predation pressure on pests such as grape moths (Korányi et al., 2025). However, intensive pesticide use can weaken the effects of natural enemies. Therefore, within an IPM framework, pesticide reduction, vegetation management, and habitat optimization should be integrated to achieve more stable biological regulation (Tortosa et al., 2025).

4.3 Botanical and biopesticides

Plant-derived products, including plant extracts and essential oils, are increasingly becoming important tools in the green management of grape diseases and are considered viable alternatives to some synthetic fungicides. Studies have shown that essential oils from thyme, rosemary, eucalyptus, lavender, and cinnamon can inhibit the growth of key grape pathogens, and when combined with reduced doses of copper-based products under field conditions, they can effectively reduce disease incidence (Kenfaoui et al., 2023; Alimzhanova et al., 2025). Among them, some essential oils can achieve inhibition rates exceeding 80% against pathogens associated with grapevine trunk diseases, and their control efficacy in woody tissues may even exceed 90%, indicating strong potential for managing trunk diseases, downy mildew, powdery mildew, and bunch rot (Kenfaoui et al., 2023). These products offer advantages such as biodegradability, low residue levels, and suitability for organic production systems, although their effectiveness is still influenced by pathogen type, the composition of active compounds, and environmental conditions.

Current developments in biopesticides are no longer limited to crude plant extracts but are gradually shifting toward more stable formulations and resistance-inducing products. Chitosan is a representative example, as it not only exhibits direct antimicrobial activity but also induces immune responses in grapevines, showing good control efficacy against downy mildew and powdery mildew (Brulé et al., 2024). Overall, although plant-derived and microbe-derived products have clear advantages in terms of environmental safety and pesticide reduction, they still face challenges such as limited stability, relatively short persistence, and variable field performance. Future efforts should focus on improving formulation technologies, developing combined products, and integrating them with precision application and decision-support systems to further enhance their role in integrated grape protection systems (Thiéry et al., 2018; Hajji-Hedfi et al., 2025).

5 Integrated Pest and Disease Management (IPM) Strategies in Grapevine

5.1 Principles and framework of IPM

In grape production, IPM is regarded as a systematic management framework whose core aim is to integrate agronomic, biological, physical, and chemical measures in order to keep pests and diseases below economically damaging levels while minimizing risks to human health and the environment (Pertot et al., 2017; Zhou et al., 2024). Its basic principle is to prioritize prevention through rational vineyard design and cultivation management, rely on natural regulation and biological control, and use pesticides selectively only when necessary as a last resort (Pertot et al., 2017; Pavan et al., 2026). Modern grape IPM emphasizes replacing and reducing the use of synthetic pesticides through resistant or tolerant cultivars, biological control, mating disruption, and optimized agronomic practices such as canopy management, ground cover, and vineyard sanitation, while establishing an integrated management system at both vineyard and landscape scales (Pertot et al., 2017; Wilson and Daane, 2017; Pavan et al., 2026). This multilevel integration is dynamic and regionally adaptable, allowing growers to gradually introduce new technologies and move from low-input IPM toward highly bio-intensive IPM systems (Barzman et al., 2015; Deguine et al., 2021).

One of the central pillars of this framework is threshold-based decision-making, meaning that control measures are implemented only when pest or disease levels, or predicted risks, exceed economic and agronomic thresholds (Lessio and Alma, 2021; Bashyal et al., 2022). Economic thresholds are determined by combining pest density, infection risk, crop growth stage, and expected yield loss, and are increasingly being incorporated into decision support systems (DSS) and predictive models (Pertot et al., 2017; Román et al., 2021; Bregaglio et al., 2022). The European Union’s eight IPM principles explicitly require monitoring, the use of warning systems, and the prioritization of non-chemical control measures, thereby translating the threshold concept into practical standards