# AGROECOLOGICAL FACTORS INFLUENCING THE DEVELOPMENT AND SPREAD OF FUNGAL DISEASES IN APPLE ORCHARDS OF UZBEKISTAN

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***Abstract.*** *This paper examines the influence of agroecological factors on fungal disease development in apple orchards, with particular emphasis on temperature, relative humidity, precipitation, leaf wetness, and orchard microclimate. Evidence from recent studies shows that these factors affect spore germination, infection, sporulation, and disease progression in major apple fungal diseases. Studies from Central Asia and Uzbekistan highlight the relevance of moisture-related conditions and the occurrence of important fungal pathogens. However, quantitative relationships between environmental conditions and disease development under Uzbek orchard conditions remain limited. Local multi-season epidemiological studies are therefore needed to support disease-risk assessment and forecasting.*

***Keywords:*** *apple; fungal diseases; agroecological factors; temperature; humidity; precipitation; leaf wetness; orchard microclimate; Uzbekistan.*

## 1. Introduction

Apple (*Malus domestica* Borkh.) production in Uzbekistan is affected by fungal diseases that can reduce fruit quality and orchard productivity. Recent research has confirmed the presence of diverse fungal pathogens in the region, including *Colletotrichum gloeosporioides*, recently identified as the causal agent of apple bitter rot in Tashkent Province (Sherimbetov et al., 2026).

Fungal disease development is strongly influenced by environmental conditions. Temperature, relative humidity, precipitation, and leaf wetness regulate key stages of pathogen development, including spore germination, infection, and sporulation. Studies of apple pathogens have demonstrated significant effects of temperature and moisture on infection and colonization (Liu et al., 2022; Lian et al., 2021), while leaf-wetness duration is an important determinant of infection by *Venturia inaequalis* (Philion et al.,

2020). Canopy-level microclimatic variation can further influence disease incidence within orchards (Harteveld et al., 2014).

Although these relationships are well documented in other apple-growing regions, their quantitative relevance under Uzbek agroecological conditions remains poorly characterized. This limits the development of locally appropriate disease-risk assessment and forecasting approaches. Therefore, this paper examines the principal agroecological factors influencing fungal disease development and spread in apple orchards of Uzbekistan, focusing on temperature, moisture, precipitation, leaf wetness, and orchard microclimate.

## 2. Agroecological Factors Influencing Fungal Disease Development

### 2.1. Temperature

Temperature is a major environmental factor regulating fungal development because it affects spore germination, mycelial growth, infection, and sporulation. However, its effect is pathogen-specific and should be considered together with moisture availability. Experimental studies on apple pathogens demonstrate that different stages of the disease cycle have distinct temperature requirements. For *Diplocarpon mali*, temperature affected conidial germination, infection, and acervulus formation, while these processes also depended on adequate moisture (Lian et al., 2021). Similarly, *Botryosphaeria dothidea* showed temperature-dependent conidial germination and colonization of apple tissues, with moisture conditions modifying these responses (Liu et al., 2022).

Temperature can also interact with seasonal disease development under field conditions. Harteveld et al. (2014) found differences in Alternaria disease incidence according to canopy position and seasonal conditions, indicating that pathogen development is influenced by the environmental conditions experienced within the tree canopy rather than by temperature alone. Therefore, temperature should be interpreted as one component of a broader orchard microclimate.

### 2.2. Relative Humidity, Precipitation and Moisture

Moisture availability is another critical determinant of fungal disease development. Relative humidity and free water can affect spore germination, sporulation, infection, and pathogen establishment on apple tissues. In *Glomerella cingulata*, Wang et al. (2025) demonstrated that spore production on diseased apple leaves was strongly dependent on wetness or very high relative humidity, with the duration of leaf wetness also affecting conidial production. These results demonstrate that moisture conditions can regulate the availability of secondary inoculum.

Field observations provide complementary evidence. In apple orchards of Kazakhstan, Kairova et al. (2026) observed differences in *Alternaria alternata* disease severity between growing seasons and identified significant associations between disease severity and relative humidity. The study therefore provides regionally relevant evidence that moisture-related meteorological conditions can contribute to seasonal variation in apple disease development.

Precipitation may influence disease epidemics through several pathways, including increasing surface moisture and creating conditions favorable for pathogen reproduction and infection. However, its effect is not necessarily uniform among pathogens. Consequently, rainfall should be evaluated together with temperature, relative humidity, and leaf-wetness duration rather than treated as an independent predictor of disease severity.

### 2.3. Leaf Wetness and Orchard Microclimate

Leaf wetness represents a more direct measure of the moisture conditions experienced by plant surfaces than general atmospheric humidity. Its importance is particularly evident for pathogens whose spores require free water or prolonged surface moisture for germination and infection. In *V. inaequalis*, infection increased with increasing leaf-wetness duration, although the required duration varied with temperature and leaf age (Philion et al., 2020).

The spatial distribution of leaf wetness within an orchard is also important. Wrzesień et al. (2019) demonstrated that the position of leaf-wetness sensors within the apple canopy affected disease prediction, emphasizing that measurements from a single location may not fully represent conditions throughout the canopy. Likewise, Harteveld et al. (2014) reported differences in Alternaria disease incidence between canopy positions. Together, these findings indicate that **orchard microclimate can create spatially heterogeneous disease risk**, even within the same orchard.

For apple orchards in Uzbekistan, this interaction between temperature, moisture, leaf wetness, and canopy microclimate is particularly relevant. However, the thresholds established in studies from other countries should not be assumed to apply directly to Uzbek orchards. Local measurements across multiple seasons are required to determine which environmental variables most consistently explain disease development under Uzbekistan's specific agroecological conditions.

## 3. Agroecological Responses of Major Fungal Diseases of Apple

The response of apple fungal diseases to environmental conditions differs among pathogen species and disease stages. Therefore, disease development should be

considered as the outcome of specific interactions between pathogen biology, host susceptibility, and prevailing agroecological conditions.

### 3.1. Apple Scab

Apple scab, caused by *Venturia inaequalis*, is strongly dependent on environmental conditions during primary infection. The interaction between temperature and leaf-wetness duration determines whether germinated ascospores can successfully infect susceptible apple tissues. Philion et al. (2020) demonstrated that infection time varied according to temperature and leaf wetness, while leaf age also influenced infection efficiency. These observations indicate that periods favorable for scab development are determined by combinations of environmental and host conditions rather than by temperature or moisture alone.

Weather-based prediction approaches have subsequently incorporated variables such as temperature, relative humidity, and leaf wetness to estimate periods of increased scab risk. Wrzesień et al. (2019) demonstrated the potential of weather-station and leaf-wetness data for predicting apple scab, emphasizing the importance of accurately representing the microclimatic conditions surrounding susceptible tissues.

### 3.2. Alternaria Diseases

Alternaria diseases provide an example of how disease development can vary spatially within an orchard. Harteveld et al. (2014) observed differences in Alternaria leaf blotch and fruit-spot incidence according to canopy position and disease-development stage. Their findings indicate that environmental conditions within the canopy can influence disease expression and that orchard-scale weather measurements may not fully describe the conditions experienced by individual leaves and fruits.

More recent evidence from Central Asia supports the importance of moisture-related conditions for Alternaria disease development. Kairova et al. (2026) reported seasonal differences in *A. alternata* disease severity in apple orchards in Kazakhstan and identified a significant association between disease severity and relative humidity. This regional evidence is particularly relevant for Uzbekistan because it demonstrates that moisture-related environmental variables can contribute to variation in disease severity under continental Central Asian orchard conditions.

### 3.3. Glomerella Leaf Spot and Bitter Rot

Environmental moisture also plays an important role in diseases associated with *Colletotrichum/Glomerella*. Wang et al. (2025) demonstrated that temperature, moisture, and leaf-wetness duration affected the production of conidia and ascospores of *Glomerella cingulata* on diseased apple leaves. Thus, environmental conditions can

influence not only infection but also the production of inoculum responsible for subsequent disease spread.

The relevance of these pathogens to Uzbekistan has recently increased following the first report of apple bitter rot caused by *Colletotrichum gloeosporioides* in Tashkent Province (Sherimbetov et al., 2026). Although this report established the pathogen and its pathogenicity, it did not quantify the environmental conditions responsible for disease development. Consequently, additional epidemiological studies are required to determine how temperature, moisture, rainfall, and canopy conditions influence bitter rot development under Uzbek orchard conditions.

Overall, available evidence demonstrates that different apple fungal diseases respond to distinct combinations of environmental variables. This pathogen-specific response highlights the need for locally validated epidemiological models rather than applying a single environmental threshold to all fungal diseases.

**4. Relevance to Apple Orchards in Uzbekistan**

Apple fungal disease risk in Uzbekistan may vary with seasonal weather, orchard microclimate, cultivar, and tree phenology. However, quantitative evidence linking these factors to disease development under Uzbek conditions remains limited.

The recent detection of *Colletotrichum gloeosporioides* causing apple bitter rot in Tashkent Province confirms the presence of an economically relevant fungal pathogen in Uzbek orchards (Sherimbetov et al., 2026). Regional evidence from Kazakhstan also indicates that moisture-related meteorological conditions can be associated with seasonal variation in *Alternaria alternata* disease severity (Kairova et al., 2026).

These findings highlight the need for multi-season studies in Uzbekistan integrating temperature, relative humidity, precipitation, leaf-wetness duration, and orchard microclimate with disease incidence and severity. Such locally generated data are necessary for identifying disease-favorable periods and developing epidemiological forecasting approaches adapted to Uzbek apple production.

**5. Research Gaps and Implications**

Current evidence confirms that temperature, moisture, precipitation, and leaf wetness influence different stages of fungal disease development in apple. However, most quantitative thresholds have been established outside Uzbekistan, and their applicability to local orchards remains uncertain. In Uzbekistan, systematic multi-season datasets linking weather and orchard microclimate with disease incidence and severity are still needed.

Future research should combine meteorological measurements, leaf-wetness monitoring, pathogen detection, and field disease assessments to identify locally

relevant environmental conditions associated with infection and epidemic development. Such information could support disease-risk forecasting and more precisely timed management interventions, while reducing reliance on generalized environmental thresholds developed under different agroecological conditions.

For the development of microbiome-based disease-management strategies, understanding these environmental drivers is also important because pathogen pressure and disease-favorable conditions can influence the performance requirements of future biological interventions. Establishing the environmental context of disease development can therefore provide a complementary epidemiological basis for developing locally adapted and sustainable approaches to apple disease management.

**6. Conclusion**

Temperature, moisture, precipitation, and leaf wetness are important environmental determinants of fungal disease development in apple orchards, while canopy microclimate can influence disease risk within trees. Although fungal pathogens are documented in Uzbek apple production, quantitative relationships between agroecological conditions and disease development remain limited. Multi-season studies integrating weather, leaf wetness, microclimate, and disease observations are therefore needed to develop locally relevant epidemiological and forecasting approaches for Uzbekistan.

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