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Research Article

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POPULATION FLUCTUATIONS OF FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*) AND PHYSIOMORPHIC CHARACTERIZATION OF MAIZE VARIETIES CULTIVATED UNDER FIELD CONDITIONS IN PUNJAB-PAKISTAN

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ABSTRACT

Fall Armyworm, *Spodoptera frugiperda*, the most notorious insect pest of maize, has led to major crop losses globally. The experiment was conducted to study the impact of three maize varieties on *S. frugiperda* populations and their losses assessment. The results revealed that variety YH-1898 had highest germination rate, larval infestation, pupal density, number of tassels, total grain yield, (84.06±2.14%), (15.41±0.61 larvae/plant), (12.44±0.93 tassels/plant) and (9324.71±266.63 kg/acre) from standard week-03 to standard week-23, 2023 respectively. The variety, FH-2313 was found to be the tallest with plant height, leaf area index, leaf and node count, and internodal distance (67.13±3.71 cm), (70.96±3.97 cm^2), (11.44±0.44 leaves/plant), (11.44±0.44 nodes/plant) and (4.33±0.22 cm) respectively. *S. frugiperda* females deposited 66.13±2.07 eggs/plant with grain yield 6434.06±361.84 kg/acre. Correlation between environmental factors and *S. frugiperda* population elucidated a positive impact with maximum and minimum temperature (0.766 and 0.679) and negative with relative humidity during morning and evening (0.790 and 0.525).

Keywords: Biotic stress, Infestation, Maize, Environmental conditions, Physiomorphic Characters, Correlation, *Spodoptera frugiperda.*

INTRODUCTION

Maize or corn (*Zea mays* L.) is a third important annual cereal monocotyledonous food crop of the world belonging to the family Poaceae. In Pakistan, total area under maize was 1.016 million acre with the production of 3.037 million tons with average grain yield 2,864 kg/acre during 2019-2020 which was the highest among the cultivated cereal crops (Abid *et al*., 2020). However, the cultivation area increased over the last few years, with production declined in the country. This yield reduction is attributed to several factors, dominated by the attack of insect pests (Fall armyworms, cutworms, earworms, stem borers, grain moths, beetles, rootworms, wireworms, grubs, grain borers and weevils). These insect pests not only deteriorates the quality but also causes huge yield losses if not properly managed. Maize stem borer and fall armyworm are major maize insects in Pakistan, which reduce yield about 21-53% (Ahmad *et al*., 2021). Management strategies against Fall armyworm, *Spodoptera frugiperda* include the application of insecticides, cultural practices, use of natural enemies and cultivation of resistant cultivars Yigezu and Wakgari, 2020; Abbas *et al*., 2022). Insecticides like Chlorpyrifos, Sulprofos and Thiodicarb insecticides with new chemistry have proved to be effective against *S. frugiperda* in different areas with synthetic pyrethroids as an erratic control of the larvae. Spray applications proved to be the most effective when high volumes of aqueous carriers were used with either ground, chemigation or air equipment. Ground equipment with the higher water rates provide higher levels of insect control (Grewal 2002). *S. frugiperda* population peaks in maize appear from April to December but some are found even during the winter months. *S. frugiperda* larvae can attack maize at all growth stages. In the scenario of climate change, Fall Armyworm, *S. frugiperda* found well adapted to a diversified agrometeorological condition (Bailey *et al*., 2007).

Yield losses are extended if the population of *S. frugiperda* is not controlled at early stages. To suppress the population of *S. frugiperda* blending of a number of control interventions are desired that are economically sound and environmentally compatible (Tendeng *et al*., 2019; Matova *et al*., 2020). The sporadic nature, development of insecticide resistance and worldwide adaptability of *S. frugiperda* have made it very difficult to control to reduce yield losses. Integrated pest management (IPM) practices show their impact if implement when the population of *S. frugiperda* is started to establish in the field.

S. frugiperda has four life stages, larvae is the most damaging stage (Capinera, 2002; Kenis *et al*., 2022). The adults mate at night and females lay up to 1,000 eggs. Freshly laid eggs are pearly green in color and darken to a brown color in about 12 hours. The eggs are hatched in 2-4 days. The larvae pass through 5-6 instars within 14-22 days and then pupate (Johnson 1987; Kalleshwaraswamy *et al*., 2018; Jing *et al*., 2021). During its larval development the larvae cause severe damage reducing yield up to 70-80% (Ghooshchi *et al*., 2008; Baudron *et al*., 2019; Maruthadurai and Ramesh, 2020). To devise a concrete management strategy it is required to identify all life stages and critical crop stage attacks. Keeping in view the significance of the potential yield losses and broad host range, the present research was conducted to determine the yield losses, physiomorphic characteristics, population infesting three maize varieties and correlation with prevailing weather conditions.

MATERIAL AND METHODS

Location: The study was conducted at Maize Research Institute (MRI), and Entomological Research Institute (ERI), Ayub Agricultural Research Institute, (AARI), Faisalabad. Three maize varieties viz., TH-5427, YH-1898 and FH-2313 were sown in field, 31º 23′ 57 ″ N and 73º 03′ 16″ E, on SW-06 at MRI, Faisalabad under randomized complete block design (RCBD). Each variety was sown in three blocks (0.25 acres/ block) with all standard agronomic practices except the application of insecticide for the control of Fall Armyworm, *Spodoptera frugiperda* (Rukundo *et al*., 2020). The data regarding percentage germination was recorded three times during SW-08 to SW-10 (Mathews and Khajeh, 2006; Florez *et al*., 2007; Taye *et al*., 2013). Laboratory research work was executed in the Insect Molecular Laboratory (IML) at ERI, Faisalabad.

Fieldwork: The population of *S. frugiperda* (eggs, larvae and pupae) was recorded from each block through diagonal walking in the field. Nine plants per block showing the symptoms of *S. frugiperda* infestation were randomly selected. Number of eggs (egg mass collected and counted in laboratory), larvae and pupae were collected, brought in laboratory and recorded (Horikoshi *et al*., 2021; Niassy *et al*., 2021). The eggs were kept in plastic boxes, incubated; first instar larvae were provided with freshly collected maize leaves and pupae in glass petri dishes for laboratory culture of *S. frugiperda*. The data of *S. frugiperda* population (eggs, larvae and pupae) was recorded after one month from date of sowing (DOS) till harvest at one week intervals.

Other parameters like physiomorphic characteristics (chlorophyll content, leaf area index, plant height/number of nodes/internodal distance/number of leaves/number of tassels, and total grain yield/average grain weight per ear/total grain weight per plant/average grain yield per acre) were also recorded (Kennedy and Storer, 2000; Shah *et al*., 2016; Skonieski *et al*., 2017). Leaf area index of the selected plants was recorded (SW-11-SW-23, during 2023) at one week intervals by leaf area meter (Model: Li-3000 C, LI-COR Biosciences) (Wihelm *et al*., 2000; Baez-Gonzalez *et al*., 2005; Nguy-Robertson *et al*., 2012; Gao *et al*., 2013).

Similarly, plant height (from the top soil layer to the plant apex) and internodal distance was measured by random selection of five plants per block with the help of meter stick at one week interval (SW-09-SW-23, during 2023) (Gilliot *et al*., 2021; Oehme *et al*., 2022; Qui *et al*., 2022). Other parameters like number of nodes, leaves, tassels, average grain yield per ear, per plant and per acre by simple counting and with electronic weighing balance (Model: JJ224BC, G&G, electronics Scale) respectively (Wu *et al*., 2020; Fang *et al*., 2022). Environmental data including temperature °C (maximum and minimum), relative humidity % (morning and evening) and rainfall (mm) was collected from Agro-met section, at Ayub Agricultural Research Institute, Faisalabad.

Laboratory Tasks: Five plants were randomly selected per block showing the symptoms of *S. frugiperda*. Three leaf samples from each plant (upper, middle and lower) were taken for the determination of chlorophyll contents (chlorophyll-a, chlorophyll-b and carotenoids) (Argenta *et al*., 2004; Ciganda *et al*., 2009; Nguy-Robertson *et al*., 2015). Coin sized leaf discs (0.1g) were approximately excised from leaves samples. Sterilized plastic vials of 50 ml (removable lids) were filled with 5 ml of ethanol; the leaf discs were placed in vials and lids were tightly closed. These vials were incubated for 24 hours at 25±2 °C and 65±5% relative humidity (Tait and Hik, 2003; Swarna Lakshmi *et al*., 2013). After 24 hours, the extracts were centrifuged at 10,000 rpm for 15 minutes at 4ºC and the supernatant was diluted with water (1:4 / water: ethanol). Diluted supernatant (2 ml) was pipetted into a cuvette and placed into a spectrophotometer (Model: T-80 UV/VIS Spectrometer, PG Instruments, Ltd.) to record optical density. The absorbance/ optical density was recorded at wavelengths of 663, 645 and 680 nanometers (nm), for chlorophyll-a, chlorophyll-b and carotenoids respectively (Ciganda *et al*., 2009; Dey *et al*., 2016; Liu *et al*., 2022; Richardson *et al*., 2002). Statistical analysis of the data of all the parameters was performed using computer based statistical software "Statistica" to check the significance, compare the means following post-hoc, correlation and regression results.

RESULTS AND DISCUSSION

Among the three tested varieties (TH-5427, YH-1898 and FH-2313), the highest germination was found in variety (YH-1898) and the lowest in variety (FH-2313) when observed for three weeks (SW-08 to SW-10, 2023). Irrespective of the varieties, the highest germination rate was found in SW-10, 2023 (table#1).

Table 1: Germination rate (%age) in different maize varieties under field conditions

Observation Dates	Germination rate (percentage) Mean±SE			
	V_1 (TH-5427)	V_2 (YH-1898)	V_3 (FH-2313)	Average
SW-08, 2023	73.30±1.91	78.87±2.94	66.63±1.93	**72.93±2.11c**
SW-09, 2023	81.10±1.10	86.67±3.33	72.17±2.94	**79.98±2.49b**
SW-10, 2023	84.40±1.10	86.63±3.84	79.97±1.39	**83.67±1.61a**
Average	**79.60±1.79b**	**84.06±2.14a**	**72.92±2.25c**	

The population of *Spodoptera frugiperda* (eggs, larvae and pupae) record revealed that the test variety, YH-1898 showed an egg deposition, larval infestation, and pupal density of 59.13±1.99, 15.41±0.61 and 0.10±0.02 (pupae per plant) during the cropping year 2023(from SW-08 to SW-22, 2023) respectively. While on the variety, TH-5427 showed the lowest response towards all biotic parameters (egg deposition, larval infestation and pupal density). Nevertheless, the pupal density on the other two varieties (TH-5427 and FH-2313) found to be statistically at par (table#2).

Irrespective of the varieties, maize crop was found to be immediately infected as the crop complete germination phase (three weeks after sowing) by the eggs, larvae and pupae of *S. frugiperda* which reach at peak (SW-21, SW-13 and 14 and SW-14, 2023) respectively.

The role of Physiomorphic characteristics in relation to biological infestation by *S. frugiperda* was determined. The results of the chlorophyll contents (chlorophyll-a, chlorophyll-b and carotenoids) were found to be statistically at par in all the three maize varieties. The results of contents (chlorophyll-a and chlorophyll-b) elucidated high level at the initial crop developmental stage (SW-09, 2023) then declined as the cropping season progressed (lowest during SW-21, 2023) in all the three test varieties respectively. Contrarily, the carotenoids contents increased over time from minimum to maximum during SW-09 to SW-21, 2023 accordingly (table#3).

Considering the crop phenology, the variety FH-2313 remained at the top with highest leaf area index, plant height, number of nodes, internodal distance and number of leaves (table#4 and table#5).

The variety YH-1898 produced maximum number of tassels with average grain weight per year, per plant and per acre 219.10±0.45, 511.23±14.70 and 9324.71±266.63 respectively. Nevertheless, the variety FH-2313, produced minimum 10.96±0.82 tassels per plant with 139.44±6.01 average grain weight (per ear, per plant and per acre), 362.28±19.82 and 6434.06±361.48, respectively (table#6).

The correlation analysis results between the absolute population of *S. frugiperda* (egg densities, larval infestation, pupal density) and the environmental factors including temperature (maximum and minimum) and relative humidity (morning and evening) indicated a positive correlation with temperature (0.766 and 0.679) and negative with relative humidity (- 0.790 and -0.525) respectively (table#7).

Likewise, the regression analysis between the biotic factors (population of *S. frugiperda*) and the environmental variables revealed the highest contribution (54.83%) is attributed to temperature (maximum) and the least (2.23%) by relative humidity (morning) (table#8).

Table. 2: Population dynamics of fall armyworm (*Spodoptera frugiperda*) recorded on different maize varieties under field conditions.

Observation dates	Egg density				Larval infestation				Pupal density			
	TH-5427	**YH-1898**	**FH-2313**	**Average**	**TH-5427**	**YH-1898**	**FH-2313**	**Average**	**TH-5427**	**YH-1898**	**FH-2313**	**Average**
SW-08, 2023	4.56±1.87	6.00±1.87	9.50±1.68	6.69±1.06p	0.28±0.11	0.44±0.12	0.33±0.14	0.35±0.07m	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00h
SW-09, 2023	15.67±0.58	16.06±0.93	18.11±0.30	16.61±0.40o	2.67±0.21	1.89±0.14	1.67±0.16	2.07±0.10l	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00h
SW-10, 2023	17.50±0.55	24.39±0.79	26.39±0.39	22.76±0.62n	7.50±0.27	3.22±0.13	2.78±0.19	4.50±0.31k	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00h
SW-11, 2023	35.11±1.01	32.11±0.47	33.83±0.51	33.69±0.43m	13.39±0.3	4.83±0.17	4.94±0.15	7.72±0.56j	0.00±0.00	0.06±0.06	0.00±0.00	0.02±0.02g
SW-12, 2023	41.00±1.29	38.06±0.38	37.94±0.71	39.00±0.53l	14.67±0.3	7.39±0.22	6.61±0.22	9.56±0.11i	0.00±0.00	0.06±0.06	0.00±0.00	0.02±0.02g
SW-13, 2023	58.83±1.03	43.89±0.44	44.33±0.95	49.02±1.07k	18.06±0.2	9.50±0.19	8.00±0.18	11.85±0.62h	0.00±0.00	0.11±0.08	0.06±0.06	0.06±0.03f
SW-14, 2023	68.39±0.45	50.72±0.47	57.28±0.77	58.80±1.05j	21.28±0.3	15.94±0.19	9.61±0.18	15.61±0.67g	0.06±0.06	0.17±0.09	0.11±0.08	0.11±0.04d
SW-15, 2023	74.06±0.89	58.06±0.36	80.61±1.09	70.91±1.38i	24.11±0.3	12.67±0.24	13.94±0.26	16.91±0.72f	0.06±0.06	0.11±0.08	0.11±0.08	0.09±0.04e
SW-16, 2023	83.06±0.98	63.50±0.55	95.06±0.59	80.54±1.83g	28.06±0.2	18.61±0.22	24.89±0.33	23.85±0.56c	0.17±0.09	0.11±0.08	0.06±0.06	0.11±0.04d
SW-17, 2023	79.44±0.78	70.28±0.58	101.72±2.15	83.81±1.97f	24.50±0.2	23.11±0.28	27.56±0.58	25.06±0.34a	0.11±0.08	0.17±0.09	0.17±0.09	0.15±0.05b
SW-18, 2023	74.44±0.73	76.72±0.64	107.50±1.90	86.22±2.18d	21.50±0.3	25.83±0.34	28.83±0.23	25.39±0.45a	0.17±0.09	0.11±0.08	0.22±0.10	0.17±0.05a
SW-19, 2023	73.28±0.96	85.00±0.81	99.06±1.90	85.78±1.63e	18.50±0.2	28.11±0.21	27.89±0.28	24.83±0.63b	0.11±0.08	0.11±0.08	0.11±0.08	0.11±0.04d
SW-20, 2023	76.11±1.18	96.06±0.79	95.22±1.54	89.13±1.44c	16.11±0.2	28.50±0.28	26.56±0.37	23.72±0.77c	0.11±0.08	0.17±0.09	0.11±0.08	0.13±0.05c
SW-21, 2023	77.11±1.11	109.44±2.03	97.06±1.08	94.54±2.10a	13.39±0.2	28.11±0.24	25.67±0.30	22.39±0.90d	0.17±0.09	0.17±0.09	0.06±0.06	0.13±0.05c
SW-22, 2023	66.67±1.71	116.67±1.63	88.28±1.29	90.54±2.95b	13.17±0.4	23.06±0.38	24.11±0.39	20.11±0.71e	0.06±0.06	0.11±0.08	0.00±0.00	0.06±0.03f
Average	56.35±1.58c	59.13±1.99b	66.13±2.07a		15.11±0.40c	15.41±0.61a	15.26±0.66b		0.07±0.02b	0.10±0.02a	0.07±0.02b	

Table. 3: A-Biotic characteristics (chlorophyll contents) of maize varieties

Observation Dates	Chlorophyll-a (mg/g of fresh leaf weight)				Chlorophyll-b (mg/g of fresh leaf weight)				Carotenoids (mg/g of fresh leaf weight)			
	TH-5427	**YH-1898**	**FH-2313**	**Average**	**TH-5427**	**YH-1898**	**FH-2313**	**Average**	**TH-5427**	**YH-1898**	**FH-2313**	**Average**
SW-09, 2023	0.70±0.02	0.66±0.02	0.68±0.02	0.68±0.01a	0.65±0.02	0.54±0.01	0.59±0.01	0.59±0.01a	0.61±0.01	0.60±0.03	0.56±0.01	0.59±0.01c
SW-13, 2023	0.52±0.01	0.47±0.02	0.38±0.02	0.46±0.01b	0.32±0.01	0.28±0.01	0.28±0.01	0.29±0.01b	1.14±0.06	1.12±0.09	1.07±0.05	1.11±0.04b
SW-17, 2023	0.09±0.03	0.18±0.04	0.15±0.03	0.14±0.02c	0.12±0.02	0.16±0.02	0.14±0.02	0.14±0.01c	1.56±0.10	1.47±0.10	1.54±0.05	1.52±0.05b
SW-21, 2023	0.07±0.02	0.12±0.02	0.11±0.02	0.10±0.01c	0.08±0.01	0.12±0.01	0.09±0.01	0.09±0.01d	2.64±0.18	2.72±0.22	2.62±0.11	2.66±0.10a
Average	0.35±0.04a	0.36±0.03a	0.33±0.03a		0.29±0.03a	0.27±0.02a	0.27±0.03a		1.49±0.11a	1.48±0.12a	1.45±0.10a	

Table.4: Summary of phonological characteristics (leaf area index, plant height and number of nodes) of maize varieties

Observation Dates	Leaf area index				Plant Height				Number of Nodes			
	TH-5427	YH-1898	FH-2313	Average	TH-5427	YH-1898	FH-2313	Average	TH-5427	YH-1898	FH-2313	Average
SW-09, 2023	3.84±0.15	4.73±0.18	5.18±0.24	4.58±0.14	4.27±0.12	4.80±0.11	5.27±0.12	4.78±0.09	3.47±0.13	3.73±0.15	4.27±0.21	3.82±0.11
SW-11, 2023	10.59±0.32	12.36±0.38	21.50±0.99	14.82±0.81	14.60±0.13	16.67±0.13	19.27±0.12	16.84±0.30	4.73±0.12	5.00±0.10	5.47±0.13	5.07±0.08
SW-13, 2023	17.38±0.37	25.21±0.52	37.50±1.22	26.70±1.33	29.20±0.14	34.47±0.19	37.13±0.13	33.60±0.50	6.47±0.13	6.93±0.18	7.80±0.17	7.07±0.12
SW-15, 2023	34.37±1.21	37.73±1.16	69.13±2.05	47.08±2.51	45.53±0.13	52.00±0.32	60.40±0.39	52.64±0.93	9.60±0.35	9.20±0.24	11.40±0.31	10.07±0.2
SW-17, 2023	54.30±2.01	69.13±2.05	90.05±2.72	71.16±2.56	50.53±0.53	62.00±0.82	86.07±0.45	66.20±2.26	10.80±0.37	12.93±0.2	13.60±0.35	12.44±0.2
SW-19, 2023	68.48±2.71	85.04±3.52	101.06±2.69	84.86±2.62	56.67±1.13	72.40±0.75	97.40±0.42	75.49±2.57	12.47±0.48	15.60±0.5	15.93±0.32	14.67±0.3
SW-21, 2023	83.26±4.07	96.60±4.01	110.97±1.90	96.94±2.60	60.20±0.47	82.27±0.51	115.60±1.1	86.02±3.46	12.67±0.42	15.80±0.4	16.47±0.22	14.98±0.3
SW-23, 2023	96.09±4.23	109.40±3.3	132.30±2.61	112.59±2.9	60.67±0.36	82.33±0.49	115.87±1.0	86.29±3.45	12.67±0.42	15.93±0.4	16.60±0.21	15.07±0.3
Average	46.04±3.10c	55.02±3.54b	70.96±3.97a		40.21±1.87c	50.87±2.54b	67.13±3.71a		9.11±0.34c	10.64±0.4b	11.44±0.44a	

Table. 5: Summary of phonological characteristics (internodal distance, number of leaves, and number of tassels) of maize varieties

Observation Dates	Internodal distance				Number of leaves				Number of Tassels			
	TH-5427	YH-1898	FH-2313	Average	TH-5427	YH-1898	FH-2313	Average	TH-5427	YH-1898	FH-2313	Average
SW-09, 2023	0.27±0.02	0.37±0.01	0.42±0.01	0.35±0.01	3.47±0.13	3.73±0.15	4.27±0.21	3.82±0.11	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
SW-11, 2023	0.85±0.02	1.15±0.04	1.11±0.03	1.04±0.03	4.73±0.12	5.00±0.10	5.47±0.13	5.07±0.08	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
SW-13, 2023	1.69±0.07	2.45±0.11	2.89±0.05	2.34±0.09	6.47±0.13	6.93±0.18	7.80±0.17	7.07±0.12	4.40±0.24	3.87±0.17	4.47±0.13	4.24±0.11
SW-15, 2023	2.74±0.11	4.17±0.16	4.83±0.06	3.92±0.15	9.60±0.35	9.20±0.24	11.40±0.31	10.07±0.2	7.53±0.13	7.73±0.12	7.87±0.13	7.71±0.08
SW-17, 2023	3.53±0.13	5.40±0.13	5.80±0.11	4.91±0.16	10.80±0.37	12.93±0.27	13.60±0.35	12.44±0.2	17.27±0.94	17.00±0.43	12.20±0.38	15.49±0.50
SW-19, 2023	3.85±0.13	5.85±0.12	6.35±0.03	5.35±0.17	12.47±0.48	15.60±0.50	15.93±0.32	14.67±0.3	19.40±1.09	22.20±0.61	16.87±0.46	19.49±0.54
SW-21, 2023	4.23±0.08	6.15±0.08	6.55±0.01	5.64±0.16	12.67±0.42	15.80±0.43	16.47±0.22	14.98±0.3	20.20±0.86	24.07±0.37	21.40±0.51	21.89±0.42
SW-23, 2023	4.69±0.09	6.23±0.07	6.67±0.01	5.86±0.13	12.67±0.42	15.93±0.41	16.60±0.21	15.07±0.3	20.20±0.86	24.67±0.37	24.87±0.32	23.24±0.46
Average	2.73±0.14c	3.97±0.20b	4.33±0.22a		9.11±0.34c	10.64±0.45b	11.44±0.44a		11.13±0.81b	12.44±0.93a	10.96±0.82c	

Table. 6: Final grain yield of different maize varieties grown under field conditions

Varieties	Total Grain yield		
	Average grain weight per ear	Average grain yield per plant	Average grain yield per acre
TH-5427	258.43±0.31	447.97±17.28	8323.98±325.35b
YH-1898	219.10±0.45	511.23±14.70	9324.71±266.63a
FH-2313	139.44±6.01	362.28±19.82	6434.06±361.48c
Average	205.66±17.59c	440.49±23.28b	8027.58±453.00a

Table. 7: Correlation between weather and population of *Spodoptera frugiperda*

Environmental Factors	Egg density		Larval infestation		Pupal density		Absolute population of S. frugiperda	
	Correlation Coefficient (r)	P-value	Correlation Coefficient (r)	P-value	Correlation Coefficient (r)	P-value	Correlation Coefficient (r)	P-value
Temperature (Max.)	0.764	0.001*	0.741	0.002*	0.692	0.004*	0.766	0.001*
Temperature (Min.)	0.709	0.003*	0.570	0.027^{NS}	0.418	0.121^{NS}	0.679	0.005*
Relative Humidity Morning (%)	-0.802	0.000*	-0.736	0.002*	-0.666	0.007^{NS}	-0.790	0.000*
Relative Humidity Evening (%)	-0.541	0.037^{NS}	-0.463	0.082^{NS}	-0.429	0.111^{NS}	-0.525	0.044*
Rainfall (mm)	-0.176	0.531^{NS}	-0.134	0.634^{NS}	-0.196	0.484^{NS}	-0.167	0.552^{NS}

Table. 8: Regression analysis of environmental factors and population of *Spodoptera frugiperda* on different maize varieties

Environmental Factors	Egg density		Larval infestation		Pupal density		Absolute population	
	Coefficient of determination (R^2)	Individual role (%)	Coefficient of determination (R^2)	Individual role (%)	Coefficient of determination (R^2)	Individual role (%)	Coefficient of determination (R^2)	Individual role (%)
Temperature °C(maximum)	55.12	55.12	51.51	51.51	43.93	43.93	54.83	54.83
Temperature °C(minimum)	61.23	6.11	49.41	2.10	39.34	4.59	58.59	3.76
Relative humidity%(morning)	58.96	2.27	47.33	2.08	40.59	1.25	56.36	2.23
Relative humidity%(evening)	78.30	19.34	68.98	21.47	51.64	11.05	76.43	20.07
Rainfall (mm)	80.25	1.95	70.66	1.68	47.33	4.31	78.38	1.95

Hence, the highest/upper temperature range is the key determinant for the development of *S. frugiperda* population under field conditions.

Crop phenology of three maize varieties (TH-5427, YH-1898 and FH-2313) in relation to biotic stress caused by the infestation of *S. frugiperda* and abiotic variables (environmental factors) revealed that a broad germination rate (%) in the test varieties during SW-08 to SW-10, 2023. These results conform to those reported by Ahammad *et al*., (2014) and Raikar *et al*., (2012) who determined the germination rate in the range 60-84.00% and 90.65% from SW-01 to SW-06, 2014 in a number of maize varieties respectively. Similar results for enhanced germination rates, seedling biomass and seed yields were obtained by Tian *et al*., (2014) who performed seed priming with different concentrations of priming solutions in maize crops.

Among the test varieties, FH-2313 showed highest biomass in terms of plant height, number of leaves and other phonological parameters of this maize variety. It can be presumed that it caught maximum eggs of the *S. frugiperda* with peak during SW-18, 2023 due to the high biomass contents of this variety. Regardless of the cropping phase, this variety ranked second for susceptibility toward larvae infestation and pupal density. These findings contradict those elaborated by Durocher et al., (2021) and Mallapur et al., (2018) who recorded larvae infestation range (16-18 and 6.00-10.00 larvae per plant) and egg density (67-75 and 28.83-50.07 eggs per plant) in a survey conducted in different districts (Sirsi, Mudgod, Vijayapura, Dharwad, Belagavi, Bagalkot, Gadag, Haveri) respectively. The possible reason for the deviation in the results could be the change in geographical location (Pakistan vs India), different environmental conditions (temperature/ maximum, relative humidity evening and rainfall vs temperature minimum, rainfall (higher intensity) favoring S. frugiperda infestation in Pakistan and India accordingly.

The comparison of the chlorophyll-a and chlorophyll-b and carotenoids showed a declining trend from SW-09 and SW-21, 2023. These findings do not conform to those reported by Jawale *et al*., (2017) who determined the chlorophyll-a and chlorophyll-b in the range of 0.12- 0.34 and 0.52-0.76 (mg/g of fresh leaf weight). Decline in the chlorophyll-a and chlorophyll-b contents over time found to be the same as reported by Tas (2022) who showed the same trend of decrease. Whereas a detailed analysis of the types of carotenoids by Kimura *et al*., (2007) showed a varied content of the individual components. The deviation in the results might be due to the varietal difference and the cropping season (winter vs summer crop).

At early and final crop development phase (SW-09, 2023) and (SW-23, 2023), leaf area index differed from those documented by Lukeba *et al*., (2013) who reported 6.2 and 7.6-8.00 (cm^2) during early and later crop developmental stages respectively. These deviations might be because of varietal differences, cropping season, attack of insect pests, abiotic factors (application of different fertilizer doses, soil moisture contents) and different environmental conditions. These deviations were also supported by the findings of Tadesse *et al*., (2015) who achieved an increase in leaf area expansion of 24.69% with the application of nitrogen.

The findings for plant height contradict to those elaborated by Tahir *et al*., (2008) and Johnson *et al*., (1986) who recorded maximum plant height 195.00-206.00 (cm) in different maize hybrids (Pioneer-32B3, FSH421, HG-3740 and pioneer3062) minimum in the range of 173.75 (cm) in Rafhan-2303 and 179-282 (cm) respectively. The reason behind the deviated results could possibly be the change of variety (varietal difference), different fertilizer application rate (250 kg N, 120 kg P and 125kg K per acre).

Nonetheless, final grain yield produced (upper and lower yield) contradicts to those reported by Lima *et al*., (2010) and Cheruiyot *et al*., (2020) who recorded 34% yield losses due to the attacked of *S. frugiperda* and obtained higher grain yield with the application of higher application dose rate of fertilizers (180-130 kg per ha). While working on heterosis effect on yield in maize Tollenaar *et al*., (2004) elaborated increase in grain yield upto 150-167% considering the dry matter accumulation, which are in line with our results (154%) higher grain yield.

The correlation results between *S. frugiperda* population and environmental factors were found to be significantly correlated. Temperature (maximum and minimum) and relative humidity (morning and evening) were found positive and negative (0.766 and 0.679) and (-0.790 and -0.525) respectively. These findings do not conform to those reported by Anandhi *et al*., (2020) and Girsang *et al*., (2020) who documented the contrary results regarding temperature and relative humidity with *S. frugiperda* population. The eccentricity could be due to changes of cropping season, geographical variation and varietal characteristics. From all the discussion it is clear that the biotic stress caused by in the infestation of *S. frugiperda* has a greatly impacts on grain yield, strong correlation with the environmental factors and physiomorphic characteristics of maize plants.

CONCLUSION:

It can be concluded that maize varieties resistant to *Spodoptera frugiperda* and low foliage index should be cultivated if the crop is cultivated for seed production programme. Contrarily, maize varieties with high biomass index as well as low susceptibility for *S. frugiperda* should be preferred for forage crops.

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