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RESEARCH ARTICLE

Seasonal pattern of pests and predator activity in tomato ecosystem

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Abstract

An investigation was conducted over two consecutive years (*Rabi* 2023-24 and 2024-25) to study the temporal pattern of insect pests and natural enemies activity and their relationship with weather parameters. The study focused on key pests; fruit borer (*Helicoverpa armigera*), whitefly (*Bemisia tabaci*), aphid (*Aphis gossypii*) and jassid (*Amrasca biguttula biguttula*) as well as their natural enemies, primarily Coccinellids. The fruit borer was first observed during the 43rd Standard Meteorological Week (SMW) with an initial mean population of 0.06±0.06 larvae per plant, peaking at 3.52±0.42 larvae per plant in the 52nd SMW. Whiteflies first appeared in the 42nd SMW with an initial population of 1.99±0.46 individuals per three leaves, peaking at 15.16±13.38 individuals in the 51st SMW. Aphids were initially recorded at 1.15±1.15 individuals per three leaves during the 42nd SMW, reaching a peak of 5.06±2.08 in the 51st SMW. Jassids emerged during the 42nd SMW with a mean population of 1.48±0.62 individuals, peaking at 6.49±2.71 individuals per three leaves in the 50th SMW. Natural enemies such as Coccinellids were first seen in the 42nd SMW and a peak population (1.99±0.81 individuals per plant) observed in the 49th SMW. Correlation analysis revealed that fruit borer populations were significantly and negatively correlated with maximum (r = -0.787**) and minimum (r = -0.734**) temperatures while positively and significantly associated with morning relative humidity (r = 0.637**). Whitefly showed a significant negative correlation with maximum (r = -0.436*) and minimum (r = -0.549*) temperatures. Aphids also displayed substantial negative correlations with maximum (r = -0.579**) and minimum (r = -0.708**) temperatures and had a strong positive correlation with Coccinellids (r = 0.895**), indicating a predator-prey relationship. Jassids showed a significant negative correlation with evening relative humidity (r = -0.496*), while other weather parameters showed non-significant associations. The multiple regression analysis revealed that maximum temperature (°C), minimum temperature (°C), morning relative humidity (%), evening relative humidity (%), rainfall (mm) together influenced to an extent of 73.50 (R^2=0.735), 54.80 (R^2=0.548), 85.10 (R^2=0.851) and 63.20 (R^2=0.632) per cent of fruit borer, whitefly, aphid and jassid population, respectively.

Keywords: aphid; fruit borer; jassid; tomato; whitefly

Introduction

Tomato, *Solanum lycopersicum* L. is one of the important vegetable crops grown in India. It is grown as an off-season vegetable in India and farmers fetch good income (1). It is used in various culinary preparations like sabzi, curry and fries and eaten raw as a salad. The fruit can be eaten raw or cooked. Tomato in large quantities is used to produce soup, juice, ketchup, puree, paste and powder (2). Tomato is a globally significant vegetable crop, ranking second after potato in cultivation area and production. Rich in essential nutrients, it provides a substantial source of vitamin C, minerals like manganese and phytonutrients including lycopene, zeaxanthin and beta-carotene, which contribute to reduced risks of heart diseases through antioxidant support and regulation of blood fats (3). Tomato fruit content water (93.1 %), fat (0.3 g), calorie (23), vitamin 'A' (320I.U), vitamin 'B1' (0.07 mg), vitamin 'B2' (0.01 mg), carbohydrates (3.6 %), nicotinic acid (0.4 mg), vitamin 'C' (31 mg), fibre (0.7 %), calcium (20 mg), phosphorus (36 mg), protein (1.9 %) and iron (0.8 mg) (4). In India, tomato is cultivated over 789.15 thousand hectares, producing 19759.32 metric tons with a productivity of 25.03 tons per hectare (5). However, biotic factors, particularly insect pests, remain a critical constraint to its productivity. Over 100 insect species and 25 non-insect pests have been reported to attack tomato crops (6). Several factors are responsible for reducing the quality and the production of tomato. Insect pests are one of the significant causes that limit the production of tomato (7). The incidence of insect pests may vary from season to season and crop growth stages. The population fluctuation of the insects is primarily governed by different weather factors that prevail during the crop-growing period. In India, about 16 pests reportedly feed on tomato, commencing from the germination to the harvesting stage, reducing their yield and degrading quality (8).

Insect pests cause direct damage through feeding and act as vectors for several plant viruses, exacerbating crop losses. Significant pests of tomato include the fruit borer (*Helicoverpa armigera* Hubner), which can cause up to 40–50 % yield loss (9) and several sucking pests like whiteflies (*Bemisia tabaci*

Gennadius), aphids (*Myzus persicae* Thomas and *Aphis gossypii* Glover) and jassids (*Amrasca biguttula biguttula* Ishida). These pests impact crop health by feeding on plant sap and transmitting viral diseases (9, 10). Additionally, *Liriomyza trifolii* Burgess, the serpentine leaf miner, has gained prominence recently due to its increasing damage potential.

Environmental factors such as temperature, humidity and rainfall significantly influence pest population dynamics by affecting their growth, survival and reproductive behaviours (11). Temperature variations can alter egg-laying and oviposition behaviour, directly impacting pest infestations. Pests like *H. armigera*, being nocturnal and polyphagous, can thrive under diverse climatic conditions, infesting leaves and fruits at various crop growth stages (12).

A comprehensive understanding of these dynamics is essential for developing sustainable pest management strategies. For instance, a temperature rise may accelerate pest life cycles, leading to more frequent generations and severe infestations. Conversely, extreme temperatures could diminish pest populations by exceeding their thermal tolerance. Humidity and rainfall are crucial in influencing the moisture levels in crop fields, affecting pest survival and activity. High humidity can create favourable conditions for certain pests, while excessive rainfall might wash away pest larvae or disrupt their breeding cycles. It is critical to manage the pest population appropriately with adequate management strategies to prevent insect pest infestations and produce a quality crop. Understanding the incidence of insect pests under changing climatic conditions is essential for effective research. Therefore, a study was undertaken to examine the relationship between insect pest populations and weather parameters in order to identify the environmental conditions favourable for their development.

Materials and Methods

The investigations on the temporal pattern of insect pests and natural enemies activity and correlation with abiotic factors were conducted during the *Rabi* season of 2023-24 and 2024-25 under field condtidions, infesting tomato at Students' Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India which geographically located at 26.47˚N latitude, 82.12˚E longitude and an altitude of 113m mean sea level during the *Rabi* season of 2023–24 and 2024-25 on tomato variety ND-1. Agronomic practices were adopted as per recommendations, excluding plant protection measures. The experimental plot measured 6 × 6 m, with plant spacing maintained at 60 cm × 45 cm (row-to-row and plant-to-plant, respectively). The crop was monitored weekly for pest and natural enemy incidence.

Method of observation

The crop is grown in saline soil condition having pH 7.8. The observations were recorded from the ten days after transplanting to till the maturity of the crop and crop field was free from weed and other alternate host during entire crop period. The insect data was recorded on five randomly selected plants. Upper, middle and lower leaves from the plant canopy were examined for whitefly (*B. tabaci*), aphid (*A. gossypii*) and jassid (*A. biguttula biguttula*). The *Coccinellids* and fruit borer (*H. armigera*) population was recorded from five randomly selected plants. To investigate the correlation between pest incidence and abiotic factors, minimum and maximum temperatures (°C), morning and evening relative humidity (%) and rainfall (mm) were obtained from the Department of Agricultural Meteorology.

Statistical analysis

The weekly pest incidence data were correlated with the corresponding weekly abiotic and biotic factors and multiple regression was also workedout using SPSS 20 software to understand the influence of environmental parameters on pest dynamics.

Results and Discussion

The present investigation focused on the seasonal dynamics of major insect pests infesting tomato under fluctuating weather parameters. The weekly observations were recorded to monitor the population dynamics of insect pests and natural enemies such as *Coccinellids*.

Fruit borer (*Helicoverpa armigera*)

The population dynamics of *H. armigera* revealed substantial variation over the cropping season in response to changing weather conditions. Initial larval infestation was recorded during the 43rd Standard Meteorological Week (SMW), with an average of 0.06±0.06 larvae per plant. The population gradually increased over the subsequent weeks, peaking at 3.52±0.42 larvae per plant during the 52nd SMW (late December). This was followed by a slight decline, with larval density recorded as 3.25±0.31 in the 1st SMW and gradually reducing to 0.77±0.47 larvae per plant by the 5th SMW (early February). The decreasing trend can be attributed to the maturation of the tomato crop, which becomes a less favourable host for larval development as the season progresses (Table 1 & Fig. 1).

The statistical analysis indicated that maximum and minimum temperatures exhibited a strong and significant negative correlation with the fruit borer population, with r = -0.787** and r = -0.734**, respectively. This suggests that lower temperature conditions during the cooler winter months favoured the multiplication and activity of *H. armigera*, while higher temperatures likely suppressed their development. On the other hand, morning relative humidity was positively and significantly correlated (r = 0.637**) with the pest population, indicating that humid conditions in the early hours of the day may have enhanced larval survival and activity (Table 2 & Fig. 2). The data analyzed by using multiple regression revealed that maximum temperature (°C), minimum temperature (°C), morning relative humidity (%), evening relative humidity (%), rainfall (mm) together influenced to an extent of 73.50 (R^2=0.735) per cent of fruit borer larval population (Table 3).

These findings are consistent with similar patterns of increased larval activity under cooler and more humid conditions in West Bengal (13). Likewise, peak infestations during the cooler weeks of the cropping cycle attribute the pest's decline to increased temperatures and crop senescence. Together, these results reaffirm that temperature and humidity play crucial roles in shaping the seasonal trends of *H. armigera* in tomato ecosystems and emphasize the importance of weather-based forecasting models and timely pest management interventions (14).

Table 1. Temporal pattern of pests and natural enemies predator activity in tomato ecosystems during *Rabi*, 2023-24 and 2024-25 (pooled)

SMW	Fruit borer larvae $plant^{-1}$	Whitefly per three $leaves^{-1}$	Aphids per three $leaves^{-1}$	Jassids per three $leaves^{-1}$	Coccinellids per plant	Weather parameters				
						Temperature (°C)		Relative humidity (%)		Rainfall (mm)
						Maximum	Minimum	Morning	Evening	
42	0.00±0.00	1.99±0.46	1.15±1.15	1.48±0.62	0.35±0.35	33.35±0.75	20.30±0.80	86.00±1.50	56.50±1.70	0.00±0.00
43	0.06±0.06	2.82±1.34	1.56±1.56	1.77±0.83	0.30±0.30	31.90±0.10	18.55±1.35	86.20±0.80	57.30±3.10	0.00±0.00
44	0.23±0.23	4.35±2.89	2.14±1.70	2.23±0.97	0.25±0.25	31.40±0.80	16.55±1.45	85.35±1.35	55.60±0.20	0.00±0.00
45	0.32±0.32	6.48±5.37	2.81±1.83	2.58±1.02	0.39±0.06	30.30±0.30	16.55±0.65	84.10±1.40	53.95±2.55	0.00±0.00
46	0.88±0.33	7.89±6.63	3.28±2.17	3.46±1.64	0.57±0.18	29.20±0.40	14.95±0.55	86.75±0.35	52.65±3.85	0.00±0.00
47	1.03±0.21	8.98±7.43	3.61±2.28	4.67±2.53	1.70±0.77	27.55±1.15	12.30±1.80	87.10±0.30	50.15±4.65	0.00±0.00
48	1.05±0.07	10.68±8.70	3.94±2.19	5.52±2.68	1.83±0.77	26.60±0.50	10.90±1.70	85.85±1.85	46.80±6.60	1.20±1.20
49	1.70±0.14	12.79±10.95	4.45±2.33	6.47±3.33	1.99±0.81	26.50±0.20	10.15±2.45	85.75±2.75	48.70±6.50	1.00±1.00
50	2.31±0.33	14.49±11.67	4.86±2.40	6.49±2.71	1.84±0.61	24.50±1.40	9.20±5.00	86.10±2.60	49.20±5.80	0.00±0.00
51	2.79±0.33	15.16±13.38	5.06±2.08	5.37±1.43	1.79±0.42	23.90±0.70	6.10±0.10	85.75±2.25	48.45±6.25	0.00±0.00
52	3.52±0.42	13.98±13.34	4.70±2.17	4.52±0.67	1.82±0.37	20.70±0.00	10.30±0.70	89.05±1.95	57.60±3.10	0.00±0.00
1	3.25±0.31	12.95±12.37	4.43±2.31	3.92±0.68	1.59±0.31	16.85±1.35	8.40±1.30	92.30±1.50	67.65±2.45	2.50±2.50
2	2.55±0.35	10.36±9.85	4.14±2.31	3.39±0.41	1.33±0.27	17.90±1.20	7.10±0.40	87.20±0.00	63.45±4.25	1.00±1.00
3	2.07±0.09	8.11±7.64	3.45±2.22	2.03±0.43	0.90±0.06	16.70±3.50	7.65±1.15	86.95±1.55	63.15±6.95	0.00±0.00
4	1.28±0.48	3.96±3.52	3.04±2.20	1.51±0.61	0.77±0.13	18.90±3.70	6.15±0.85	85.80±1.00	58.50±3.70	0.00±0.00
5	0.77±0.47	3.11±2.71	2.24±1.86	1.17±0.67	0.65±0.24	22.85±0.85	7.75±0.25	87.00±1.80	51.60±7.50	0.00±0.00

SMW= Standard Meteorological Weeks

Table 2. Correlation coefficient between pests, weather parameters and natural enemies during *Rabi* 2023-24 and 2024-25 (Pooled)

Weather Parameters/ Natural Enemies	Correlation coefficient (r)			
	Fruit Borer	Whitefly	Aphid	Jasssid
Maximum temperature (ºC)	-0.787**	-0.436*	-0.579**	-0.082
Minimum temperature (ºC)	-0.734**	-0.549*	-0.708**	-0.316
Morning Relative Humidity (%)	0.637**	0.353	0.337	0.084
Evening Relative Humidity (%)	0.295	-0.151	-0.121	-0.496*
Rainfall (mm)	0.421	0.398	0.378	0.315
Coccinellids	-	-	0.895**	-

**Correlation is significant at the 0.01 level *Correlation is significant at the 0.05 level

Table 3. Multiple regression between insect pests, natural enemies and weather factors during *Rabi* 2023-24 and 2024-25 (Pooled)

Variables	Regression equation	R^2 Value
$T_{max}(x_1)$,$T_{min}(x_2)$,$RH_M(x_3)$,$RH_E(x_4)$,$RF(x_5)$ Vs mean fruit borer population (y_1)	$y_1 = -14.402-0.151x_1-0.002x_2+0.267x_3-0.064x_4-0.032x_5$	0.735
$T_{max}(x_1)$,$T_{min}(x_2)$,$RH_M(x_3)$,$RH_E(x_4)$,$RF(x_5)$ Vs mean whitefly population (y_2)	$y_2 = 2.923-0.807x_1+0.398x_2+0.659x_3-0.662x_4+1.161x_5$	0.548
Coccinellids(x_1),$T_{max}(x_2)$,$T_{min}(x_3)$,$RH_M(x_4)$,$RH_E(x_5)$,$RF(x_6)$ Vs mean aphid population (y_3)	$y_3 = 4.793+1.574x_1+0.013x_2-0.068x_3-0.055x_4+0.038x_5-0.101x_6$	0.851
$T_{max}(x_1)$,$T_{min}(x_2)$,$RH_M(x_3)$,$RH_E(x_4)$,$RF(x_5)$ Vs mean aphid population (y_4)	$y_4 = 15.456-0.317x_1+0.235x_2+0.144x_3-0.356x_4+1.099x_5$	0.632

T_{max}-(Maximum temperature, °C), T_{min}-(Minimum temperature, °C), RH_M - (Morning relative humidity, %), RH_E Evening relative humidity, %), RF - (Rainfall, mm).

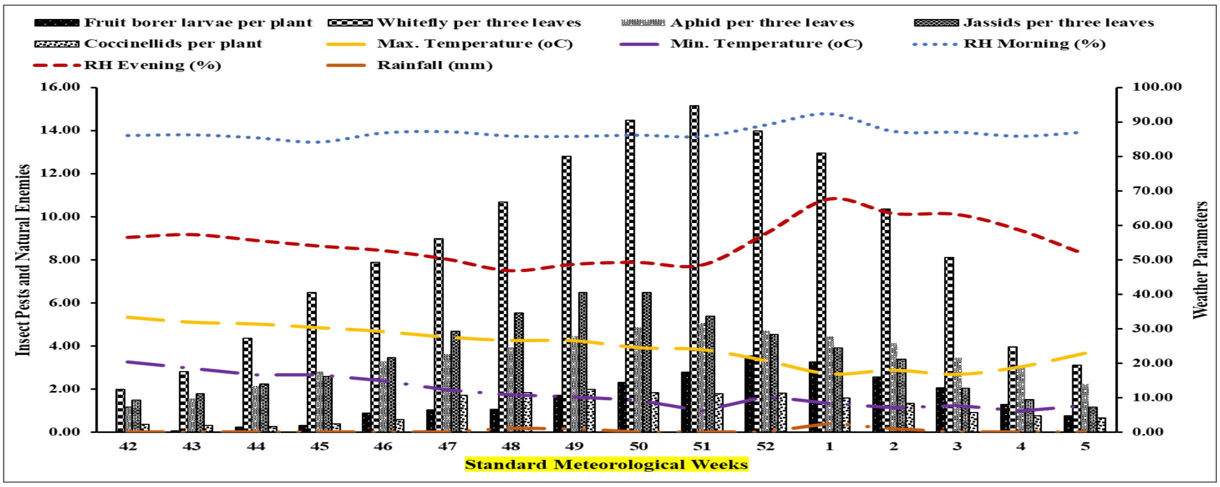

Fig. 1. Temporal pattern of pests and natural enemies activity in tomato ecosystems.

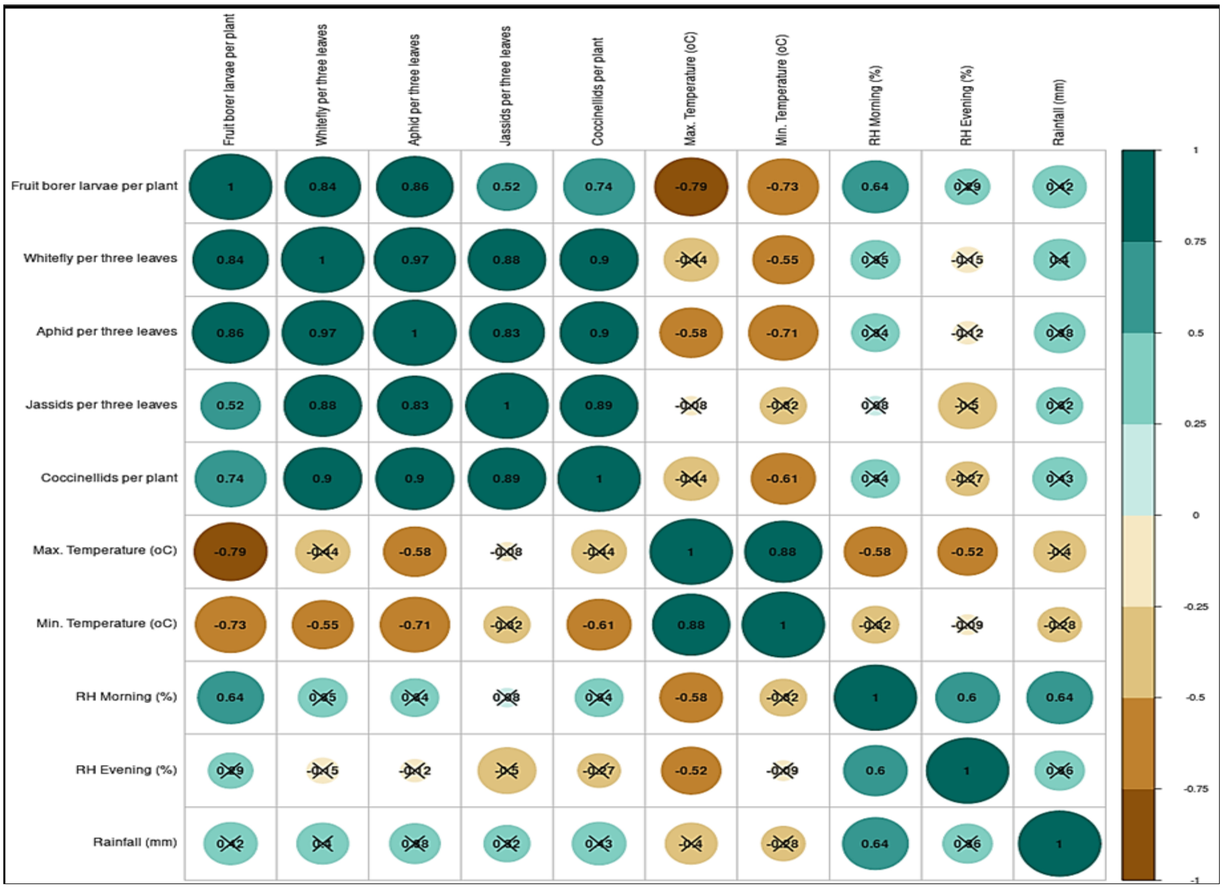

Fig. 2. Correlogram showing the relationship between insect pests, natural enemies and weather factors.

Whitefly (*Bemisia tabaci*)

The population trend of *B. tabaci* under fluctuating weather conditions revealed a steady build-up during the early growth stages of the tomato crop, followed by a gradual decline. The initial population was observed in the 42nd Standard Meteorological Week (SMW) with 1.99±0.46 individuals per three leaves. The population steadily increased through the crop's vegetative and early reproductive phases, peaking at 15.16±13.38 individuals per three leaves during the 51st SMW (late December). Following this peak, a gradual decline was noted from the 1st SMW (early January) onward, which likely corresponds with changes in plant physiology, weather conditions and possibly the implementation of pest management practices (Table 1 & Fig. 1). Correlation analysis revealed that whitefly populations were significantly negatively correlated with both maximum temperature ($r = -0.436^{*}$) and minimum temperature ($r = -0.549^{*}$), indicating that whiteflies preferred relatively cooler conditions during the observed period. Morning relative humidity showed a positive but non-significant correlation ($r = 0.353$), whereas evening relative humidity exhibited a negative correlation ($r = -0.151$) (Table 2 & Fig. 2). The data analyzed by using multiple regression revealed that maximum temperature (°C), minimum temperature (°C), morning relative humidity (%), evening relative humidity (%), rainfall (mm) together influenced to an extent of 54.80 ($R^2=0.548$) per cent of whitefly population (Table 3).

Additionally, rainfall had a positive but non-significant correlation ($r = 0.398$), suggesting that precipitation events did not considerably influence whitefly numbers (Table 2 & Fig. 2). These findings contrast slightly with some previous studies. For instance, higher temperatures were conducive to whitefly proliferation, while humidity had a suppressive effect (15). Similarly, it was noted that temperature strongly influences whitefly dynamics in tomato ecosystems. However, the findings suggest a more complex interaction, possibly due to local microclimatic differences, crop stage, or regional pest behaviour (16).

Aphid (*Aphis gossypii*) and *Coccinellids*

The population of *A. gossypii* exhibited clear seasonal dynamics influenced by prevailing weather conditions. The initial infestation was recorded during the 42nd Standard Meteorological Week (SMW), with a population of 1.15±1.15 aphids per three leaves. The aphid population progressively increased, peaking at 5.06±2.08 aphids per three leaves in the 51st SMW (late December). The population build-up was most notable from early November to the end of December, coinciding with favourable climatic conditions and tender crop growth stages (Table 1 & Fig. 1). Correlation analysis demonstrated that both maximum temperature ($r = -0.579^{**}$) and minimum temperature ($r = -0.708^{**}$) had significant negative correlations with the aphid population, indicating that lower temperatures favoured aphid multiplication.

In contrast, morning relative humidity ($r = 0.337$) and rainfall ($r = 0.378$) had positive but non-significant correlations, suggesting that higher humidity and occasional rain might have indirectly supported population build-up (Table 2 & Fig. 2). The data analyzed by using multiple regression revealed that maximum temperature (°C), minimum temperature (°C), morning relative humidity (%), evening relative humidity (%), rainfall (mm) together influenced to an extent of 85.10 ($R^2=0.851$) per cent of aphid population (Table 3). These observations confirm previous findings that aphid populations flourish under cool and humid conditions (17). The coccinellids were first observed in the 42nd SMW with a population of 0.35±0.35 individuals per plant, reaching their peak of 1.99±0.81 individuals per plant during the 49th SMW. The predator population followed a pattern like the aphids but declined slightly ahead of the pest's peak, likely influenced by environmental changes or prey availability. A strong and significant positive correlation ($r = 0.895^{**}$) was found between aphid and coccinellid populations, highlighting a close predator-prey relationship (Table 2; Fig. 2). Regarding biological control, Coccinellids recognized predators of aphids and the can consume a thousand of soft bodied insect like aphid during his entire life (18). These results align with similar synchrony in aphid and ladybird beetle populations, reinforcing the potential of coccinellids in regulating aphid infestations under field conditions. This underscores the importance of conserving and augmenting natural enemies in Integrated Pest Management (IPM) strategies for sustainable aphid control in tomato ecosystems (19).

Jassid (*Amrasca biguttula biguttula*)

The population dynamics of *A. biguttula biguttula* exhibited a distinct seasonal trend throughout the tomato growing season. Initial infestation was noted during the 42nd Standard Meteorological Week (SMW), with a population of 1.48±0.62 individuals per three leaves. The population gradually increased and peaked at 6.49±2.71 individuals per three leaves in the 50th SMW (mid-December). The highest population levels were recorded from November to mid-December, followed by a steady decline from January onward (Table 1 & Fig. 2). This trend suggests that jassids were more active during the crop's active vegetative and early reproductive stages. Unlike other major pests, the jassid population showed no statistically significant correlation with weather parameters. Correlation analysis revealed non-significant negative relationships with maximum temperature ($r = -0.082$), minimum temperature ($r = -0.316$), morning relative humidity ($r = 0.084$) and rainfall ($r = 0.315$) showed non-significant positive relationships. Evening relative humidity showed a significant negative correlation ($r = -0.496^{*}$), suggesting some sensitivity to changes in late-day moisture conditions (Table 2 & Fig. 2). The data analyzed by using multiple regression revealed that maximum temperature (°C), minimum temperature (°C), morning relative humidity (%), evening relative humidity (%), rainfall (mm) together influenced to an extent of 63.20 ($R^2=0.632$) per cent of jassid population (Table 3). These observations indicate that jassid population dynamics are relatively stable and less influenced by short-term climatic variations than other sap-sucking pests. These findings are supported by earlier research. Similar behaviour is noted in that jassid populations tend to fluctuate more with crop stage and host suitability rather than with specific temperature or humidity thresholds (20). Likewise, environmental parameters are relatively limited in determining jassid abundance compared to other factors like varietal resistance and crop phenology (21).

Conclusion

In conclusion, while pests like fruit borer, whitefly and aphid showed significant correlations with temperature and humidity, jassids appeared less sensitive to climatic changes, indicating the need for consistent monitoring irrespective of weather trends. Understanding the temporal peak periods and relative climate independence of jassid infestations is critical for ensuring timely interventions as part of a comprehensive Integrated Pest Management (IPM) approach in tomato production systems. Multiple regression revealed that weather factors explained 54.8 % to 85.1 % of pest population variations, highlighting their crucial role in pest forecasting and management.

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Authors' contributions

N carried out conceptualization, data curation, methodology, investigation and original drafts preparation. SKS carried out conceptualization, supervision, formal analysis, review editing. KRS, VKD and AR carried out draft preparation and editing. UC carried out supervision, drafts preparation and editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical issues: None

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