Infestation Level of Helicoverpa Armigera (Hubner) in Different Tomato Varieties in Selected Districts of Khyber Pakhtunkhwa, Pakistan

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The study compared the dynamics of infestation of Helicoverpa armigera (Hubner), associated fruit damage, and yield losses in six tomato varieties (Red King, Rio Grande, Florida King, Roma, Sahel, and 1359) in 2020 and 2021, and their correlation with weather parameters in three districts of Khyber Pakhtunkhwa, Pakistan (Peshawar, Bajaur, and Swat). The level of infestation was considerably different during the growing season, with the first appearance of eggs in the 11th meteorological week, followed by the appearance of larvae in the 13th week, peak population in the 19th week, and gradual decline in the 21st week in all locations and varieties. The lowest infestations were recorded in Sahel (1.24-1.87 eggs plant^{-1} and 1.241.56 larvae plant^{-1}) and Rio Grande (1.942.58 eggs plant^{-1} and 1.72 2.58 larvae plant^{-1}). Temperature significantly affected the level of infestation, with the highest population being at 20–26 °C and 27–30 °C. Relative humidity had significant negative relationships with the population of larvae in all districts and years, as compared to rainfall, which had no significant effect because it had low occurrence during the cropping season. Infestation varietal variations were directly converted into fruit damage and loss of production. Damage to fruits fell between 19.97 with Roma and Rio Grande experiencing the greatest damage, and Sahel and 1359 had the lowest damage in all the districts. There is a negative correlation between the infestation intensity and yield performance, where Sahel and 1359 gave the best yield (a maximum of around 15,800 kg ha^{-1}), and Rio Grande and Florida King were the lowest yielders. Correlation analysis indicated that there were location-specific temperature and infestation correlations, with a significant positive correlation in Bajaur, a non-significant positive correlation in Peshawar, and a significant negative correlation in Swat. Comprehensively, the research proves that abiotic factors, especially temperature and relative humidity, and varietal resistance are major factors in determining the level of H. armigera infestation, fruit damage, and yield results. It is highlighted that it is essential to implement location-specific controls of pests and develop tolerant varieties like Sahel and 1359 to reduce losses caused by pests and increase the tomato yields.

Keywords: Helicoverpa Armigera, Tomato Fruit Borer, Abiotic Factors, Tomato Varieties, Infestation Levels

Introduction:

Tomato (Solanum lycopersicum) is the most prominent vegetable after the potato in the world. The total growing area worldwide for tomato is 4.85 million ha and has an average yield of 37.60 tons/ha, as per the report. In reducing the yield of tomatoes there are many biotic and abiotic factors. In the biotic factors, the fruit borer, Helicoverpa armigera (Hubner) is counted as the most damaging one and crucial pest [1].

Tomato fruit borer Helicoverpa armigera (Hubner) is a multiple host pest and a key menace to the tomato crop, with substantial yield loss. Annual yield losses due to it are around 5 billion US dollars. In Pakistan, fruit infestation up to 32-35% in tomato was observed, and 53% fruit loss was recorded in Peshawar, Province Khyber Pakhtunkhwa. Pest Incidence severity can be judged from the use of 80% of total insecticides against only this specific pest [2].

Swat, Peshawar, Mansehra, and Bajaur are key vegetable-growing areas of Khyber Pakhtunkhwa, Pakistan. The high altitudes and different locations except Peshawar minimize these areas' temperature, turning it to natural offseason vegetable-growing areas. The main vegetable crop of these regions is tomato. Due to low temperatures at high altitudes, minimal insect activity was observed. very few studies on tomato pests is available for these regions. The current study is specifically designed to examine the infestation level of the pest and its occurrence in the tomato crop [3].

Tomatoes, Maize, Chickpea, cotton, alfalfa, and tobacco are some crops that are heavily damaged and infested by H. armigera. In Central Asia, the threshold harm of this pest per hundred plants of staple-long plants of cotton is three to five larvae, while that on medium staple plants is eight to twelve. Cotton blossoms open prematurely due to pest attack, reducing fruit set due to the attack of this pest, and become fruitless. Bolls that get damaged fall off, and the remaining fail to produce lint of the best quality. Fungi and bacteria are common pest of secondary infection that leads to fruit rotting and injured growing tips of plants in cotton. These injured tips disturb the development and maturity of plants, which may be delayed and results in fruit drop. The bollworm H. armigera is a great threat to agriculture [4]. The wide broadcasting of the pest is recognized due to its polyphagous nature and its capability of going through collective seasonal migration and diapause. The nature of migration of H. armigera makes it the key pest in all the continents [5].

According to many studies conducted on the population of H armigera on different host plants in Brazil since the occurrence of the pest, many genetic determinants (haplotypes) have been reported and highlighted in North, Northeast, and Midwest Brazil. However, it is still unclear whether the spread of the pest is due to a single invasion or multiple invasions [6]. To measure the intensity of a pest, it is necessary to calculate its population, the influence of Natural enemies on its population, assess crop losses, check on the pest's arrival and identification, and implement control methods. It is important to form interactions between the pest population, its arrival, and the total timespan of damage it causes to a crop at an important growth level, and the resulting yield loss due to the pest, to work out an economic threshold. In Pakistan, major hosts of H. armigera are tomato, cotton, chickpea, okra, and a few other vegetables and crops. Damage has been recorded in cultivated 60 plant species and a minimum of 67 plant species other belongs to 39 families worldwide.

It is necessary to have data on the effect of different varieties of crop and their effect on the nutritional catalogues of the pest, which is important in determining the different varieties' potential to resist against H. armigera and manage its population. As per the economic ranking of this pest in tomato crops, we still have little knowledge and published information regarding the nutritional catalogues of the pest on different tomato varieties. However, we have some linked studies being conducted on dietary indices of the pest [7].

The biotic and abiotic factors are the regulators of insect abundance and dispersal. Temperature and humidity are the most significant ones among the abiotic factors in boosting insect population and distribution. Adding to it, it is recorded that these abiotic factors, specifically temperature is a regulator of insect communities and their ecology. Temperature (1445 °C), relative humidity (15-95), and a photoperiod of (10-14hrs) along with sporadic and ideal precipitation, are among the ecological regulators of insect adults' emergence and fertility of female of H. armigera [8].

According to recent studies, climate variability has a strong impact on the phenology, voltinism, and space distribution of H. armigera in tomato and other solanaceous crops. An increase in temperature enhances faster larval growth and higher turnover of generations, whereas relative humidity affects oviposition and egg survival. It has been reported that climate-induced changes in pest pressure in South Asia, the Middle East, and Mediterranean areas necessitate the use of location-specific evaluation that combines weather parameters with host plant resistance. The advances offer a modern paradigm in understanding the pest dynamics beyond the classical seasonal descriptions [9].

Objectives of the Study:

To determine the frequency, density, and level of infestation of Helicoverpa armigera in tomato fields within the major vegetable growing areas/Districts of Khyber Pakhtunkhwa (Swat, Peshawar, and Bajaur).

To estimate the amount of tomato crops damaged and the losses in yield due to H. armigera and the economic threshold level (ETL) of the pest and pest management.

To determine the importance of biotic factors that affect the abundance and infestation of tomato agro-ecosystems with H. armigera.

To examine how the population dynamics and spatial distribution of H. armigera are influenced by the abiotic factors, especially the temperature and the relative humidity.

Materials and Methods:

Study Parameters and Location:

Several tomato growing seasons of 2020 and 2021 in three of the largest tomato-producing districts, Peshawar, Swat, and Bajaur, in Khyber Pakhtunkhwa, Pakistan, were chosen as field trials to determine the level of infestation of tomatoes by Helicoverpa armigera (Hubner). Such districts are characterized by a distinct difference in altitude and climatic conditions, whereby the elevation of 1086 ft (Peshawar), 3220 ft (Swat), and 2850 ft (Bajaur) gives a variety of agro-climatic conditions which are to be studied.

Each location had an experiment that was designed in a randomized complete block design (RCBD). Different districts were used as experimental locations, and blocks within a location were used as replications to consider variability in fields like heterogeneity of the soils and microclimatic variations. The treatments were six types of tomatoes, namely, Red King, Rio Grande, Roma, Florida King, Sahel, and Line-1359. The varieties were replicated five times within the districts.

The six tomato varieties were used in this research due to their popularity in farming, contrast in genetic background, and the producer preference of the tomatoes in Khyber Pakhtunkhwa (Rio Grande, Red King, Florida King, Roma, Sahel, and 1359). Popular commercial varieties include Rio Grande, Roma, Red King, and Florida King, which are high-yielding and of which farmers have often reported being vulnerable to insect pests, and Sahel and 1359 are being adapted locally and are assumed to be partially resistant. Their inclusion provided them with the possibility of comparative analysis of pest response to identical agronomic practices, and it was also possible to identify varieties that can be incorporated in integrated pest management programs.

The size of each experimental unit was 4.45 m 2, and the overall size of the experimental area at a site was about $2000m^2$. A transplanting of tomato seedlings was done in 70 cm row to row spacing and 45 cm plant to plant spacing. All separation was done at a distance of 1 m between replications and 0.5 m between plots and treatments to minimize border effects.

Nursery Raising and Crop Establishment:

The nursery of tomatoes was planted at 250-300 g of seed per hectare. All the chosen varieties were sown on seedling trays with peat moss medium on them to facilitate uniform germination. The ploughing was done, and then the cultivator and rotavator activities were done, and transplanting was done by creating raised ridges.

A mid-February transplant of forty-day-old healthy seedlings was done at all three locations. Planting of the seedlings took place on both sides of the raised beds according to the general agronomic standards, and there was no application of insecticides during the experiment to enable the infestation of pests.

Monitoring of Helicoverpa armigera Infestation:

The infestation of H. armigera was observed a week following the transplantation to the end of crop maturity. In both varieties and replications, 10 plants were selected randomly to be observed. Eggs and larvae per plant were counted every week. Ten fruits per plant were picked at random after the initiation of the fruit to determine the damage to the fruits. The drop-sheet method (1 × 1 m), which is used to estimate larval population weekly, was used according to [10].

In this case, observations were taken based on the Standard Meteorological Week (SMW) system that began on the 10th SMW (early March) and went on till the 23rd SMW (early June).

Study Parameters:

The parameters that were measured during the study were as follows:

H. armigera eggs per plant

Number of larvae per plant

Fruits per plant that are destroyed

Yield/plant (kg) of every tomato variety

Percent Population was calculated using the following formula:

$$\text{Percent Population} = \frac{\text{No of Infested fruit per Plant}}{\text{Total Number of Fruits per Plant}} \times 100$$

Abiotic Factors:

Maximum and minimum temperature (ºC), relative humidity (percent), and rainfall (millimeters) were taken out of the Meteorological Department of Pakistan data for each district during the time the research was conducted (2020-2021). These parameters were examined using their weekly mean values in order to show the correlation between them and the dynamics of pest populations.

Study Flow Description:

The research had a systematic order:

Study sites and tomato varieties were selected.

Field preparation and nursery raising.

Sowing of seedlings under RCBD.

Monitoring of H. armigera eggs, larvae, and fruit damages weekly.

Gathering of weather information.

Pest infestation, varietal response, and weather statistical analysis.

Statistical Analysis:

The statistical analysis of the pieces of information about the H. armigera infestation, fruit damages, and yield was performed by the Analysis of Variance (ANOVA) using the Statistix 8.1 program, in order to establish the impact of location and variety and their interaction. At the probability level of 5 per cent, the least significant difference (LSD) test was used in performing a mean comparison. Pearson correlation analysis was conducted to assess the effect of abiotic factors on the pest population parameters by the maximum temperature, minimum temperature, relative humidity, and rainfall in accordance with the approach mentioned by [11].

Table 1. Standard Meteorological Weeks (SMW)

SMW#	Dates	SMW#	Dates
1	1-Jan-7-Jan	27	2-Jul-8-Jul
2	8-Jan-14-Jan	28	9-July-15-Jul
3	15-Jan-21-Jan	29	16-Jul-22-Jul
4	22-Jan-28-Jan	30	23-Jul-29-Jul
5	29-Jan-4-Feb	31	30-Jul-5-Aug
6	5-Feb-11-Feb	32	6-Aug-12-Aug
7	12-Feb-18-Feb	33	13-Aug-19-Aug
8	19-Feb-25-Feb	34	20-Aug-26-Aug
9*	26-Feb-4-Mar	35	27-Aug-2-Sep
10	5-Mar-11-Mar	36	3-Sep-9-Sep
11	12-Mar-18-Mar	37	10-Sep-16-Sep
12	19-Mar-25-Mar	38	17-Sep-23-Sep
13	26-Mar-1-Apr	39	24-Sep-30-Sep
14	2-Apr-8-Apr	40	1-Oct-7-Oct
15	9-Apr-15-Apr	41	8-Oct-14-Oct
16	16-Apr-22-Apr	42	15-Oct-21-Oct
17	23-Apr-29-Apr	43	22-Oct-28-Oct
18	30-Apr-6-May	44	29-Oct-4-Nov
19	7-May-13-May	45	5-Nov-11-Nov
20	14-May-20-May	46	12-Nov-18-Nov
21	21-May-27-May	47	19-Nov-25-Nov
22	28-May-3-Jun	48	26-Nov-2-Dec
23	4-Jun-10-Jun	49	3-Dec-9-Dec
24	11-Jun-17-Jun	50	10-Dec-16-Dec
25	18-Jun-24-Jun	51	17-Dec-23-Dec
26	25-Jun-1-Jul	52**	24-Dec-30-Dec

*** Week No. 9 will be 8 days during a leap year**

**** Week No. 52 will always have 8 days**

Results:

Weather parameters and H. armigera (Hubner) infestation level at Peshawar during the years 2020 and 2021:

Eggs per plant, larvae per plant, percent fruit damage, and yield were analyzed using two-way ANOVA, whereby tomato variety and year were used as independent variables. Tukey HSD test at $P \leq 0.05$ was performed to perform a mean separation. Unless otherwise specified, differences that are termed significant are in reference to this analysis.

H. armigera infestation began in the 7th meteorological week of both years, but the earliest egg occurrence was observed in the 13th meteorological week, and larval incidence in all six tomato varieties, Red King, Rio Grande, Florida King, Roma, Sahel, and 1359 (Tables 2 and 3).

The first egg density of the 11th meteorological week was between 2.56 and 4.52 eggs per plant by the varieties, whereas the larval density was between 2.40 and 3.24 larvae per plant in the 13th week. Egg density in the 11th week was 2.72-3.92 eggs/plant, and larval density in the 13th week was 3.36-4.5 2 larvae/plant (Tables 2 and 3).

The combined seasonal averages showed huge variance in the varietal differences (Table 4). Namely, the mean egg density was 1.32-2.50 eggs/plant, and larval density was 1.81-

2.45 larvae/plant in 2020 and 2021, respectively. The Red King and Rio Grande had the highest mean egg density (1.81 and 2.50 eggs per plant, respectively), and Sahel and 1359 were the lowest in egg density (1.32 and 1.49 eggs per plant, respectively). Equally, the larval density was found to be considerably greater on Rio Grande and Red King (2.45 and 2.30 larvae per plant), but Sahel and Roma had the least larval density (1.81 and 2.03 larvae per plant).

Red King and Rio Grande were once more found to have the highest egg density (1.93 and 2.67 eggs per plant), whereas Sahel and 1359 recorded the lowest values (1.41 and 1.59 eggs per plant). The highest density of larvae was recorded on Florida King (2.03) and Rio Grande (2.67), and the lowest on Sahel (1.93) and 1359 (2.16).

It was shown that the two-year mean infestations showed that Sahel and 1359 had the lowest egg density (1.37 and 1.54 eggs per plant), but Florida King and Rio Grande had higher egg density populations. (1.96 and 2.58 eggs per plant). A similar trend was observed with the larval density, whereby Red King and Rio Grande recorded the highest larvae per plant (2.38 and 2.58), and Sahel and 1359 had the lowest larvae per plant (1.87 and 2.10 larvae per plant). These variations can be attributed to varietal physical characteristics like the hardness of the pericarp of the fruit, as was also cited by [12].

There was a wide range in fruit damage between varieties (Table 5), 24.67 -40.13 and 21.70 -45.05 in 2020 and 2021, respectively. The highest percent of fruit damage was registered in Florida, King, and Rio Grande with 38.17% and 40.13% respectively, and Sahel and 1359 with the least damage of 24.67% and 26.61 respectively in 2020. Roma and Rio Grande had the most damage in the year 2021 (41.74% and 45.05%), Sahel and 1359 had the lowest damage in the year 2021 (21.70% and 27.08%). The mean of the two years proved that Roma and Rio Grande were the most vulnerable, and Sahel and 1359 were the most tolerant.

The data on yields were expressed in the level of infestation (Table 6), yield per plant was 1.02-1.37 kg in 2020 and 1.16-1.44 kg in 2021. The largest yield per plant was observed in 1359 and Sahel (1.33 and 1.37kg), and the lowest in Rio Grande and Florida King. The same trend could be observed in 2021. Both years (1359 15,884 -1 and Sahel 15,325 -1) had the highest yield per hectare, followed by the Red King and Rio Grande, whose yields were lowest.

The seasonal changes in the population of eggs and larvae were indicators of different biological processes. The highest egg density at cooler and relatively moist times indicates good conditions of adult oviposition and egg survival, whereas later changes in larval density suggest faster development and survival of the immature stages in warmer conditions. The temporal delay between egg and larval peaks corresponds to the life cycle duration of H. armigera, highlighting the influence of temperature on its development.

Correlation between the weather parameters and H. armigera infestation at Peshawar:

The correlation analysis showed uniform trends according to the varieties and years (Table 7). The point of correlation between egg density and mean maximum and minimum temperature in all varieties was strong and significant in the years 2020 and 2021. On the other hand, the density of the egg recorded a strong positive relationship with morning and evening relative humidity and weakly with rainfall, which was mainly not significant.

Denser larvae, on the other hand, were found to have a positive relationship with temperature (especially minimum temperature) and a negative relationship with relative humidity. There were weak and inconsistent relationships between rainfall and the larval density. Such results indicate that lower temperatures and higher humidity are conducive to oviposition, whereas high temperatures and comparatively drier conditions are conducive to larval growth.

Weather parameters and infestation of Bajaur with H. armigera in 2020 and 2021:

Infestation pattern at Bajaur was similar to that of Peshawar, which followed a temporal pattern. The initial appearance of the eggs was documented in the 11th meteorological week, and the incidence of larvae in all the varieties occurred in the 13th week (Tables 8 and 9).

In the year 2020, the highest mean egg density was registered in Red King and Rio Grande (1.70 and 1.88 eggs per plant, respectively), and the lowest in Sahel and Roma. Red King and Rio Grande also had the highest larval density, and Sahel and Roma had the least (Table 9). The varietal trend in 2021 was similar, whereby Red King and Rio Grande produced higher numbers of eggs and larvae. compared to Sahel and Roma.

The average of the two years showed that Red King and Rio Grande were the most vulnerable varieties (1.75-1.94 eggs/plant and 1.77-1.87 larvae/plant), whereas Sahel and Roma were relatively tolerant to it (1.25-1.45 eggs/plant and 1.29-1.50 larvae/plant). Statistical significance was achieved between the differences between the varieties ($P \leq 0.05$).

The extent of infestation followed by percent fruit damage (Table 10) ranged between 19.97 and 36.63 percent in 2020 and 23.29 and 43.11 percent in 2021. During the two years, the Roma and Rio Grande were the ones with the most damage in their fruit, whereas Sahel and 1359 had the least damage. Data on yields indicated that Sahel and 1359 did best in terms of highest yields per hectare, and Red King and Rio Grande did the worst in terms of yields (Table 11).

Correlation between the weather parameters and the infestation of H. armigera at Bajaur:

At Bajaur, correlation analysis showed the same trend as the trends were seen at Peshawar (Tables 12 and 14). The maximum and minimum temperatures had negative correlation with the egg density, and the relative humidity had positive correlation with the egg density. Temperature had a positive relationship with larval density and humidity had a negative relationship with larval density. The effects of rainfall were poor and intermittent.

Weather conditions and H. armigera infestation at Swat in 2020 and 2021:

At Swat, the eggs and larvae had the same seasonal distribution as at the other stations, the eggs being first reported in the 11th meteorological week and larvae in the 13th week (Tables 14 and 15).

The egg densities were highest in Florida King and Rio Grande and lowest in Sahel and Roma in 2020 (Table 16). The larval density was also highest on 1359 and Red King and lowest on Sahel and Roma. Florida King and Rio Grande once again recorded the highest egg densities, with Sahel and Roma being the least infested in 2021.

The two-year average infestation was a confirmation that Sahel and Roma were relatively tolerant, whereas Florida King, Red King, and Rio Grande were the vulnerable ones. There were similar patterns in the fruit damage, with Roma and Rio Grande having the highest damage and Sahel and 1359 having the lowest damage (Table 17).

Yield performance was the same as infestation (Table 18), and yields per hectare were between 12,947 and 15,657 kg ha -1 in varieties. The highest yields per hectare were always obtained using Sahel and 1359, with the lowest yield being registered by Red King and Florida King.

Correlation of weather parameters and H. armigera infestation at Swat:

Some variation in location was found in the correlation analysis at Swat (Table 19). In 2020, the egg density had positive correlations with temperature on a variety of agro-climatic conditions, but the larval density had negative correlations with temperature and rainfall. Overall, the temperature had a negative relationship with the egg density and a positive relationship with the larval density, whereas the relative humidity had a positive relationship with the egg density and a negative relationship with the larval density.

In general, in all predetermined regions and seasons, the temperature and the relative humidity turned out to be the primary abiotic factor that affects the population trends of H. armigera, whereas rainfall was less significant and sporadic.

The positive associations between the egg density and relative humidity result in a successful oviposition and egg survival in humid conditions, and negative associations with the temperature indicate a decrease in the viability of eggs at high thermal conditions. Conversely, the positive relationships between the larval density and the temperature indicate that the larval development rate is rapid and the feeding frequency is greater in high temperatures. These opposing reactions indicate that there is a level of climatic sensitivity in a given stage, and why the difference between the dynamics of an egg and larval population was observed.

An increase in the levels of infestation led to massive damage to fruits and a quantifiable decrease in yield, and this directly impacted marketable produce. Losses due to yield in vulnerable varieties translate to loss of revenue for farmers in terms of quantity and quality loss. Use of tolerant varieties can therefore be seen as an economically sound approach where pest-induced losses are decreased, and lower input costs on pest control are achieved through the use of the chemically tolerant varieties, and enhances net returns.

The variation in the infestation level between Peshawar, Bajaur, and Swat can be partly explained by the presence of the local altitude that affects the local temperature and humidity regime. Warmer temperatures earlier infested and had high larval densities in lower altitude locations, and delayed population accumulation in higher altitude locations. Though the altitude as an independent variable was not considered, the indirect effect on the climatic parameters was shown in the correlation analyses.

Discussion:

Weather parameters and H. armigera infestation levels at Peshawar, Bajaur, and Swat during the years 2020 and 2021:

The results related to the infestation level of H. armigera in six selected varieties of tomato at three different districts, Peshawar, Bajaur, and Swat, showed that the infestation varied during the different weeks of the growing season significantly. The first egg population was observed in the 11th standard meteorological week, while the first larval observation on all varieties at every district was observed in the 13th standard meteorological week. The infestation level was significantly raised from the first week of observation till the 19th standard meteorological week. And a gradual fall in the infestation level was observed in the later weeks up to the 21st standard meteorological week in all selected varieties in all three districts.

These results show similarities with the results of [13] who reported the same in the initial two weeks of transplantations there were no egg population of H. armigera recorded and from the 3rd week of recoding infestations showed peak in egg populations and in the fifth week of observation observed peak in larval populations of H. armigera in the selected tomato germplasms in different locations of studies. And then in the later stages of recording, populations were observed. Our results also showed accordance with the results of [14] who also reported The appearance of H. armigera on tomato plants, was initially observed in the fourth 11th SMW in regard of egg population and after a week of observing egg population observed the first larval population. The egg and larval population subsequently reached its highest point, with an average of 1.20 larvae per plant in the initial weeks, and then in the later stages, the pest population declined.

The lowest cumulative mean egg population at districts Peshawar, Bajaur, and Swat in both years 2020 and 2021 was found on variety Sahel, which was (1.37, 1.25, and 1.24 eggs per plant) respectively for all three districts, and the maximum was found on variety Rio Grande (2.58, 1.94, and 2.05 per plant) respectively. The lowest cumulative mean larval population at districts Peshawar, Bajaur, and Swat for both years 2020 and 2021 was found on variety Sahel, which was (1.87, 1.5, and 1.56 eggs per plant) respectively for all three districts, and the maximum was found on variety Rio Grande (2.58, 1.76, and 1.72 per plant) respectively. These results were in resemblance with ,who studied the population level of H.

armigera in tomato crop at different areas of Haryana, i.e., Sujagarh and Mantanahail, reported a difference between the populations/infestation of H. armigera in the selected sites of study that shows the impact of altitude and other abiotic factors on the infestation levels.

Population peaks were observed at 20–26 °C, declined at 27–30 °C, and were lowest at 31–35 °C and onwards in all the districts of study. Bajaur and Peshawar showed similarities in results due to a slight difference of 1-2^{0} ˚C in temperatures, while in Swat population was recorded as low due to the differences in altitude, temperature, humidity, and rainfall.

Similar observations are also reported by [13], who conducted research at the Experimental Farm, Faculty of Agriculture, Wadura, Sopore, SKUAST-K, during the period from 2016 to 2017. Observed a peak larval population of H. amrigera in the temperature range of 20-27^{0} ˚C, a bit downfall in the temperature range of 28-31^{0} °C, and a minimum at 32-36^{0} ˚C, and so on.

The current study compared its findings with those, who reported that average temperature, relative humidity, and rainfall are significant abiotic factors influencing the infestation level of lepidopterous pests in the field. Overall, periods of rainfall were associated with higher pest populations, while normal temperature conditions showed a negative correlation with larval population. However, relative humidity did impact pest mortality, and low temperatures did not significantly affect the infestation level. It is essential to consider that different study locations may yield varied results in this regard.

The abiotic factors identified in the study played a crucial role in influencing the variation of H. armigera infestation levels across different Standard Meteorological Weeks (SMWs). Among these factors, altitude, were particularly influential.

The correlation matrix of Fruit Borer H. armigera infestation levels with weather Parameters in Peshawar, Bajaur, and Swat during the years 2020 and 2021:

The study related to correlation was conducted between infestation levels of H. armigera and the mean weather parameters during the years of observations in 2020 and 2021 at the districts of Peshawar, Bajaur, and Swat. While studying the correlation, it has been discovered that both maximum mean temperature and minimum mean temperature have a positive significant correlation ($P<0.01$) with the H. armigera infestation level at district Bajaur, while has non-significant positive correlation ($P<0.01$) with the H. armigera infestation level at district Peshawar. At district Swat, both maximum mean temperature and minimum mean temperature have a significant negative correlation ($P<0.01$) with the H. armigera infestation level. Overall, these results are similar to the results of [14], who reported that the insect population might be significantly high when the temperatures are rising. The Relative humidity in the morning showed a significant negative correlation ($p<0.01$) with the infestation level of the pest, while the relative humidity in the evening also showed a significant negative correlation ($p<0.01$) with the infestation level of the H. armigera in all districts during both years. With the rainfall, the population had no significant correlation with the total rainfall in all three districts. The differentiations in correlation of H. armigera populations with weather factors may be because of the different attitudes and latitudes.

The findings of the study align with the results of [13], who conducted their research during the period from 2016 to 2017 at the Experimental Farm, Faculty of Agriculture, Wadura, Sopore, SKUAST-K. In both studies, larval infestation of H. armigera in all tomato genotypes was observed to begin approximately one and a half months after transplanting the crop when the temperature ranged between 20-27^{0} ˚C. The study reported a negative and non-significant correlation between H. armigera larval population and maximum temperature ($r = -0.032$), while a negative and significant association was found between sunshine hours and fruit borer larvae ($r = -0.566$). Furthermore, the study highlighted significant and positive correlations between other abiotic factors, such as minimum temperature, rainfall, maximum humidity, and minimum humidity, with r values of 0.874, 0.734, 0.543, and 0.593, respectively.

The current study's findings were also compared with those of who revealed that relative humidity, mean temperature, and rainfall are prominent abiotic factors that highly affected the infestation level of lepidopterous pests in the field. Overall, during rainfall, the population was high, as in a normal had no significant correlation, but relative humidity had an impact on mortality of the pest, and low temperature had no impact on the infestation level. However, different areas selected for studies can have different results.

The patterns of varietal susceptibility in the majority of the studies are also similar to the reports in other parts of South Asia and the Mediterranean, where the tolerant genotypes have lower infestation and greater yield stability in the changing climatic conditions. The general applicability of the findings, as well as the significance of local validation, is supported by similar temperature-driven larval activity increases observed internationally.

The findings are very informative to IPM as they have indicated tolerant varieties, established critical monitoring time, and the importance of weather-based forecasting. Integrating varietal resistance with timely monitoring can decrease unnecessary application of insecticides. To the farmers, the study provides workable suggestions concerning the selection of varieties and the best time to monitor to reduce losses. In the case of extension services, it is observed that advisory packages incorporating varietal choice along with climate-based pest alerts should be developed to aid in the making of informed decisions at the field level.

Conclusions:

It was evident in the present research that the varietal susceptibility of tomato to the infestation of H. armigera and the weather conditions present in Peshawar, Bajaur, and Swat in the 2020 and 2021 seasons were significant in the infestation of tomato. The trend was consistently initiated at the early vegetative stage with the first appearance of eggs in the 11th week of meteorology and an incidence of larvae in the 13th week, demonstrating a consistent seasonal trend.

The tomato varieties varied widely regarding how they respond to infestation with H. armigera across all the places and all the years. Rio Grande, Red King, Florida King, and Roma varieties were typically more vulnerable to it, with higher egg and larval concentration, fruit destruction, and relatively lower yields. However, Sahel and 1359 had, in comparison, a lower egg and larval population, less fruit damage, and greater yields compared to others, which suggests a relatively tolerant or resistant reaction.

Weather parameters were decisive in the dynamics of the pest population. Maximum and minimum temperatures had a negative relationship with egg density, but the relative humidity had a positive relationship, indicating that low temperature and high humidity are favorable to oviposition. On the other hand, there was a positive correlation between the larval density and temperature and a negative relationship between the larval density and the relative humidity, which means that larval development was boosted at higher temperatures and lower relative humidity. Rainfall showed weak and unpredictable impacts on the egg and larval population.

In general, host plant resistance and climatic conditions had a significant influence on the intensity of infestation, fruit damage, and yield performance. The uniform high performance of Sahel and 1359 at various agro-ecological zones is a reference to its aptness.

Recommendations:

Tomato Sahel and Sahel 1359 varieties should be encouraged to grow in Peshawar, Bajaur, and Swat, and other agro-ecological areas because these varieties were found to have low egg and larva population, less damage to fruits, and high yield.

The monitoring of H. armigera should start with the 7th meteorological week, but the most vigilance must be during the 11th -13th weeks, the period of time when egg laying is at its peak, and larval hatching occurs.

Pest forecasting systems should include weather parameters, especially temperature and humidity, because of their ability to enhance the accuracy of forecasting and the application of management practices in time.

The farmers are advised to embrace integrated pest management (IPM) methods that will embrace varietal resistance, routine scouting, and threshold-based interventions in minimizing the pest pressure.

Cultivation of relatively tolerant tomato varieties can reduce chemical pesticide reliance. The relatively tolerant tomato varieties can reduce chemical pesticide reliance to control the use of chemicals on these crops, thereby reducing the costs of production and controlling the adverse environmental and health impacts.

Future studies ought to be directed at finding the biochemical and morphological characteristics used in varietal resistance and the development of location-specific pest prediction models considering the climatic variables.

References:

[1] Asif Ali, Mohamed A. Rakha, Farid ASIF Shaheen, Srinivasan Ramasamy, "Resistance of Certain Wild Tomato (Solanum spp.) Accessions to Helicoverpa armigera (Hbner) (Lepidoptera: Noctuidae) Based on Choice and No-Choice Bioassays," *Florida Entomol.*, vol. 102, no. 3, pp. 544–548, 2019, doi: 10.1653/024.102.0311

[2] M. S. Amjad Usman, Imtiaz Ali Khan, Mian Inayatullah, Ahmad Ur Rahman Saljoqi, "Appraisal of Different Tomato Genotypes against Tomato Fruit Worm (Helicoverpa armigera Hub.) Infestation," *Pakistan J. Zool*, vol. 45, no. 1, pp. 113–119, 2013, [Online]. Available: file:///C:/Users/VAIO/Desktop/New folder/Appraisaloftomatogenotype2013.pdf

[3] Sidrah Ishtiaq, Waheed Ali Panhwar, Sardar Azhar Mehmood, Imran Ahmd, Khatri, Shabir Ahmad "Population and incidence of pests on different tomato (Lycopersicon esculentum L.) varieties from district Mansehra Pakistan," *J. Entomol. Zool. Stud.*, vol. 5, no. 5, pp. 800–803, 2017

[4] L. Sigsgaard, M. H. Greenstone, and S. J. Duffield, "Egg cannibalism in Helicoverpa armigera on sorghum and pigeonpea," *BioControl*, vol. 47, no. 2, pp. 151–165, 2002, doi: 10.1023/A:1014577114915/METRICS.

[5] H. Feng, X. Wu, B. O. Wu, and K. Wu, "Seasonal migration of Helicoverpa armigera (Lepidoptera: Noctuidae) over the Bohai Sea," *J. Econ. Entomol.*, vol. 102, no. 1, pp. 95–104, Feb. 2009, doi: 10.1603/029.102.0114.

[6] T. Mastrangelo *et al.*, "Detection and genetic diversity of a heliothine invader (Lepidoptera: Noctuidae) from north and northeast of Brazil," *J. Econ. Entomol.*, vol. 107, no. 3, pp. 970–980, 2014, doi: 10.1603/EC13403.

[7] Muahmmad Ashfaq, Muhammad Sajjad, Muhammad Noor ul Ane, Noureen Rana "Morphological and chemical characteristics of tomato foliage as mechanisms of resistance to Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae) larvae," *African J. Biotechnol.*, vol. 11, no. 20, pp. 7744–7750, 2012,doi: 10.5897/AJB11.3511

[8] Matilda Savopoulou-Soultani, Nikos T. Papadopoulos, Panagiotis Milonas, Pascal Moyal, "Abiotic Factors and Insect Abundance," *Psyche A J. Entomol.*, 2012, [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1155/2012/167420

[9] A. Raza *et al.*, "Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review," *Plants 2019, Vol. 8, Page 34*, vol. 8, no. 2, p. 34, Jan. 2019, doi: 10.3390/PLANTS8020034.

[10] G. Pooran Mal Kharia, Rajesh Kumar, Mukesh Kumar Jat, "Population dynamics of fruit borer, Helicoverpa armigera and whitefly, Bemisia tabaci on tomato," *J. Entomol. Zool. Stud.*, vol. 6, no. 6, pp. 396–399, 2018, [Online]. Available: https://www.entomoljournal.com/archives/2018/vol6issue6/PartG/6-5-267-

359.pdf

[11] R. J. H. Ravi C. Nirmal, Agnelo Furtado, Parimalan Rangan, "Fasciclin-like arabinogalactan protein gene expression is associated with yield of flour in the milling of wheat," *Sci. Rep.*, vol. 7, 2017, [Online]. Available: https://www.nature.com/articles/s41598-017-12845-y

[12] M. Sajjad, M. Ashfaq, Saad Hussain Akhtar, A. Suhail, "Screening of tomato genotypes for resistance to tomato fruit borer (Helicoverpa armiger hubner) in Pakistan," *Pakistan J. Agric. Res.*, vol. 48, no. 1, pp. 59–62, 2011, [Online]. Available: https://www.researchgate.net/publication/288789562_Screening_of_tomato_genotypes_for_resistance_to_tomato_fruit_borer_Helicoverpa_armiger_hubner_in_Pakistan

[13] S. S. P. Aoufa Mushtaq, "Effect of Abiotic Factors on Larval Population Build Up of Tomato Fruit Borer, Helicoverpa armigera Infesting Different Tomato Germplasm," *Int.J.Curr.Microbiol.App.Sc*, vol. 8, no. 12, pp. 2669–2675, 2019, [Online]. Available: https://www.ijcmas.com/8-12-2019/Aoufa Mushtaq and S. S. Pathania.pdf

[14] B. S. Vijay Kumar, MK Mahla, Jhumar Lal, "Effect of abiotic factors on the seasonal incidence of fruit borer, Helicoverpa armigera (Hub.) on tomato with and without marigold as a trap crop," *J. Entomol. Zool. Stud.*, vol. 5, no. 2, pp. 803–807, 2017,