

Impact of Temperature and Humidity Variability on the Development and Epidemiology of Major Tomato Diseases under Changing Climatic Conditions

Naiba Valiyeva^{1*} , Gunel Ramazanova¹ ,
Sahila Mammadova¹ , and Gulnara Abbasova¹ 

Abstract. Climate variability influences crop disease epidemiology by modifying host susceptibility, pathogen development, and infection conditions. Tomato (*Solanum lycopersicum* L.), an economically important vegetable crop, is particularly sensitive to temperature and relative humidity fluctuations. This study evaluated the relationship between temperature and relative humidity variability and major tomato diseases under greenhouse conditions at Azerbaijan State Agricultural University (ADAU), Ganja, Azerbaijan, during the 2024 and 2025 growing seasons. Particular attention was given to late blight caused by *Phytophthora infestans*, powdery mildew associated with *Leveillula taurica* and/or *Oidium neolycopersici*, and gray mold caused by *Botrytis cinerea*. Greenhouse air temperature and relative humidity were monitored, and symptomatic plant tissues were assessed visually and microscopically. The results revealed distinct temporal and microclimatic patterns of disease occurrence. Late blight and gray mold were observed more frequently under moderate temperatures and relatively high humidity, whereas powdery mildew remained detectable under warmer and moderately humid conditions. Joint assessment of temperature and relative humidity showed that late blight and gray mold occurred primarily under moderate-temperature/high-humidity combinations, while powdery mildew was associated with moderately warm/intermediate-humidity conditions. Microscopic examination revealed morphological structures consistent with the respective disease groups, supporting symptom-based diagnosis. Late blight and gray mold occurred most frequently at 18–24 °C and 82–89% RH, whereas powdery mildew was predominantly observed at 22–28 °C and 60–78% RH. These findings indicate that temperature and relative humidity jointly influence major tomato disease occurrence patterns under greenhouse conditions. Integrating microclimatic monitoring with regular visual and microscopic disease assessment may improve disease surveillance and support climate-adaptive disease management in tomato production.

Keywords: *Solanum lycopersicum*, climate variability, greenhouse microclimate, plant disease epidemiology, temperature, relative humidity, *Phytophthora infestans*, *Botrytis cinerea*, powdery mildew

¹Azerbaijan State Agricultural University, Ganja, Azerbaijan

*Corresponding author. E-mail: naiba.valiyeva@adau.edu.az

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1. Introduction

Climate change and climatic variability can influence plant disease development through simultaneous effects on pathogen biology, host physiology, and environmental conditions required for infection. Temperature, relative humidity, precipitation, atmospheric composition, and extreme weather events may alter pathogen survival, reproduction, dispersal, infection processes, and host defense responses. Consequently, the classical disease triangle—host, pathogen, and environment—must increasingly be interpreted in the context of changing climatic conditions (Coakley et al., 1999; Garrett et al., 2006; Roussin-Léveillé et al., 2024).

Recent evidence indicates that climate-driven changes in temperature may alter the infection risk and geographical distribution of fungal and oomycete crop pathogens (Chaloner et al., 2021). Climate change may also facilitate shifts in pathogen ranges and contribute to the emergence of plant disease threats in new agricultural environments (Fones et al., 2020; Singh et al., 2023).

Climate-associated environmental stresses can additionally modify plant immunity and host susceptibility. Changes in temperature and other environmental factors may affect defense signaling and host–pathogen interactions, indicating that climate change can influence disease through simultaneous effects on both the pathogen and the plant (Son & Park, 2022).

Tomato (*Solanum lycopersicum* L.) is particularly suitable for examining these interactions because its growth, flowering, reproductive development, physiology, and productivity are strongly influenced by temperature. Heat stress is an important constraint in tomato production, and recent research has emphasized the physiological and molecular basis of tomato thermotolerance (Singh et al., 2022).

In protected cultivation, greenhouse temperature and relative humidity may fluctuate substantially within short periods and may also vary spatially within the same greenhouse. Dense tomato canopies can create localized microclimates that are not fully represented by a single central measurement point. Recent commercial-greenhouse monitoring demonstrated measurable spatial and temporal variation in tomato-canopy temperature and vapor pressure deficit (Šalagovič et al., 2024). Such microclimatic heterogeneity is relevant to both crop physiology and disease development.

Temperature and moisture are among the most important environmental components governing plant disease epidemiology. Their effects are pathogen-specific and frequently nonlinear. Increasing temperature does not necessarily increase every disease; disease development depends on whether environmental conditions approach or move away from the biological optimum of the particular pathogen. Reviews of economically important tomato diseases likewise emphasize the importance of temperature and relative humidity in determining disease risk (Panno et al., 2021).

Gray mold caused by *Botrytis cinerea* is an important tomato disease in protected cultivation. Experimental work on greenhouse tomato demonstrated significant interactions among inoculum concentration, relative humidity, and temperature during *B. cinerea* infection (Eden et al., 1996). More recent experimental evidence confirms that combined temperature and humidity conditions strongly influence tomato–*B. cinerea* interactions and infection success (Li et al., 2023).

Powdery mildew represents another environmentally responsive tomato disease. Controlled experiments with *Leveillula taurica* demonstrated strong effects of relative humidity and temperature on spore germination and disease development (Guzman-Plazola et al., 2003). This contrasting response is important because powdery mildew may remain favored under environmental conditions that differ from those associated with highly moisture-dependent diseases.

2. Materials and Methods

2.1. Study Site and Experimental Conditions

The study was conducted during the 2024 and 2025 growing seasons in the greenhouse facilities of Azerbaijan State Agricultural University (ADAU), Ganja, Azerbaijan. The investigation was designed to evaluate the occurrence of major tomato diseases under greenhouse conditions and their possible association with variations in temperature and relative humidity. Tomato plants were grown according to the standard cultivation practices routinely applied in the university greenhouse.

2.2. Plant Material

Tomato (*Solanum lycopersicum* L.) plants of the cultivar/hybrid currently recorded as 'Zolushka Papagi' were evaluated during both study years.

2.3. Monitoring of Temperature and Relative Humidity

Air temperature (°C) and relative humidity (%) inside the greenhouse were monitored during the experimental period. Measurements were performed by students participating in the study. The environmental records were organized according to the corresponding disease observation periods and were used to investigate temporal associations between greenhouse microclimatic conditions and disease occurrence.

2.4. Disease Monitoring and Symptom Assessment

Tomato plants were regularly examined for naturally occurring disease symptoms. Assessment included visual examination of leaves, stems, flowers, and fruits. Particular attention was given to late blight associated with *Phytophthora infestans*, powdery mildew associated with *Leveillula taurica* and/or *Oidium neolycopersici*, and gray mold associated with *Botrytis cinerea*. The presence of disease was initially evaluated on the basis of characteristic macroscopic symptoms and signs. Symptomatic plant material was subsequently collected for microscopic examination.

2.5. Microscopic Examination of Symptomatic Plant Material

Plant tissues showing characteristic disease symptoms were collected from affected tomato plants and subjected to microscopic examination. Prepared specimens were examined using a light microscope. Macroscopic symptoms and microscopic morphological characteristics were considered together for disease identification. Identification is therefore interpreted as morphology-supported diagnosis rather than molecular confirmation.

2.6. Assessment of Disease Occurrence

Because quantitative disease severity assessments were not performed, disease occurrence was evaluated according to the presence or absence of characteristic symptoms during individual observation periods. For each disease, observations were organized according to sampling date and corresponding greenhouse temperature and relative humidity conditions.

2.7. Analysis of Microclimate–Disease Relationships

Temperature and relative humidity measurements were aligned with corresponding disease observation dates. Environmental conditions recorded during periods in which late blight, powdery mildew, and gray mold symptoms were observed were compared descriptively with periods in which the corresponding symptoms were not recorded. Because standardized disease severity measurements were not performed, the analysis was designed primarily to evaluate associations between microclimatic conditions and disease occurrence rather than quantitative changes in disease severity.

3. Results

3.1. Greenhouse Temperature and Relative Humidity Dynamics

Considerable variation in greenhouse temperature and relative humidity was observed during the 2024 and 2025 growing seasons. In the dataset, mean air temperature ranged from 18.6 to 29.4 °C, while relative humidity varied between 58.2 and 88.5%. Cooler observation periods were characterized by lower mean temperatures and relatively high humidity, whereas warmer periods generally showed higher temperatures and lower relative humidity.

Table 1
Temperature and relative humidity data

Observation period	Mean temp. (°C)	Min temp. (°C)	Max temp. (°C)	Mean RH (%)
April 2024	19.2	14.8	25.1	82.4
May 2024	21.8	16.7	27.6	78.3
June 2024	25.4	19.5	31.8	70.6
July 2024	28.7	22.4	35.2	61.8
April 2025	18.6	13.9	24.7	85.6
May 2025	22.1	16.4	28.9	80.2
June 2025	26.2	20.1	32.7	72.4
July 2025	29.4	23.0	36.1	58.2

3.2. Occurrence of Major Tomato Diseases

Visual examination revealed temporal differences in the occurrence of the major diseases investigated. In the pattern, late blight and gray mold occurred more frequently during periods characterized by moderate temperatures and relatively high humidity, whereas powdery mildew remained detectable during warmer and moderately humid periods.



Figure 1
Representative symptoms of major tomato diseases observed under greenhouse conditions during 2024–2025

Table 2
Disease-occurrence pattern under different greenhouse microclimatic conditions

Disease	Temperature (°C)	RH (%)	Occurrence
Late blight	18–23	82–89	Frequent
Gray mold	18–24	81–88	Frequent
Powdery mildew	22–28	60–78	Frequent

3.3. Microscopic Examination of Symptomatic Tissues

Microscopic examination supported the symptom-based assessment of the major disease groups observed in the greenhouse. Symptomatic tissues showed morphological structures consistent with the respective disease groups. Because pathogen identification was based on symptomatology and microscopic morphology rather than molecular methods, the microscopic findings should be interpreted as morphological support for diagnosis.



Figure 2

Representative microscopic structures observed in symptomatic tomato tissues

3.4. Association Between Relative Humidity and Disease Occurrence

In the dataset, periods of elevated relative humidity coincided more frequently with late blight and gray mold observations, whereas powdery mildew was more frequently represented at intermediate relative humidity.

Table 3

Association between relative humidity and disease occurrence

Relative humidity	Late blight	Gray mold	Powdery mildew
<65%	8%	6%	28%
65–79%	18%	17%	51%
≥80%	74%	77%	21%

3.5. Association Between Temperature and Disease Occurrence

The distribution suggested that late blight and gray mold were most frequently observed at moderate temperatures, whereas powdery mildew was more frequent at moderately warm temperatures.

Table 4

Association between temperature and disease occurrence

Temperature class	Late blight	Gray mold	Powdery mildew
<18 °C	12%	14%	5%
18–23 °C	68%	58%	24%
24–28 °C	17%	24%	66%
>28 °C	3%	4%	5%

3.6. Combined Effects of Temperature and Relative Humidity

The occurrence patterns indicate that temperature and relative humidity should be interpreted jointly. Late blight and gray mold were represented primarily under moderate-temperature/high-humidity combinations, whereas powdery mildew showed a contrasting pattern under moderately warm/intermediate-humidity conditions.

4. Discussion

The study was designed to examine the relationship between greenhouse temperature and relative humidity and the occurrence of major tomato diseases during the 2024 and 2025 growing seasons. The working results suggest that the investigated disease groups may show distinct environmental patterns, emphasizing that climate–disease relationships should be interpreted at the individual pathosystem level rather than assuming a uniform response of all pathogens to warming or increased humidity.

This interpretation is consistent with the disease-triangle framework, in which disease development depends on interactions among a susceptible host, a virulent pathogen, and a conducive environment. Climate change and climatic variability can modify each component by influencing host physiology, pathogen biology, and environmental suitability for infection (Coakley et al., 1999; Garrett et al., 2006; Roussin-Léveillé et al., 2024).

In greenhouse production, microclimate deserves particular attention because temperature and relative humidity may change substantially within short periods. For gray mold, the expected association with humid greenhouse conditions is biologically plausible. Eden et al. (1996) experimentally demonstrated significant interactions among inoculum concentration, relative humidity, and temperature during *Botrytis cinerea* infection of greenhouse tomato.

Microscopic examination is an important strength of the present study because it provides morphological support for visual diagnosis. Nevertheless, microscopy does not provide the same taxonomic resolution as molecular identification. Species-level names should therefore be used conservatively when diagnostic structures are not unequivocal, particularly for powdery mildew.

A principal limitation of the study is the absence of a standardized disease-severity scale. Accordingly, the findings should be interpreted in terms of disease occurrence and environmental association rather than quantitative disease intensity. Future studies should record the total number of examined plants and the number of symptomatic plants at each observation date, permitting calculation of disease incidence and more robust statistical analysis.

5. Conclusion

The study provides a framework for evaluating the relationship between greenhouse microclimatic variability and the occurrence of major tomato diseases. Monitoring conducted during the 2024 and 2025 growing seasons combined greenhouse temperature and relative humidity measurements with visual and microscopic examination of symptomatic tomato plants.

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Conflict of Interest

The authors declare no conflict of interest.

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Data Availability Statement

The data generated during the study are available from the corresponding author upon reasonable request.

References

- Chaloner, T. M., Gurr, S. J., & Bebber, D. P. (2021). Plant pathogen infection risk tracks global crop yields under climate change. *Nature Climate Change*, 11, 710–715. <https://doi.org/10.1038/s41558-021-01104-8>
- Coakley, S. M., Scherm, H., & Chakraborty, S. (1999). Climate change and plant disease management. *Annual Review of Phytopathology*, 37, 399–426. <https://doi.org/10.1146/annurev.phyto.37.1.399>
- Eden, M. A., Hill, R. A., Beresford, R., & Stewart, A. (1996). The influence of inoculum concentration, relative humidity, and temperature on infection of greenhouse tomatoes by *Botrytis cinerea*. *Plant Pathology*, 45(4), 795–806. <https://doi.org/10.1046/j.1365-3059.1996.d01-163.x>
- Fones, H. N., Bebber, D. P., Chaloner, T. M., Kay, W. T., Steinberg, G., & Gurr, S. J. (2020). Threats to global food security from emerging fungal and oomycete crop pathogens. *Nature Food*, 1, 332–342. <https://doi.org/10.1038/s43016-020-0075-0>
- Garrett, K. A., Dendy, S. P., Frank, E. E., Rouse, M. N., & Travers, S. E. (2006). Climate change effects on plant disease: Genomes to ecosystems. *Annual Review of Phytopathology*, 44, 489–509. <https://doi.org/10.1146/annurev.phyto.44.070505.143420>
- Guzman-Plazola, R. A., Davis, R. M., & Marois, J. J. (2003). Effects of relative humidity and high temperature on spore germination and development of tomato powdery mildew (*Leveillula taurica*). *Crop Protection*, 22(10), 1157–1168. [https://doi.org/10.1016/S0261-2194\(03\)00157-1](https://doi.org/10.1016/S0261-2194(03)00157-1)
- Li, T., Zhou, J., Yuan, Z., Liu, R., & Li, J. (2023). Intermittent changes in temperature and humidity repress gray mold in tomato. *Plant Disease*, 107(2), 306–314. <https://doi.org/10.1094/PDIS-03-22-0607-RE>
- Panno, S., Davino, S., Caruso, A. G., Bertacca, S., Crnogorac, A., Mandić, A., Noris, E., & Matic, S. (2021). A review of the most common and economically important diseases that undermine the cultivation of tomato crop in the Mediterranean Basin. *Agronomy*, 11(11), 2188. <https://doi.org/10.3390/agronomy11112188>
- Roussin-Léveillé, C., Rossi, C. A. M., Castroverde, C. D. M., & Moffett, P. (2024). The plant disease triangle facing climate change: A molecular perspective. *Trends in Plant Science*, 29(8), 895–914. <https://doi.org/10.1016/j.tplants.2024.03.004>
- Šalagovič, J., Vanhees, D., Verboven, P., Holsteens, K., Verlinden, B., Huysmans, M., Van de Poel, B., & Nicolaï, B. (2024). Microclimate monitoring in commercial tomato (*Solanum lycopersicum* L.) greenhouse production and its effect on plant growth, yield and fruit quality. *Frontiers in Horticulture*, 3, 1425285. <https://doi.org/10.3389/fhort.2024.1425285>
- Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., & Trivedi, P. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nature Reviews Microbiology*, 21, 640–656. <https://doi.org/10.1038/s41579-023-00900-7>
- Singh, A. K., Mishra, P., Kashyap, S. P., Karkute, S. G., Singh, P. M., Rai, N., Bahadur, A., & Behera, T. K. (2022). Molecular insights into mechanisms underlying thermo-tolerance in tomato. *Frontiers in Plant Science*, 13, 1040532. <https://doi.org/10.3389/fpls.2022.1040532>
- Son, S., & Park, S. R. (2022). Climate change impedes plant immunity mechanisms. *Frontiers in Plant Science*, 13, 1032820. <https://doi.org/10.3389/fpls.2022.1032820>