	77.00	85.00	4.40	5.40±0.36
36	94.60	30.60	23.60	27.10	91.00	79.00	85.00	4.70	9.70±0.31
37	0.00	32.40	23.60	28.00	88.00	68.00	78.00	7.80	10.20±0.44
38	53.40	32.50	22.80	27.65	88.00	65.00	76.50	6.80	11.60±0.51
39	0.00	33.40	25.90	29.65	92.00	63.00	77.50	8.50	11.00±0.55
40	0.00	34.20	20.80	27.50	83.00	51.00	67.00	9.10	10.30±0.38
41	0.00	31.00	20.00	25.50	89.00	61.00	75.00	6.00	11.20±0.29
42	0.00	33.40	16.50	24.95	84.00	40.00	62.00	9.60	5.40±0.36
43	0.00	31.50	14.40	22.95	89.00	41.00	65.00	9.10	4.00±0.22
44	0.00	31.10	16.70	23.90	91.00	48.00	69.50	8.70	7.00±0.36
45	0.00	28.20	12.20	20.20	87.00	44.00	65.50	7.70	2.00±0.13
46	0.00	29.00	11.70	20.35	89.00	45.00	67.00	7.90	1.00±0.16
47	0.00	27.90	10.10	19.00	88.00	44.00	66.00	8.70	0.00±0.00

Note: SMW (Standard Meteorological Week), RF (Rainfall, mm), T_{max} (Maximum temperature °C), T_{min} (Minimum temperature °C), T_{avg} (Average temperature °C), RH_M (Morning relative humidity, %), RH_E (Evening relative humidity, %), RH_A (Average relative humidity, %), SSH (Sunshine hours), RLF (Rice leaf folder, % incidence per hills) insect pest species (Ali et al. 2019). Kumar et al. (2023) also observed that relative humidity was positively correlated with rice leaf folder damage. Shyamrao and Raghuraman (2019) found a significant positive correlation between leaf folder population and maximum temperature, as well as a highly significant negative correlation with rainfall. Rasul et al. (2019) reported that average temperature had a negative effect on leaf folder population while relative humidity and rainfall had a positive effect on *C. medinalis* prevalence. Zainab et al. (2017) found that the rice leaf folder significantly and negatively correlated with mean temperature, but positively correlated with mean relative humidity and rainfall. Other parameters did not have a significant positive or negative relationship with the leaf folder population

Table 3. Influence of abiotic factors on the rice leaf folder infestation during *kharif* 2019-2020

SMW	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
28	194.80	31.40	22.80	27.10	87.00	76.00	81.50	5.30	0.00±0.00
29	0.00	36.40	25.10	30.75	82.00	54.00	68.00	0.50	0.00±0.00
30	25.80	31.90	23.50	27.70	89.00	72.00	80.50	1.90	0.00±0.00
31	2.00	32.30	23.80	28.05	85.00	72.00	78.50	4.40	1.00±0.08
32	61.00	31.00	23.20	27.10	89.00	79.00	84.00	4.50	2.70±0.11
33	56.90	32.80	23.10	27.95	89.00	74.00	81.50	2.40	5.30±0.18
34	115.40	31.20	21.70	26.45	94.00	80.00	87.00	4.70	7.33±0.26
35	11.40	34.20	24.60	29.40	90.00	69.00	79.50	5.10	8.42±0.40
36	11.60	32.10	24.00	28.05	87.00	77.00	82.00	3.10	10.37±0.27
37	48.20	33.20	23.30	28.25	89.00	71.00	80.00	2.90	13.22±0.52
38	164.00	30.80	21.60	26.20	93.00	82.00	87.50	2.70	13.00±0.41
39	532.20	27.80	20.40	24.10	95.00	87.00	91.00	2.30	14.66±0.46
40	39.00	30.00	20.40	25.20	94.00	78.00	86.00	5.80	11.67±0.30
41	0.00	32.20	19.20	25.70	91.00	59.00	75.00	6.50	11.00±0.42
42	3.80	29.60	19.10	24.35	91.00	68.00	79.50	8.70	7.33±0.27
43	0.00	28.50	17.20	22.85	84.00	60.00	72.00	7.70	8.00±0.18
44	0.00	30.20	16.60	23.40	92.00	62.00	77.00	8.00	4.00±0.35
45	0.00	29.50	14.20	21.85	91.00	56.00	73.50	3.90	3.33±0.24
46	0.00	29.00	11.20	20.10	90.00	41.00	65.50	6.60	0.00±0.00
47	0.00	27.30	11.30	19.30	90.00	52.00	71.00	4.70	0.00±0.00

See Table 2 for details

Table 4. Correlation matrix (Pearson's) for weather-based observations with rice leaf folder infestation in rice ecosystem during pool data (*Kharif* 2018-19 and 2019-20)

Variables	RF	T_{max}	T_{min}	T_{avg}	RH_M	RH_E	RH_A	SSH	RLF
RF	1	0.173	0.504^{*}	0.437	0.442	0.588^{**}	0.625^{**}	-0.330	-0.501^{*}
T_{max}		1	0.779^{**}	0.871^{**}	-0.340	0.387	0.301	-0.219	0.527^{*}
T_{min}			1.000	0.983^{**}	-0.029	0.864^{**}	0.799^{**}	-0.631^{**}	-0.255
T_{avg}				1.000	-0.121	0.773^{**}	0.698^{**}	-0.566^{**}	0.252
RH_M					1.000	0.313	0.468^{*}	-0.034	0.465^{*}
RH_E						1.000	0.986^{**}	-0.726^{**}	0.278
RH_A							1.000	-0.681^{**}	0.541^{*}
SSH								1.000	0.182
RLF									1.000

'*' Significant correlation at $P< 0.05$ and data followed by '**' significant correlation at $P< 0.01$

Note: RF (Rainfall, mm), T_{max} (Maximum temperature °C), T_{min} (Minimum temperature °C), T_{avg} (Average temperature °C), RH_M (Morning relative humidity, %), RH_E (Evening relative humidity), RH_A (Average relative humidity), SSH (Sunshine hours), RLF (Rice leaf folder infestation)

CONCLUSION

The population of rice leaf folder were observed at the start of the season, from the early tillering stage, and peaked at booting stage of crop with more or less population fluctuation until the rice crop matured. Among the abiotic factors, morning temperature, evening relative humidity, average relative humidity and rainfall had a significant impact on rice leaf folder infestation in rice ecosystems. Pest population dynamics and crop phenology are critical factors in implementing management strategies in the rice ecosystem. It can be used to create a prediction and forecasting model that will help understand infestation and pest dynamics in rice fields, as well as ensure readiness to deal with pest problems quickly while avoiding crop losses.

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