

and sporulation depend on temperature and moisture together, and lesions produce abundant sporangia when leaves are wetted or exposed to 100% relative humidity, but only a few at 90% relative humidity. Field-oriented greenhouse observations similarly show that downy mildew initiation is favored by relative humidity above 90% for several hours, with disease increasing under humid, cooler conditions and declining in dry-hot periods (Khudhair and Aljarah, 2023).

Humidity dynamics also differ among disease types because the relevant moisture source may be aerial or soil-based. Greenhouse reviews indicate that cucumber disease pressure is dominated by phytopathogenic fungi favored by high relative humidity as well as soilborne pathogens, showing that both canopy moisture and root-zone wetness contribute to disease risk (Fanourakis et al., 2026). This distinction is supported by *Fusarium* wilt experiments, where soil moisture played an important role in disease initiation and development, with maximum incidence observed at 45% soil moisture and no disease at 15% soil moisture. Crop architecture and air exchange further shape local humidity accumulation within cucumber houses. Greenhouses with elevated humidity and restricted airflow create optimal conditions for diverse fungal pathogens, including mixed infections involving *Fusarium*, *Botrytis*, *Alternaria*, and *Cladosporium*, which suggests that poor ventilation can intensify both single-pathogen and multi-pathogen problems. Broader greenhouse monitoring likewise shows that cucumber diseases under covered production are strongly influenced by temperature and humidity, with many pathogens remaining active within roughly 15°C-20°C and 80%-100% relative humidity.

2.2 Effects of humidity on cucumber growth and physiological processes

Humidity affects cucumber growth not only through disease pressure but also through direct regulation of photosynthesis, water relations, and biomass accumulation. Under greenhouse conditions, environmental management is important for improving resource-use efficiency and yield, and long-term modeling shows that nighttime relative humidity has a significant relationship with cucumber production. However, high humidity becomes physiologically harmful when combined with low temperature, as young cucumber plants exposed to low temperature plus 95% humidity showed reduced shoot and root biomass, lower photosynthetic rate and chlorophyll fluorescence, and greater oxidative stress (Amin et al., 2024). Recent physiological work indicates that the effect of high humidity depends on the broader stress context and developmental stage. In cucumber seedlings, combined low temperature and high relative humidity reduced chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids, while also impairing chlorophyll biosynthesis and increasing oxidative damage. At the same time, older plants at the six-leaf stage showed greater tolerance than plants at the two- and four-leaf stages, suggesting that humidity-related stress sensitivity is developmentally regulated rather than uniform across crop stages (Amin et al., 2024).

Humidity also shapes disease severity in ways that feed back onto cucumber growth and yield. Downy mildew can spread rapidly under favorable heat and humidity and may cause severe productivity and quality losses, making humidity control relevant to both plant health and harvest performance (Abdelfatah et al., 2025). Seasonal surveys likewise found that increased relative humidity combined with low or moderate temperature increased downy mildew severity, and these disease changes were accompanied by differences in fresh weight, dry weight, fruit number, and yield. Not all cucumber pathogens respond to humidity in the same way, but moisture remains a core physiological and epidemiological driver. For target leaf spot caused by *Corynespora cassicola*, maximum spore production occurred at 100% relative humidity, and moisture explained a large share of spore-size variation, which matters because larger spores were more virulent (Zhao et al., 2022). By contrast, powdery mildew showed best development under intermediate humidity ranges of 50-70%, whereas very low relative humidity suppressed germination and very high relative humidity favored germination but limited continued lesion growth, underscoring that humidity management must consider pathogen-specific responses rather than assuming a single threshold for all diseases (Saad and Khalifa, 2021).

2.3 Environmental monitoring and humidity control technologies

Because humidity fluctuates rapidly and disease responses can be threshold-based, effective cucumber production increasingly depends on continuous monitoring and active control technologies. Climate-informed decision