tolerant rootstocks, and biological control using non-tumorigenic *Agrobacterium* strains and antagonistic endophytes (Asghari et al., 2019; Etminani et al., 2024). In recent years, studies on the characteristic microbial communities associated with galls have also provided new ideas for crown gall diagnosis and microbiome-based control strategies (Nguyen-Huu et al., 2025).

2.2 Insect pests affecting grapevine

Grape phylloxera (*Daktulosphaira vitifoliae*) is one of the most representative pests in grape production. Native to North America, it primarily attacks the roots, forming galls on fine roots and nodose roots, which interfere with water and nutrient uptake and can also promote secondary infection by soil-borne pathogens. In severe cases, it may cause vine decline or even death (Yin et al., 2019). The phylloxera crisis in the nineteenth century devastated European vineyards and led to the adoption of resistant rootstocks as a core control strategy in grape production worldwide. However, because this pest has high genetic diversity and strong host adaptability, outbreaks may still recur when rootstock selection is inappropriate or when local biotypes overcome existing resistance.

Another important group of pests includes leafhoppers and other sap-sucking insects. These pests feed directly on xylem or leaf sap, weakening vine growth, and they also transmit several serious diseases, such as phytoplasmas associated with *Flavescence dorée* and *Xylella fastidiosa*, the causal agent of Pierce's disease (Reineke and Thiéry, 2016; Lessio and Alma, 2021). Because pathogen transmission is highly efficient and effective treatment is lacking once infection occurs, the economic losses caused by these pests are often greater than those caused by feeding damage alone. In practice, integrated control usually requires a combination of pest monitoring, phenological analysis, and agronomic, chemical, and biological measures.

Tortricid moths, leaf-feeding beetles, and other chewing pests also damage grape inflorescences, clusters, and leaves. Tortricid larvae can feed directly on fruit and create entry points for pathogens such as *Botrytis cinerea*, thereby further aggravating bunch rot and quality deterioration (Lessio and Alma, 2021; Alimzhanova et al., 2025). Leaf-feeding pests reduce effective leaf area by damaging leaves and young shoots, which in turn affects vine growth and fruit ripening (Singh and Acevedo, 2023). Current vineyard pest management places greater emphasis on integrated control, combining the use of plant defense traits with the conservation of natural enemies and habitat management to improve the stability of IPM systems (Singh and Acevedo, 2023; Alimzhanova et al., 2025).

2.3 Emerging and region-specific threats

Climate change is continuously reshaping the pattern of grape pest and disease occurrence. Rising temperatures, longer growing seasons, and more frequent extreme weather events can accelerate insect development, increase the number of generations per year, and drive the expansion of grape berry moths, mealybugs, leafhoppers, and other pests toward higher latitudes and elevations (Reineke and Thiéry, 2016). At the same time, downy mildew and powdery mildew are highly sensitive to temperature changes, and in many grape-producing regions, their epidemic risk may persist or even intensify in the future (Rienth et al., 2021; Koledenkova et al., 2022). Changes in climatic conditions may also promote the expansion of virus–insect transmission systems, further increasing the incidence of viral diseases such as leafroll disease, fanleaf disease, and red blotch disease (Rienth et al., 2021). These changes interact with regional differences in soil conditions, grape varieties, and management practices, creating marked geographic variation, and are often accompanied by the spread of invasive alien species.

With the acceleration of global trade in propagation materials and agricultural commodities, invasive vector insects such as leafhoppers and sharpshooters capable of transmitting *Xylella fastidiosa* and phytoplasmas are continually entering new production regions. Once established, these invasive species can rapidly create new epidemiological systems. For example, the spread of the glassy-winged sharpshooter in California has been closely associated with outbreaks of Pierce's disease in grapevines and other host crops (Reineke and Thiéry, 2016; Lessio and Alma, 2021). Similarly, differences in the damage caused by various phylloxera biotypes and by crown gall across regions also indicate that local climate and cultivation conditions can profoundly influence the epidemiological consequences of grape pests and diseases (Yin et al., 2019; Habbadi et al., 2023).