

chlorophyll pigments and precursor levels while increasing oxidative damage, which provides a physiological basis for greater vulnerability under prolonged humid stress (Amin et al., 2024). These humidity-driven physiological changes are not uniform across development, which means disease susceptibility can shift with plant stage. Seedlings at earlier leaf stages were more sensitive to high-temperature high-humidity stress, with larger reductions in biomass, net photosynthesis, and photosynthetic electron transfer than older seedlings, while four-leaf plants showed the greatest tolerance (Wang et al., 2024). Comparable stage dependence was observed under low-temperature high-humidity stress, where six-leaf plants were more tolerant than two- and four-leaf plants, suggesting that humidity-mediated disease risk partly reflects the developmental capacity of the host to maintain antioxidant and hormonal balance.

Humidity-mediated disease outcomes also depend on how effectively cucumber defense pathways are activated after pathogen challenge. In downy mildew resistance, increased lignin and hydrogen peroxide accumulation were associated with reduced germination and extension of *P. cubensis*, and transcriptome profiling identified defense functions involving pathogen recognition, signal transduction, reactive oxygen species, and transcriptional regulation (Gao et al., 2021). In gray mold, the resistant cucumber genotype showed shorter hyphae and lower spore germination than the susceptible mutant, together with stronger activation of redox, jasmonic acid, and ethylene signaling pathways, indicating that host biochemical responsiveness can counteract pathogen establishment even under favorable greenhouse humidity (Yang et al., 2020). At the greenhouse scale, humidity therefore acts as a regulator of both infection probability and host susceptibility. Greenhouse syntheses indicate that microclimatic stability determines infection probability and host vulnerability, while warm humid conditions generally promote fungal and bacterial pathogens in cucumber systems (Fanourakis et al., 2026). This interaction becomes agronomically important because greenhouse environments with elevated humidity and restricted airflow support mixed infections by *Fusarium*, *Botrytis*, *Alternaria*, and *Cladosporium*, so humidity stress can coincide with exposure to multiple pathogens rather than a single disease agent.

3.3 Major cucumber diseases associated with humidity conditions

Among humidity-associated cucumber diseases, downy mildew remains the clearest example of a pathogen tightly governed by moist air and leaf wetness. Greenhouse observations found that relative humidity above 90% was sufficient to trigger downy mildew development, whereas keeping humidity below 89% protected plants and sharply reduced infection and severity under early epidemic conditions (Khudhair and Aljarah, 2023). This strong moisture dependence is consistent with the infection biology of *P. cubensis*, whose sporangia germinate in free water and penetrate through stomata after zoospore release, making saturated leaf-surface conditions central to epidemic onset. Field and survey data also show that downy mildew severity rises under cooler, more humid conditions. Increased relative humidity together with low or moderate temperature increased disease severity in Egyptian production environments, and disease initiation elsewhere has been linked to high night relative humidity above 93% combined with prolonged night leaf wetness. The importance of downy mildew in cucumber production is amplified by its economic impact, because it is among the most destructive foliar diseases of cucurbits and has caused annual yield losses of up to 80% in European greenhouse and field production.

Other major cucumber diseases also show strong but distinct humidity relationships. Target leaf spot caused by *Corynespora cassiicola* produced the most spores at 100% relative humidity, and moisture explained most of the variation in spore size, which mattered because larger spores were more virulent than small spores (Zhao et al., 2022). Gray mold caused by *Botrytis cinerea* is similarly favored by greenhouse conditions of high humidity and 20°C-30°C, helping explain its persistence in continuously cropped protected systems (Yang et al., 2020). Humidity associations extend to powdery mildew, *Fusarium* wilt, and fruit rots, showing that cucumber disease risk spans both foliar and root or fruit pathogens. Powdery mildew is one of the major fungal diseases of cucumber and can recur annually, while its epidemic development is optimized at intermediate humidity rather than saturation, distinguishing it from downy mildew and target leaf spot (Saad and Khalifa, 2021). *Fusarium* wilt becomes more severe in warm, moist soil, and greenhouse disease monitoring has further shown that cucumber