Article Type: Research
J Name: Modern Phytomorphology
Short name: MP
ISSN: ISSN 2226-3063/eISSN 2227-9555
Year: 2025
Volume: 19
Page numbers: 121-128
DOI: 10.5281/zenodo.200121
(10.5281/zenodo.2025-19)
Short Title: Temporal patterns of *Diaphorina citri* (Hemiptera: Liviidae) population on selected citrus varieties in response to weather variables in Faisalabad, Pakistan

RESEARCH ARTICLE

Temporal patterns of *Diaphorina citri* (Hemiptera: Liviidae) population on selected citrus varieties in response to weather variables in Faisalabad, Pakistan

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Received: 16.01.2025, Manuscript No: mp-24-158829**|** **Editor Assigned:** 18.01.2025, Pre-QC No. mp-24-158829(PQ) **|** **Reviewed:** 27.01.2025, QC No. mp-24-158829(Q) **|** **Revised:** 02.02.2025, Manuscript No. mp-24-158829(R) **|** **Accepted:** 08.02.2025 **|** **Published:** 14.02.2025

Abstract

Citrus Greening (CG), also called Huanglongbing (HLB), is an invasive bacterial infection of citrus crops, caused by *Diaphorina citri*, or citrus psyllid. This bacterium is a major threat to productivity as well as export of citrus crops. In the current research, the population dynamics of *D. citri* was surveyed on Mosambi, Feutrell and Kinnow orchards of district Faisalabad from June 2023 to 2024. In addition, different abiotic factors i.e. temperature, rainfall, humidity, sunshine, and evaporation rates were assessed to investigate their relation with the distribution of *D. citri*. The month of September and October were found to be the most active time period of *D. citri* growth, while, their lowest population was witnessed from the month of December till March. The population of *D. citri* was maximum when abiotic factors, i.e. 21.54°C-34.32°C temperature, 57.42°C-82.57% relative humidity, 7.57 hours sunlight duration, 1.90 mm evaporation, and no rainfall were recorded. The population of *D. citri* was negatively correlated with humidity and rainfall; however, temperature, sunshine, and evaporation rates were observed to be positively correlated. These findings will be helpful for *D. citri* pest management in district Faisalabad.

Keywords: *Diaphorina citri*, Abiotic factors, Population dynamics, Correlation, Faisalabad

Introduction

Citrus belongs to the family Rutaceae, ranks first among the fruit crops in Pakistan, making up 40% of the total fruit production. Pakistan produces 2.89 million tons annually, ranking among the world's top 15 citrus producers (Sajid *et al.* 2021). Approximately 95% of citrus is merely produced by Punjab (Fateh et al. 2017) and 90% of Pakistani citrus exports comprise kinnow (Usman et al. 2018). The world's top citrus producers are China and Brazil, which together produce nearly 45 million tons annually. The USA, India, Mexico, and Spain follow with 10.7 million tons, 8.6 million tons, 7.2 million tons, and 5.5 million tons of production, respectively (Ullah et al. 2017). Citrus fruits are important sources of flavonoids, vitamins, amino acids, fatty acids, phenolic acids, carotenoids, and minerals (Liu et al. 2022). The common cultivated varieties are Oranges (Mosambi, Valencia, Red blood, and Jaffa), Mandarines (Kinnow, Sangtra), Grapefruits (Shamber, Duncan), Lime (Sweet lime, Kaghzi lime), and lemons (Eureka, Lisbon, rough), etc. (Cheema and Jamali 2020).

In Pakistan, citrus export is one of the main source of foreign exchange. This industry has been facing a major threat i.e. citrus greening or huanglongbing since the late 80s (Roma Tandel and Pandya 2020). This disease was first reported in 1908 in Taiwan and then spread to other countries (Ajene et al. 2020). The symptoms include chlorosis, tree stunting, low flowering and fruit yield that ultimately results in decreasing life span of citrus trees (Sajid et al. 2022). *Diaphornia citri* (Hemiptera: Liviidae), commonly known as Asian citrus psyllid is a vector of bacteria '*Candidatus Liberibacter*', a putative causative agent of citrus greening disease, known also as Huanglongbing (HLB), considered one of the most destructive diseases of citrus worldwide (Coralla et al. 2021). *D. citri* was first described in Taiwan in 1907, and it is thought to be native to Southwestern Asia (Halbert et al. 2004). Moreover, *D. citri* is a sap-sucking insect pest specie, responsible for direct or indirect damages of citrus fruit quality and tree health. The insect feeds on sap of younger leaves or buds and can inject toxins that produce deformations that can cause the death of the apical bud (Iqbal et al. 2020).

D. citri result in massive economic losses by reducing yields of citrus plants worldwide (Martini et al. 2014; Monzo and Stansly 2017). To control their spread, detailed information about their population dynamics is very crucial (Ahmad *et al.* 2023). Abiotic factors that impact their population dynamics include temperature, rainfall, and humidity (Sajid et al. 2022; Farooq et al. 2019). This study was designed to investigate the population dynamics of *Diaphorina citri* on three citrus varieties: Mosambi, Kinnow, and Feutrell. The research aimed to monitor and compare the pest population across these citrus types to identify any varietal differences in susceptibility or preference. Additionally, the study assessed the influence of various abiotic factors, including temperature, humidity, rainfall, sunshine duration, and evaporation, on the population distribution of *D. citri.* By analyzing the correlation between pest dynamics and environmental variables, the study sought to provide valuable insights for optimizing pest management practices and mitigating the impact of *D. citri* in citrus orchards.

Materials and Methods

Study area

This study was designed and conducted to monitor the population fluctuation of *Diaphornia citri* (nymph and adults) in citrus orchards of District Faisalabad, Punjab, Pakistan at standard week interval from June 2023 to 2024.

Data collection

The data regarding *D. citri* population was recorded after one-week interval by randomly selecting 20 plants. Five twigs were selected in each of four directions of each plant for counting nymph and adult population of *D. citri* (Zeb *et al.* 2011). Weather parameters viz; temperature (maximum and minimum), relative humidity (morning and evening), rainfall, bright sunshine and evaporation were collected from meteorological data recorded at the observatory of plant physiology section Agronomic Research Institute, Faisalabad (31.4187° N, 73. 0791° E). Data collection began one standard week prior to the initial appearance of the *D. citri* population and continued until the final week of pest presence.

Statistical analysis

The collected data was analyzed statistically using IBM SPSS software. Correlation and regression were performed to determine the relationship between *D. citri* population with respect to abiotic factors (Steel et al. 1997). Line graphs were constructed by using Graphpad Prism 10 (Boston, Massachusetts, USA) to visually depict the fluctuations in the population of *D. citri* across various time intervals.

Results

Population fluctuations of *Diaphorina citri*

The *D. citri* population (nymphs and adults/twig) were recorded from June 2023 to 2024 on three citrus varieties (Mosambi, Kinnow, and Feutrell) in orchards of Faisalabad, Punjab, Pakistan. *D. citri* was found to be the highest (6.15/twig on kinnow, 5.20/twig on Mosambi, and 4.65/twig on Feutrell) during the 2nd week of October 2023. These interpretations coincided with a maximum temperature of 34.25°C, relative humidity of 74.14%, and an evaporation rate of 1.90 mm. After October 2023, the population of *D. citri* began to decline across all selected citrus varieties. The minimum population of *D. citri* (0.65 insects per twig–0.50 insects per twig) was recorded from December 2023 to March 2024.

Remarkably, no *D. citri* individuals were observed from January 2024 to the first two weeks of February 2024, likely due to extreme environmental conditions.

Relation between *Diaphorina citri* population and abiotic factors

The positive correlation was noted between D. citri population and various abiotic factors including temperature, bright sunshine, and evaporation (Fig. 1; Tab. 1). Temperature was found to be the most important abiotic factor significantly prompting D. citri population. However, the significant negative correlation was recorded between D. citri counts and rainfall, relative humidity. The highest population was witnessed during 2nd week of October when maximum, minimum temperature, relative humidity during morning and evening, bright sunlight, rainfall, and evaporation was recorded to be 34.32, 21.54 (°C), 82.57, 57.42%, 7.57 hrs., 0 mm, and 1.90 mm, respectively. Tab. 1 represents population fluctuations of D. citri influenced by temperature, relative humidity, rainfall, sunshine and evaporation. Regression models reveal that temperature and relative humidity emerged as the primary factors influencing fluctuations in the D. citri population.

Table. 1. Average numbers of *D. citri*/twig on citrus varieties (Kinnow, Mosambi, and Feutrell) with respect to their correlation with abiotic factors (temperature, relative humidity, bright sunshine, rainfall, and evaporation) and regression coefficient.

Standard week	No. of *D. citril* twig			Temp (°C)			RH (%)			Bright sunshine (hrs)	Rainfall (mm)	Evapo-ration (mm)
	Kinnow	Mosambi	Flutter	Max.	Min.	Avg.	Mor.	Eve.	Avg.			
	V^1	V^2	V^3	X^1	X^2	X^3	X^4	X^5	X^6	X^7	X^8	X^9
June, 2023	4.35	3.9	3.1	37.64	22.5	30.08	58.71	47.28	52.99	9.42	0.2	2.54
	4.4	3.8	3.35	40.4	26.31	33.35	64.14	54	59.7	10.28	27	3.76
	4.75	3.85	3.7	39.61	27.57	33.59	64.42	51.28	57.85	8.85	2.4	3.81
	4.8	3.95	3.87	38.8	27.85	33.37	70.85	56	63.42	7.71	9.8	4.15
July	4.35	3.65	3.5	37.78	26.91	32.35	84	60.42	72.21	6.14	4.78	3.15
	4.4	3.3	3.05	35.38	26.74	31.06	87	71.71	79.35	6.14	16.6	2.12
	4.75	3.25	3.35	34.78	27.85	31.32	83.85	79.71	81.78	4.5	20.65	1.85
	4.8	3.85	3.4	34.6	27.28	30.94	84.28	76.14	80.21	3.57	10.2	1.61
August	5	4.5	3.95	38.5	28.87	33.68	79.57	60.71	70.14	9.28	0	1.94
	5.15	4.05	3.7	38.5	28.64	33.57	77.42	60.85	69.14	9.42	0	1.92
	5.25	4.35	4	38.76	29.31	33.99	75.71	60	67.85	6.85	1	2.27
	5.45	4.65	4.05	37.24	27.57	32.4	75	65.14	70.07	6.42	7.5	1.99
September	5.6	4.4	4.1	38.52	26.65	32.59	71	54.85	62.92	9.28	0	2.1

	5.5	4.85	4.25	39.07	28.28	33.67	76	56.28	66.14	7.42	0	2.28
	5.45	4.65	4.3	34.35	26.04	30.2	85.71	75.42	80.57	5.71	4.93	2.7
	5.55	4.7	4.4	33.52	22.71	28.12	87.57	69.42	78.5	6.71	33.93	1.78
	5.65	4.9	4.55	36.07	20.14	28.1	74.14	48.28	61.21	8.85	0	1.55
	6.15	5.2	4.65	34.32	21.54	27.93	82.57	57.42	70	7.57	0	1.9
October	5.75	4.45	4.1	28.07	17.18	22.62	87.71	68	77.85	7.42	12.5	1.82
	5.85	4.2	3.9	32	17.71	24.85	86.85	57.14	72	7.85	0	1.42
	4.7	3.85	3.7	28.82	18.28	23.55	93.85	67.85	80.85	3	0	0.5
	4.75	3.5	3.2	26.75	14.14	20.45	89.57	61.71	75.64	4.82	4.2	1.1
November	4.55	3.4	3.15	25.78	11.5	18.64	90.28	54.85	72.57	4.35	0	0.77
	3.9	3.5	2.85	24.88	15.46	18.17	90	66.14	78.07	3.42	0	1.35
	0.65	0.3	0.25	25.3	9.55	17.42	91.28	53	72.14	7.14	0	0.79
	0.5	0.15	0.05	22.14	6.84	14.49	94.14	61.71	77.92	5.57	0	0.6
December	0.45	0.3	0.25	22.01	6.2	14.1	91.85	58.42	75.14	6.28	0	0.45
	0.1	0.05	0.02	23.6	7.21	15.4	92.28	59.42	75.85	5.28	0	0.67
	0	0	0	11.12	6.88	9	88.85	81.71	85.28	1	0	0.33
	0	0	0	11.01	5.07	8.04	97	85.14	91.07	3	0	0.12
January, 24	0	0	0	11.57	4.65	8.11	98.85	80.85	89.85	2	0	0.12
	0	0	0	14.61	5.8	10.2	91.71	68.85	80.2	4	0	0.45
	0	0	0	19.95	8.07	14.01	85	46.57	65.78	5	2.2	0.9
February	0	0	0	23.81	6.08	14.95	84.14	39.28	61.71	7.42	0	1.06
	0.55	0.35	0.2	24.28	9.47	16.87	87.57	47.28	67.42	6.14	1.2	1.4

	0.65	0.45	0.1	23.38	8.55	15.97	80.28	39.85	60.07	6.71	4.1	1.17
	0.9	0.75	0.45	21.44	8.24	14.84	83.14	49.85	66.5	6.28	1.93	1.15
March	0.8	0.4	0.3	26.7	11.85	19.27	74.85	46.71	60.78	6.57	0.6	1.45
	0.7	0.45	0.25	30.92	13.21	22.07	74.28	37.42	55.85	8.42	0	1.89
	0.5	0.15	0.1	30.52	16.88	23.7	81.28	50.85	66.07	5.28	5.5	1.69
	2.7	1.9	1.75	33.76	16.93	25.34	59.29	30.86	45.07	9.36	0	2.8
April	3.25	2.1	1.85	33.14	19.7	26.42	61.14	44.86	53	5.57	3.6	2.64
	3.35	2.95	2.65	32.64	19.04	25.84	67.57	45.29	56.43	8.57	0	1.97
	3.7	3.15	3.05	40.86	24.86	32.86	60.86	34.86	47.86	8.57	0.5	2.99
	4.9	3.6	3.35	37.97	20.28	29.12	54.28	28	41.14	7.42	0	2.35
May	5.1	4.45	3.95	39.24	24.52	31.88	57.85	39.14	48.5	9.35	6	3.67
	5.85	4.95	4.1	43.92	27.11	35.52	42.86	24.71	33.79	11	0	4.05
	5.9	4.75	4.25	44.96	27.09	36.02	47.71	28.43	38.07	11.29	1.6	4.21
	5.35	4.8	4.35	41.91	27.32	34.62	52.14	31.28	41.71	9.85	1.6	4.4
Jun-24	5.6	4.95	4.05	42.91	27.44	35.17	44.14	22.14	33.14	11	0	4.93
	4.3	3.65	3.05	41.61	28.62	35.12	56	36.71	46.35	9.71	9.8	4.59
	3.8	3.15	3	41.18	28.9	35.04	57.57	36.28	46.92	10.28	0	4.12
			V¹	0.801**	0.851**	0.838**	-0.457**	-0.116^{NS}	-0.296*	0.482**	0.264^{NS}	0.597**
Correlation coefficient (r)			**V²**	0.806**	0.859**	0.843**	-0.477**	-0.131^{NS}	-0.314*	0.505**	0.246^{NS}	0.620**
			V³	0.798**	0.860**	0.841**	-0.445**	-0.095^{NS}	-0.278*	0.478**	0.266^{NS}	0.603**
Regression			**V¹**	64.11	72.47	70.16	20.9	1.35	8.77	23.23	6.99	35.65

V^2	65	73.71	71.08	22.75	1.71	9.87	25.49	6.06	38.44
V^3	63.61	74.01	70.65	19.79	0.91	7.76	22.83	7.09	36.38

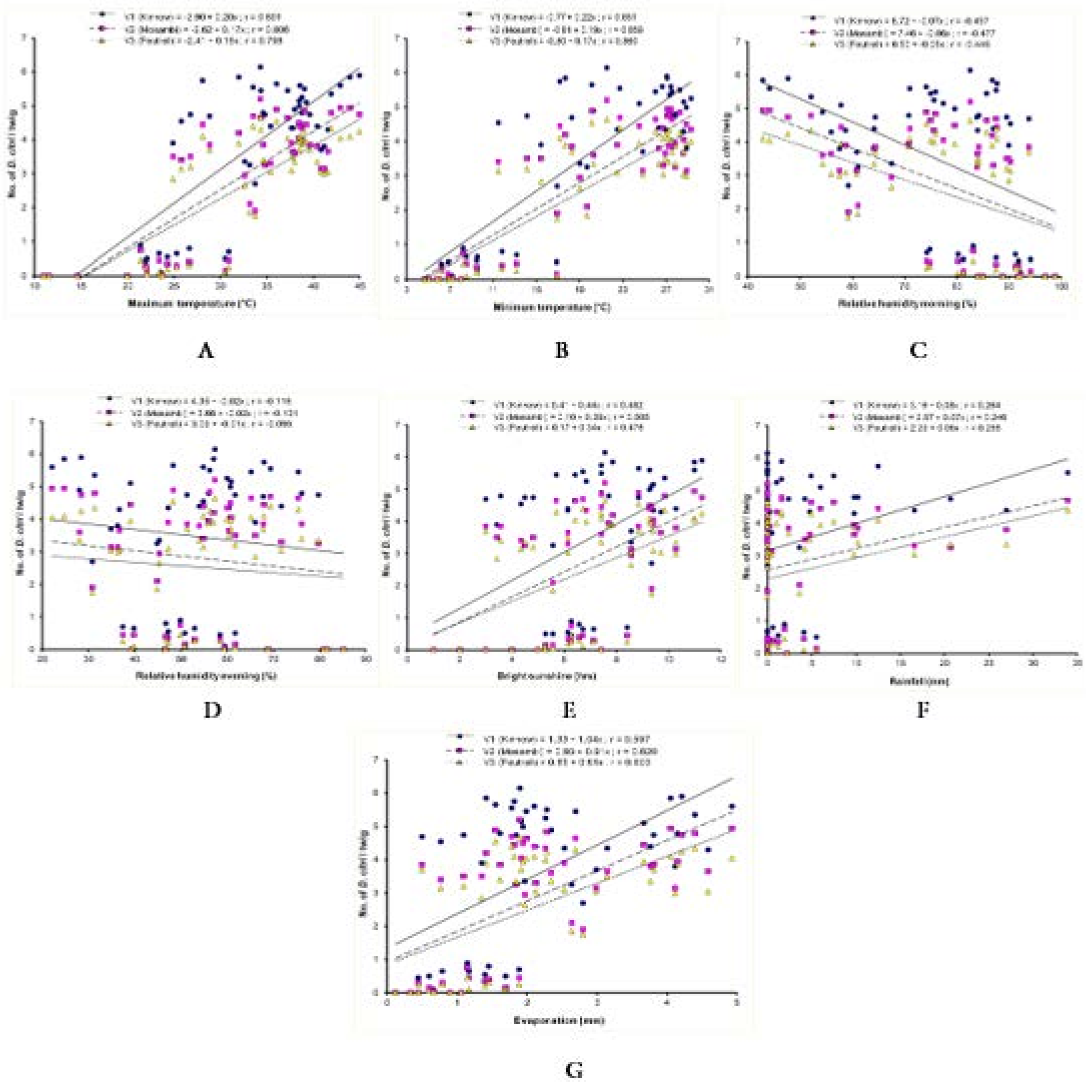

Figure. 1. **Effect of different meteorological factors [maximum temperature (a), minimum temperature (b), relative humidity morning (c), relative humidity evening (d), bright sunshine (e), rainfall (f), and evaporation (g)] with number of *D. citri*/twig regarding three varieties i.e., Kinnow, Mosambi and Feutrell.**

Discussion

The results indicated that the peak population of adult and nymph *D. citri* in the Faisalabad district was recorded in September and October, whereas the lowest populations were observed from December to March. These results align with the findings of Fiaz *et al.* (2018) and Li *et al.* (1996). The present study reveals a positive correlation between mean weekly temperature and the population of adult and nymph Asian citrus psyllids, indicating that *D. citri* population tend to increase with rising temperatures at the onset of spring. These findings are consistent with the results reported by Ahmed et al. (2004) and Fiaz et al. (2018).

Existing research indicates that temperature, rainfall, and maximum/minimum temperatures play a crucial role in the growth of *D. citri* population. However, relative humidity appears to have a negligible impact on *D. citri* population.

These findings align with previous studies by Fiaz et al. (2018) and Devi and Sharma (2014). The significant correlation between these three environmental factors and *D. citri* population suggests that their development is heavily influenced by these conditions. Temperature, in particular, has a substantial effect on the increase or decrease of *D. citri* population, as reported by Bayles et al. (2017).

The spread of *D. citri* population is primarily driven by temperature fluctuations (Bayles et al. 2017). Temperature plays a significant role in *D. citri* egg-laying. While *D. citri* females can live for up to 300 days at 16°C, they do not lay eggs at this temperature (Fung and Chen 2006). However, they begin to lay eggs when the temperature reaches 26°C (Liu and Tsai 2000). Additionally, *D. citri* females lay more eggs at temperatures between 28°C and 32°C (Fung and Chen 2006; Liu and Tsai 2000). Temperature also affects psyllid survival, as they can tolerate temperatures as high as 45°C and as low as -6°C. Overall, temperature influences the development, reproduction, and lifespan of *D. citri* population.

Rainfall plays a significant role in the growth and decline of *D. citri* population. Setamou et al. (2023) found that heavy rainfall is associated with lower *D. citri* population, as it washes away eggs and nymphs. In contrast, low rainfall conditions favor the growth of *D. citri* population (Devi and Sharma 2014). The seasonal distribution of *D. citri* is entirely dependent on rainfall patterns (Devi and Sharma 2014).

Conclusion

The study determined that the population of *Diaphorina citri* reached its peak during the second week of October, indicating this period as the most active phase for the pest. The present study concluded that temperature, bright sunshine, and evaporation exhibited a strong positive correlation with the population dynamics of *D. citri* on three citrus cultivars (Mosambi, Kinnow, and Feutrell). This denotes that a linear increase in these variables paralleled to an increase in the population of *D. citri*. In contrast, rainfall and morning relative humidity showed a non-significant influence on the population of *D. citri*. These findings highlight the influence of climatic variables on *D. citri* populations, supporting the development of predictive models and improved pest management strategies.

Conflict of interest

The authors affirm that they have no conflicts of interest to disclose, either financial or non-financial, that could have influenced the outcomes or interpretations of this research.

Authors contributions

ZA perform the whole study and wrote a manuscript. MA supervised the whole study and proof read the manuscript. SMH and AR reviewed the manuscript and provided suggestions to improve the previous version. The final manuscript has been read and authorized by all authors.

Acknowledgement

The authors extend their heartfelt gratitude to the Department of Zoology, Government College University Faisalabad, for generously providing the necessary research facilities and support for this study.

Funding

Not applicable

Ethical approval

Not applicable

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