



Research Article

Monitoring of Okra Yellow Vein Mosaic Disease in Relation to Epidemiological Factors

Muhammad Asif Shabbir¹, Yasir Iftikhar^{1*}, Muhammad Ahmad Zeshan¹, Ashara Sajid¹, Mustansar Mubeen¹ and Talha Shafique²

¹Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha-40100, Pakistan; ²Department of Knowledge Research Support Service (KRSS), University of Management and Technology, Lahore-54782, Pakistan.

Abstract | The present study was conducted to monitor Okra Yellow Vein Mosaic Disease (OYVMD) and its association with key epidemiological factors under current climate change conditions. Field experiments were carried out in selected districts of Sargodha, Khushab, Bhakkar and Mianwali where okra plants were systematically tagged for consistent monitoring throughout the study period. The objective was to assess disease severity in relation to environmental parameters including average temperature, relative humidity, wind speed and precipitation. Disease severity was recorded during regular field visits based on symptom expression and concurrent environmental data were collected to identify potential correlations. The results indicated that disease severity was negatively associated with average temperature during both 2020 ($p=0.309$) and 2021 ($p=0.859$). Precipitation exhibited a positive relationship with disease severity with p -values of 0.351 and 0.099 in 2020 and 2021 respectively. Wind speed showed a weak positive effect in 2020 ($p=0.749$) and a weak negative effect in 2021 ($p=0.716$). Relative humidity demonstrated a positive association in 2020 ($p=0.215$) and a negative association in 2021 ($p=0.907$). These findings highlight the complexity of environmental influences on OYVMD progression and suggest that environmental parameters alone do not fully explain the observed disease patterns. Although the associations identified were weak but the study highlights the importance of integrating both environmental and varietal factors in managing OYVMD. Future research incorporating additional variables, such as soil health, pest pressure, and viral strain diversity, is recommended to develop more robust predictive models and effective disease management strategies.

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***Correspondence** | Yasir Iftikhar, Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha-40100, Pakistan;

Email: yasir.iftikhar@uos.edu.pk

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Keywords | Monitoring, OYVMV, Epidemiology, Environment, Correlation, Management strategies



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Introduction

Monitoring Okra Yellow Vein Mosaic Disease (OYVMD) from an epidemiological

perspective is essential for developing effective management strategies that minimize economic losses (Dhole *et al.*, 2023). Continuous field surveillance has demonstrated that OYVMD is

influenced by a range of environmental factors including average temperature, humidity, rainfall and wind speed (Mubeen *et al.*, 2021). These factors not only affect the symptom development in okra plants but also influence the population dynamics of the vector responsible for transmitting the virus (Davis and Thompson, 2024). Temperature plays a significant role in the replication and movement of viruses within their hosts (Mubeen *et al.*, 2021). Viruses can maintain their stability and infectivity within an optimal temperature range and facilitate their movement within the host (Bisht and Te Velhuis, 2022). However, extreme temperature conditions can adversely affect both virus infection and vector survival (Yadav *et al.*, 2022). High temperatures may disturb molecular bonds within viral structures and cause denaturation or degradation which reduces viral infectivity (Dhole *et al.*, 2023). High temperatures can cause biochemical imbalances in the host and weaken its defense mechanisms which promote the virus growth and its movement (Umar *et al.*, 2023). Low temperatures help preserve viral particles outside the host and increase the chances of transmission. The survival and population dynamics of whitefly (primary vector of OYVMV) are closely linked to temperature and humidity (Yadav *et al.*, 2022). Montes and Pagán (2022) found that extreme temperatures negatively impact whitefly survival which in turn affects the incidence of viral diseases (Kumbhar *et al.*, 2023). Fluctuations in relative humidity have also been reported to influence whitefly reproduction and activity (Dhole *et al.*, 2023). Moderate humidity levels support whitefly population growth and facilitate efficient virus transmission while high rainfall may reduce vector activity by washing away insects from plant surfaces (Saghafipour *et al.*, 2020). Wind speed and precipitation significantly influence OYVMV by affecting the whitefly vector. High wind speeds can disrupt whitefly movement and reduce their ability to locate and colonize host plants (Ma *et al.*, 2022). Precipitation also affects whitefly populations and the transmission of OYVMV as high rainfall can reduce whitefly numbers by impacting their survival and reproduction rates (Yadav *et al.*, 2022). Cooler weather below 16 °C combined with high relative humidity and rainfall has been shown to be detrimental to vector populations and the spread of OYVMV (Han *et al.*, 2013; Montes and Pagán, 2022). Statistical models based on correlation and regression analyses highlight the significant associations between meteorological data and the severity of OYVMD

with specific results showing p-values less than 0.05 that indicate statistically significant relationships. These findings have enabled researchers to develop predictive tools for disease forecasting (Manju *et al.*, 2019). The complex interactions within the disease triangle e.g., host plant susceptibility, viral strain virulence and vector efficiency often complicate the development of OYVMD (Dhole *et al.*, 2023). Recent multidisciplinary research combining fields like plant pathology, entomology and environmental science emphasizes that while weather conditions play a pivotal role and factors such as host genetic resistance and mixed viral infections also contribute significantly to disease outcomes. This underscores the importance of integrated approaches that consider the dynamic interactions between host, pathogen and environmental factors (Davis and Thompson, 2024). An integrated approach that combines field monitoring, advanced statistical modeling and targeted vector management is necessary (Singh *et al.*, 2020) to develop predictive models and sustainable management strategies for OYVMD (Varman *et al.*, 2025). Investigating the effects of environmental factors on OYVMD through detailed epidemiological studies provides the foundation for developing innovative disease management and prediction models (Mathew *et al.*, 2022). Researchers can identify critical factors for predicting disease development and epidemics in the future by analyzing how various climatic and ecological conditions affect the spread and severity of OYVMD (Jamir *et al.*, 2020). Future research should aim to refine these predictive models by incorporating additional biotic factors such as soil interactions, pests and beneficial organisms. This comprehensive approach will enhance sustainable okra production and contribute to global food security by ensuring a stable supply of okra as a vegetable.

Materials and Methods

Monitoring of OYVMV

A survey was conducted across the okra-growing districts of the Sargodha Division specifically in Sargodha, Bhakkar, Mianwali and Khushab (Figure 1) during the 2020 and 2021 growing seasons. The sample collection sites in Mianwali included Musakhel, Rokhri, Chasma and Harnoli; in Bhakkar, Duellwala, Goharwala, Jhok Mehar Shah and Kotla Jam; in Khushab, Jauharabad, Mitha Tiwana, Padhrar and Naushehra; and in Sargodha, Chak 104 SB, Chak

128 SB, Chak 136 SB and Sial Sharif. Samples were classified according to the visible symptoms of Okra Yellow Vein Mosaic Virus (OYVMV) including yellowing of the veins, leaf curling, stunted growth and reduced fruit yield.

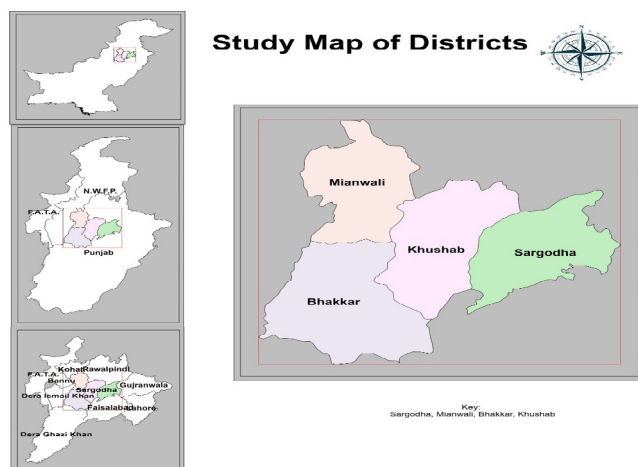


Figure 1: Map of selected districts under study.

Data collection

Meteorological data including average temperature, humidity, precipitation and wind speed were recorded daily from the NASA weather observatory. Data collection spanned the entire growing season to capture variations in environmental conditions to ensure all relevant meteorological factors were represented. All other parameters necessary for analysis were calculated from the obtained data.

Statistical analysis

The relationship between OYVMV severity and meteorological factors was analyzed using Multiple Linear Regression. Multiple Linear Regression (MLR) was employed to model the linear relationships between disease severity and the identified significant meteorological factors (temperature, humidity, precipitation, wind speed). The model assumes a straight-line relationship between the independent and dependent variables and linear model was used to assess the strength and direction of the relationships between environmental factors and OYVMV severity. All statistical analyses were performed using R-studio, with a significance level set at $P < 0.05$ (Antonelli *et al.*, 2020).

Results

Impact of environmental factors on OYVMV

The study provided detailed insights into the severity of Okra Yellow Vein Mosaic Virus (OYVMV) across

multiple divisions and okra varieties during the cropping seasons of 2020 and 2021 and the results revealed considerable variability among varieties and regions. This variability highlights the influence of varietal susceptibility and localized environmental conditions on disease developments. Significant differences in disease severity among varieties suggested that genetic resistance and interactions with environmental factors played important roles in disease expression.

Correlation of environmental factors with OYVMV

The correlation analysis between Disease Severity Index (DSI) and environmental factors, including average temperature, precipitation, wind speed and humidity indicated that no statistically significant associations were found during either 2020 or 2021. In 2020, very low coefficients of determination (R^2) were observed for average temperature (0.00084), precipitation (0.00935), wind speed (-0.01443) and humidity (0.01954) with all p-values well above the conventional significance threshold of 0.05 which confirm the absence of meaningful relationships. Similarly, in 2021, R^2 values remained weak with -0.0156 for average temperature, 0.0726 for precipitation, -0.0139 for wind speed and -0.0159 for humidity. Although precipitation in 2021 exhibited a relatively higher R^2 and a p-value of 0.0769, it still did not achieve statistical significance which highlight that only a tentative association between precipitation levels and disease severity (Table 1). Overall, the correlation results imply that the environmental variables considered in this study had little explanatory power for the variations observed in disease severity and the weak correlations observed are likely due to random variation rather than reflecting true underlying relationships.

Table 1: Correlation of disease severity index with environmental factors.

Factor	Correlation/ P (2020)	Correlation/P (2021)
Temperature	-0.129/0.309	-0.023/0.859
Precipitation	0.119/0.351	0.208/0.099
Windspeed	0.041/0.749	-0.046/0.716
Humidity	0.157/0.215	-0.015/0.907

Regression analysis of weather factors with OYVMV severity

Multiple linear regression analyses further supported the weak relationship between environmental

variables and OYVMV severity. In 2020, regression models produced minimal R^2 values for individual factors (0.0167) for average temperature (Figure 2), 0.0141 for precipitation (Figure 3), 0.00167 for wind speed (Figure 4) and 0.0247 for humidity (Figure 5) with the overall model explaining only 4.3% of the variation in disease severity ($R^2 = 0.043$) and an adjusted R^2 of -0.022 suggested no meaningful predictive power (Tables 2 and 3). Similarly, the 2021 model demonstrated very limited explanatory capacity with R^2 values of 0.00051 for average temperature (Figure 6), 0.0432 for precipitation (Figure 7), 0.00215 for wind speed (Figure 8) and 0.00022 for humidity (Figure 9). The overall model explained just 5.3% of the variation ($R^2 = 0.053$) with an adjusted R^2 of -0.011 (Tables 4 and 5). Although precipitation in 2021 approached significance ($p = 0.0994$), it still fell short of the 0.05 threshold and highlighted that even the strongest environmental predictor was insufficient to confidently explain variations in disease severity. The non-significant F-statistics further emphasized the lack of predictive strength in the models across both years and reinforced the idea that other unmeasured factors likely contributed more substantially to disease outcomes.

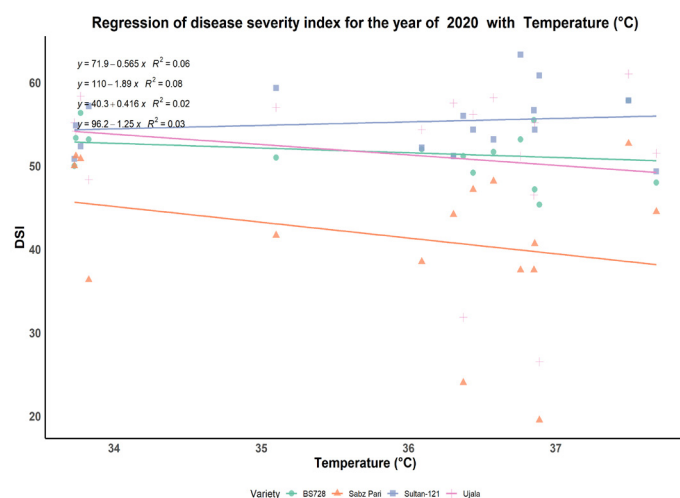


Figure 2: Regression of disease severity index of different varieties with average temperature FTY of 2020.

Table 2: Regression summary of disease severity index with the environmental factors (2020).

Coefficients of factors	Standard errors	T-Stat	P values	Parameter
-80.491	143.699	-0.560	0.578	(Intercept)
3.060	3.592	0.852	0.398	Temperature
-2.884	3.159	-0.913	0.365	Precipitation
-4.317	5.909	-0.731	0.468	Windspeed
0.881	0.730	1.206	0.233	Humidity

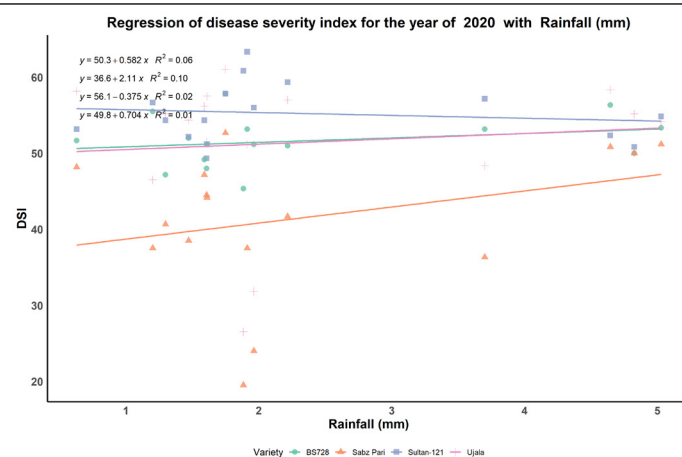


Figure 3: Regression of disease severity index of different varieties with Rainfall/Precipitation FTY of 2020.

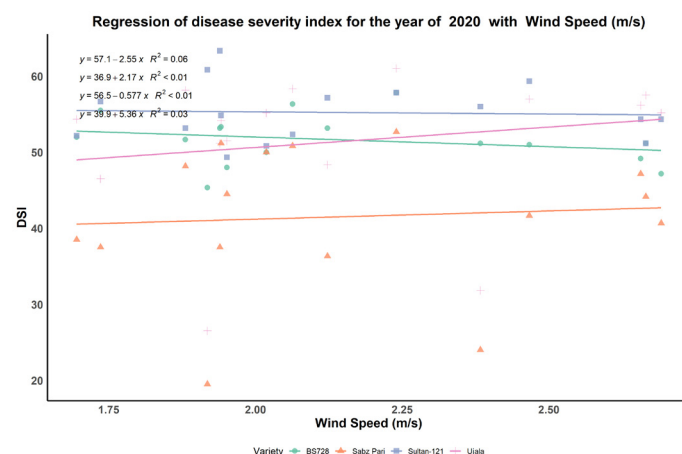


Figure 4: Regression of disease severity index of different varieties with Wind Speed FTY of 2020.

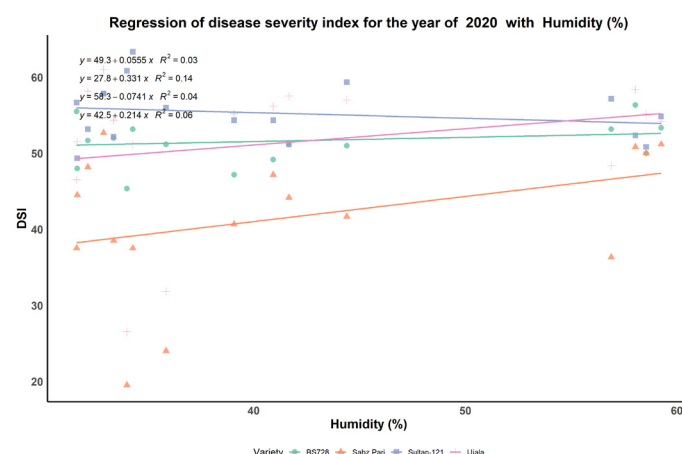


Figure 5: Regression of disease severity index of different varieties with Humidity FTY of 2020.

Table 3: Regression model statistics (2020).

Statistic	Value
R-Squared value	0.043
Adjusted R-squared value	-0.022
F value-statistic	0.665
P-value	0.619

Table 4: Regression summary of disease severity index with the environmental factors (2021).

Coefficients of terms	Standard errors	T Stats	P values	Parameter
42.001	67.534	0.622	0.536	(Intercept)
0.072	1.602	0.045	0.964	Temperature
0.764	0.446	1.711	0.092	Precipitation
1.812	7.168	0.253	0.801	Windspeed
-0.099	0.313	-0.317	0.752	Humidity

Table 5: Regression model statistics (2021).

Statistic	Value
R-squared values	0.053
Adjusted R-squared values	-0.011
F-statistics	0.829
P-Value	0.512

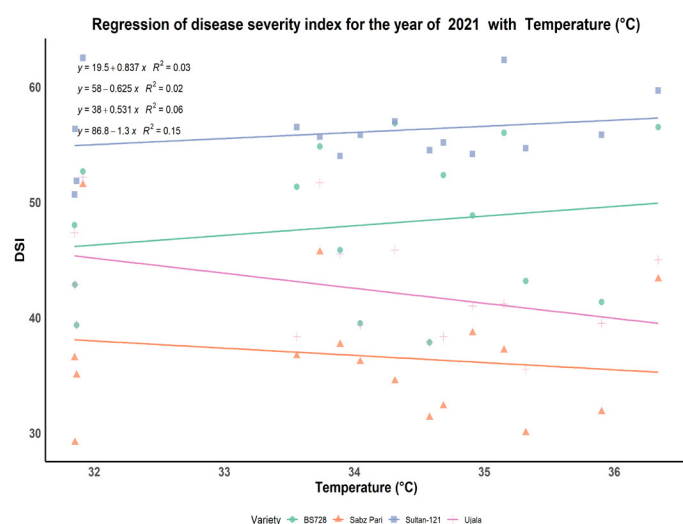


Figure 6: Regression of disease severity index of different varieties with Average Temperature FTY of 2021.

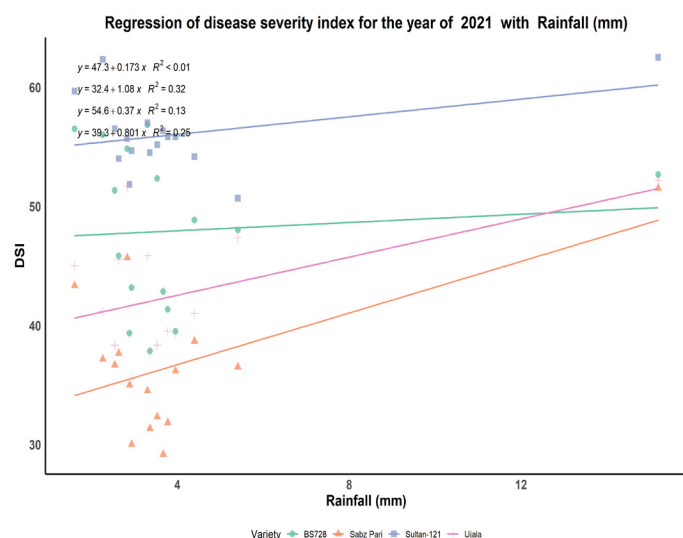


Figure 7: Regression of disease severity index of different varieties with Rainfall/Precipitation FTY of 2021.

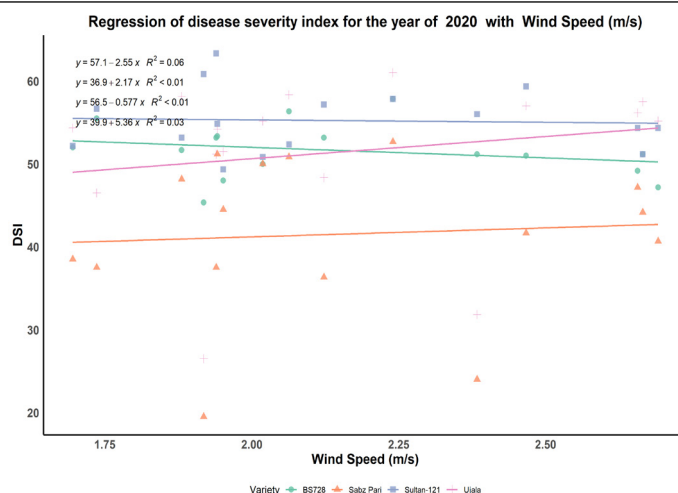


Figure 8: Regression of disease severity index of different varieties with Wind Speed FTY of 2021.

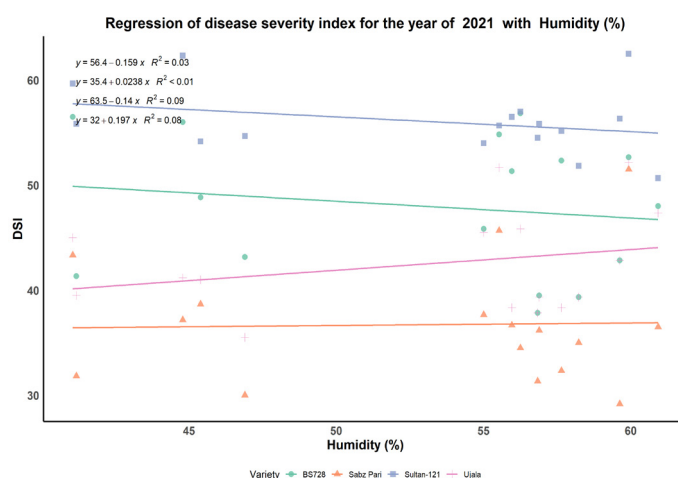


Figure 9: Regression of disease severity index of different varieties with Humidity FTY of 2021.

Varietal correlation and regression analysis

Varietal regression models revealed significant differences in disease susceptibility among the studied okra varieties. Sultan-121 consistently recorded higher DSI values across all divisions, with regression analysis in Sargodha Division showing a significantly positive slope ($\beta = 0.58$, $p < 0.01$) and that indicated higher vulnerability to OYVMV. In contrast, the varieties Ujala, BS728 and Sabz Pari exhibited lower susceptibility with β coefficients ranging from 0.15 to 0.35 which exhibited relatively better tolerance to the disease under prevailing conditions. Further regression analysis examining the relationship between environmental factors and DSI for each variety indicated only minor and statistically insignificant influences during both years. In 2020, average temperature showed a slight negative association (coefficient = -0.822 , $R^2 = 0.017$) for all varieties while precipitation demonstrated a modest positive trend (coefficient = 0.755 , $R^2 = 0.014$), wind

speed had a weak positive relationship (coefficient = 1.100, R^2 = 0.002), and humidity exhibited a minor positive association (coefficient = 0.132, R^2 = 0.025). In 2021, the pattern remained consistent with average temperature showing a slight negative relationship (coefficient = -0.140, R^2 = 0.001), precipitation presenting a slightly stronger positive trend (coefficient = 0.607, R^2 = 0.043) while wind speed exhibiting a negative association (coefficient = -1.982, R^2 = 0.002) and humidity revealing a negligible negative effect (coefficient = -0.020, R^2 = 0.000). Overall, the varietal analysis confirmed that genetic differences among okra varieties had a more substantial impact on disease severity than did environmental factors alone. The findings suggest that while minor climatic influences may exist but varietal resistance remains the key determinant of OYVMV severity under field conditions. Future research should therefore integrate additional variables such as soil health, pest pressure and viral strain characterization to refine predictive models and strengthen disease management strategies.

Discussion

This study on the monitoring of Okra Yellow Vein Mosaic Disease (OYVMD) revealed a complex epidemiological landscape where environmental factors, varietal differences and vector dynamics interact to influence disease severity (Chaudhary *et al.*, 2017). Analysis of data from the 2020 and 2021 growing seasons indicated that although environmental factors such as average temperature, relative humidity, precipitation and wind speed exerted measurable influences yet they explained only a minor proportion of the observed variability in disease severity, as evidenced by low R^2 values and high p-values in both correlation and regression models (Naseer *et al.*, 2021). The observed weak negative association between temperature and disease severity is consistent with previous studies (Yadav *et al.*, 2022) who reported that moderate temperatures between 28–32°C is optimal for viral spread and whitefly activity (Lobin *et al.*, 2022) while deviations from this range tend to suppress both virus proliferation and vector survival (Chandi *et al.*, 2021; Lakshmi *et al.*, 2020). However, the present study extended this understanding by demonstrating that temperature, although biologically relevant, accounted for only a small fraction of disease variability under field conditions. Precipitation in this study exhibited

a slight positive relationship with disease severity particularly in 2021, where the p-value approached significance (p = 0.0769) suggested a tentative but inconclusive role in influencing disease dynamics. Precipitation likely affects OYVMD indirectly by modulating whitefly populations and altering soil conditions while rainfall can physically reduce whitefly abundance (Dhole *et al.*, 2023; Gehlot *et al.*, 2023) under certain circumstances and increased precipitation combined with favorable microclimatic conditions may enhance disease transmission (Reyna *et al.*, 2023). Changes in precipitation regimes have broader ecological impacts including on soil structure and plant community interactions which could further influence disease outbreaks (Huo *et al.*, 2021; Kardol *et al.*, 2010). Wind speed demonstrated no significant effect on OYVMD severity with correlation values of 0.041 in 2020 and -0.046 in 2021 and corresponding non-significant regression p-values of 0.468 and 0.801 respectively. These findings align with the work of Thriveni (2019) who similarly reported that wind speed has a minimal role in OYVMD epidemiology. Relative humidity also showed inconsistent and weak associations with disease severity with positive correlation in 2020 (r = 0.157) and a slight negative correlation in 2021 (r = -0.015). Regression analyses confirmed that relative humidity was not a statistically significant predictor (p = 0.233 in 2020 and p = 0.752 in 2021). These observations are consistent with previous studies reporting both negative (Yadav *et al.*, 2022) and positive (Singh *et al.*, 2025) associations between relative humidity and OYVMD severity suggested that the impact of humidity may be highly context-dependent and influenced by specific regional or temporal factors. A particularly significant aspect of the findings is the strong varietal influence on disease outcomes. Sultan-121 consistently exhibited higher disease severity compared to Ujala, BS728 and Sabz Pari, highlighting the importance of host plant resistance in regulating OYVMD development. These results are consistent with the findings of (Hussain *et al.*, 2019) and (Jakada and Adepoju, 2023) who emphasized the role of varietal resistance as a cornerstone of integrated disease management strategies while the measured environmental factors provided some insight into disease variability. The low explanatory power of the models (overall R^2 values of 0.043 and 0.053 for 2020 and 2021, respectively) indicated that substantial variance remained unexplained. Mubeen *et al.* (2021) suggested that the complex nature of OYVMD epidemiology

likely involves additional interacting variables such as soil health, mixed viral infections, pest pressure and local agronomic practices. Whitefly population dynamics which were not directly measured in this study also likely contributed significantly to disease development, interacting with microclimatic factors in complex and non-linear ways (Mubeen *et al.*, 2017). The limitations identified in this study highlight the need for a more integrated epidemiological framework that incorporates biotic factors, high-resolution environmental monitoring and more dynamic modeling approaches. Emerging technologies such as remote sensing and UAV-based disease surveillance hold great promise in this regard. These tools can capture spatial and temporal environmental variations at high resolution and when coupled with machine learning algorithms can significantly enhance the precision of disease forecasting and inform timely management decisions.

Conclusions and Recommendations

The results and observations of this study demonstrated that Okra Yellow Vein Mosaic Virus (OYVMV) behaves differently across regions and among various okra varieties with certain areas and specific varieties being more severely affected. Although environmental factors such as Average temperature, humidity and pressure were evaluated for their influence on infection severity but they exhibited limited and statistically non-significant effects and suggested that additional unmeasured variables may be contributing to disease dynamics. The okra variety Sultan-121 consistently showed higher disease severity which indicated greater susceptibility to OYVMV under the observed conditions. These findings highlight the critical importance of considering both environmental and genetic factors in the management of OYVMV. Future research should expand to include assessments of soil health, pest pressures and viral strain variability in order to develop more comprehensive strategies for enhancing okra resistance against this disease.

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Novelty Statement

The study offers new insights into the temporal and spatial dynamics of disease progression by combining population level analysis with sophisticated diagnostic procedures.

Author's Contribution

Muhammad Asif Shabbir: Conducted the research.

Yasir Iftikhar: Conceived the idea and supervised the research.

Ashara Sajid: Technical helped in lab.

Muhammad Ahmad Zeshan: Co-supervised the research.

Mustansar Mubeen: Helped in research and Writing-original draft.

Talha Shafique: Analyzed the data statistically.

Data availability statement

The data will be available on request.

Conflict of interest

The research has been conducted without any involvement by commercial or financial ties that could be interpreted as a potential conflict of interest.

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