Alimzhanova et al., 2025; Liviz et al., 2025). The excessive use of single-site fungicides and insecticides has accelerated the evolution of resistance in key pathogens such as *P. viticola* and other fungal pests, thereby increasing the difficulty of control and threatening the long-term effectiveness of existing active ingredients (Pertot et al., 2017; Mwaka et al., 2024; Toffolatti et al., 2024). Climate change is also altering the distribution patterns and pressure of pests and diseases. Diseases such as downy mildew have become major threats under a wide range of climatic conditions, and even greater challenges are expected by the middle of this century (Bois et al., 2017; Van Leeuwen et al., 2024).

Integrated pest management (IPM) has gradually become the central concept in grape protection. Its goal is to integrate agronomic practices, biological control, genetic improvement, and chemical measures in order to keep pest and disease pressure below economic thresholds while minimizing pesticide inputs and their associated risks (Pertot et al., 2017; Mwaka et al., 2024; Zhou et al., 2024). At present, vineyard IPM systems incorporate a wide range of strategies, including agronomic management such as canopy management, pruning, and vineyard sanitation; the use of disease-resistant cultivars; biological control agents and plant-derived products; pheromone disruption; spray decision-support systems; as well as precision agriculture and robotic technologies (Pertot et al., 2017; Aher et al., 2025). Resistant and tolerant cultivars, together with emerging breeding and genomic technologies such as marker-assisted selection and gene editing, provide important pathways for reducing fungicide use—by up to 80% in some cases—and for developing durable resistance (Trapp and Töpfer, 2023; Rahman et al., 2024; Gan et al., 2025). The development of organic, plant-derived, and microbe-derived control technologies has also shown potential for reducing pesticide dependence, improving soil health, and supporting organic or low-input production systems, although their formulation stability and field performance still require further optimization (Zhou et al., 2024; Alimzhanova et al., 2025). Despite the growing range of available technologies, their adoption remains uneven, and many growers still rely on calendar-based chemical control programs, with insufficient awareness of alternative approaches or problems such as grapevine trunk diseases.

This study aims to systematically review the current status and development trends of integrated pest and disease management technologies in grape production, with a particular focus on their role in balancing yield, quality, environmental sustainability, and food safety. By integrating multidimensional perspectives from agronomy, ecology, technology, and socioeconomics, this research seeks to establish a comprehensive framework that can provide guidance for growers, technical advisors, researchers, and policymakers, thereby supporting the implementation of more resilient and resource-efficient IPM strategies across diverse grape-growing regions.

2 Major Pests and Diseases in Grapevine

2.1 Common fungal and bacterial diseases

The most destructive fungal diseases in grape production mainly include downy mildew, powdery mildew, and gray mold. Downy mildew, caused by *Plasmopara viticola*, spreads readily under humid conditions and can infect leaves, young shoots, inflorescences, and grape clusters, leading to early defoliation and significant yield loss in severe cases (Capriotti et al., 2020; Koledenkova et al., 2022). Powdery mildew, caused by *Erysiphe necator*, can infect green tissues and berries even under relatively dry conditions, weakening photosynthesis and affecting fruit composition and wine flavor (Capriotti et al., 2020). Gray mold, caused by *Botrytis cinerea*, mainly damages flowers and ripening fruits, resulting in postharvest decay and quality deterioration (Rienth et al., 2021).

Among bacterial diseases, crown gall is the most important in grapevine and is mainly caused by *Allorhizobium vitis*, although it can also be induced by tumorigenic *Agrobacterium tumefaciens*. The pathogen transfers tumor-inducing DNA into host cells, causing galls to form on trunks, rootstocks, and graft unions, thereby disrupting vascular tissues, weakening vine vigor, and shortening plant lifespan. The disease is especially severe in young vineyards and in regions frequently affected by frost injury (Faist et al., 2016; Habbadi et al., 2023). Its management is particularly difficult because the pathogen can persist for long periods in both plant tissues and soil, while conventional chemical treatments have limited effectiveness. At present, the most effective measures still include the use of disease-free planting material, reduction of mechanical injuries and frost damage, selection of