

systems are emerging in greenhouse horticulture, and reviews emphasize that adaptive climate regulation combined with environmental sensing offers a preventive pathway for pest and disease management (Fanourakis et al., 2026). Forecasting studies on cucumber downy mildew further show that recording temperature and relative humidity can support epidemic prediction and reduce disease risk, input costs, and fungicide residues when linked to timely intervention. Ventilation remains one of the most direct humidity-control methods in cucumber houses. In greenhouse trials, relative humidity above 90% promoted downy mildew, whereas keeping humidity below 89% was protective, and adding ventilation openings reduced infection percentage by 95.8% and disease severity by 70% under early infection conditions (Khudhair and Aljarah, 2023). This practical effect is consistent with the broader principle that microclimatic stability determines infection probability and host susceptibility, so active air exchange can disrupt disease-conducive moisture regimes before epidemics intensify (Fanourakis et al., 2026).

More advanced systems combine sensors with automated actuators to maintain target humidity conditions. In small- and medium-scale protected houses, IoT-based systems used digital temperature and humidity sensors together with foggers and exhaust fans to control relative humidity, maintained more favorable daytime humidity conditions, and increased cucumber yield by 41.6% per vine compared with conventional management. At the high-technology end, AI-controlled greenhouse compartments for cucumber production integrated ventilation, screens, heating, fogging, CO₂ supply, irrigation, and continuous sensing, and overall AI performed well in greenhouse climate control. Humidity management technologies can also be integrated with environmentally safer disease suppression methods. For diseases strongly affected by humidity such as cucumber downy mildew, thermal fogging with chlorine dioxide achieved 80.9% control efficacy and outperformed conventional diluted spray approaches, suggesting that delivery methods interacting with greenhouse moisture conditions can materially change control success (Kim et al., 2021). Older greenhouse disease-control work likewise showed that successful biological control depends on abiotic conditions such as vapor pressure deficit and humidity, indicating that future cucumber protection systems will work best when humidity regulation, monitoring, and biological or low-residue interventions are designed together rather than separately.

3 Mechanisms Linking Humidity Conditions to Cucumber Disease Occurrence

3.1 Effects of humidity on pathogen survival and infection processes

Humidity influences cucumber disease occurrence first by controlling whether propagules can survive, germinate, and complete infection on plant surfaces. In *Pseudoperonospora cubensis*, abundant sporangia are produced when infected tissue is wetted or held at 100% relative humidity, whereas only a few sporangia form at 90% relative humidity, showing that small increases near saturation can sharply increase inoculum pressure. Infection also depends on the interaction between moisture duration and temperature, with minimum wetness requirements dropping to about 1 h at 20°C-25°C but becoming much longer at cooler or hotter temperatures, which explains why short humid periods can still trigger outbreaks under favorable thermal conditions. Humidity also affects the later stages of pathogen release and dispersal rather than only germination. For cucumber target leaf spot, alternating wet and dry conditions coupled with wind were necessary for spore discharge and spread to neighboring plants, while constant high or low humidity without wind did not produce infection in healthy plants. A similar principle has been shown for angular leaf spot, where high relative humidity increased the release amount, survival time, and infectivity of *Pseudomonas amygdali* pv. *lachrymans* aerosols, with the highest survival recorded at 18°C and 95% relative humidity (Chai et al., 2023).

Not all cucumber pathogens respond to humidity in the same way, but most show humidity-sensitive windows for successful infection. Powdery mildew conidia germinated poorly at 20-40% relative humidity, developed best at intermediate humidity of 50%-70%, and showed limited continued lesion growth under prolonged 80%-90% relative humidity, indicating a nonlinear moisture response rather than a simple “more humidity, more disease” pattern (Saad and Khalifa, 2021). By contrast, *Didymella bryoniae* infection under experimental conditions depended strongly on surface wetness duration, which was a more important determinant of infection than temperature once leaves and petioles were exposed to saturated humidity. Humidity effects also extend belowground, where soil water status governs survival and infection by vascular wilt pathogens. In cucumber