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Short communication

The introduction of pathogen-resistant varieties in organic viticulture: frontiers and challenges

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Abstract

Viticulture is one of the agricultural sectors with the highest reliance on plant protection products. Downy mildew and powdery mildew, in particular, require multiple applications in spring to protect developing grape clusters. Various disadvantages of the limited copper-based products, to which organic viticulture is restricted, make the challenge even greater.

Pathogen-resistant varieties are intra-specific hybrids that inherit genetic tolerance to these fungal diseases from non-vinifera Vitis parental lines. Historically, they have been bred across Europe to reduce pesticide use, enhance vineyard sustainability, and maintain good wine quality. Currently, 45 resistant varieties are authorized in France, 35 in Italy, and about 40 in Germany. Although some recently bred Italian varieties closely resemble traditional cultivars, the enological characteristics of wines produced from these hybrids often differ from those of their parental lines.

The adoption of pathogen-resistant varieties is increasing in Europe, yet two new frontiers are emerging: (i) the need for varieties resistant to phytoplasmas such as Flavescence dorée, which threaten vineyard viability; and (ii) the potential introduction of new breeding techniques based on CRISPR-Cas technology. These techniques could produce resistant V. vinifera varieties genetically identical to standard clones (e.g., Chardonnay, Sauvignon, Riesling), potentially transforming pathogen management in viticulture. Organic farming associations will then face a critical decision: either accept these innovations or continue relying on extensive copper-based treatments.

Keywords: Pathogen control products, viticulture, copper-based products, fungal diseases, PIWI

Introduction

Viticulture is one of the agricultural sectors with the highest reliance on plant protection products, particularly due to the susceptibility of grapevines to fungal diseases such as downy mildew (*Plasmopara viticola*) and powdery mildew (*Erysiphe necator*). These pathogens force growers to perform multiple spray applications during spring to protect developing clusters, significantly increasing production costs and environmental impact. In organic viticulture, this challenge is even more pronounced, as copper-based products are among the few permitted options and are associated with drawbacks including soil contamination, toxicity to non-target organisms, and regulatory limitations.

Pathogen-resistant grapevine varieties, developed through intra-specific hybridization, inherit genetic tolerance from non-vinifera Vitis parental lines while maintaining the capacity to produce high-quality wines. Over the past decades, these varieties have been bred in several European countries with the dual aim of reducing fungicide inputs and improving vineyard sustainability (Bavaresco 2018). According to Trapp et al. (2025), currently 45 resistant varieties are authorized in France, 35 in Italy, and approximately 40 in Germany, reflecting growing acceptance among growers (Table 1). Although some recently bred Italian varieties closely resemble traditional cultivars, the enological traits of wines produced from

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these hybrids often differ from those of their parental lines (Frioni et al. 2021). Despite this, the adoption of pathogen-resistant varieties continues to expand as viticulture seeks to balance productivity, sustainability, and climate resilience (Trapp et al. 2025).

Table 1: A list of the most used pathogen resistant varieties in viticulture

Variety	Origin Country	Colour	Notes
Regent	Germany	Red	Limited tolerance to pathogen; widely planted in Germany.
Cabernet Blanc	Germany/Switzerland	White	Strong resistance to downy & powdery mildew.
Solaris	Germany	White	Early-ripening PIWI with good resistance profile.
Souvignier Gris	Germany	White (pink-skinned)	High-quality white PIWI, good resistance.
Muscaris	Germany	White	Modern resistant variety aimed at organic viticulture.
Johanniter	Germany	White	Frequently cited among PIWIs in central Europe.
Cabernet Cortis	Germany	Red	Recent red PIWI with good disease tolerance.
Floreal	France	White	French-bred resistant variety approved for cultivation.
Artaban	France	Red	French PIWI variety with multi-resistance.
Kersus	France	White	One of the newer resistant varieties in France.
Bronner	Germany	White	Early PIWI; also used in other countries.
Pinotin	Germany	Red	Resistant variety listed among top PIWIs in Germany.
Cabertin	Germany	Red	Red PIWI.
Sauvignac	Germany	White	Resistant white variety gaining cultivation area.
Hibernal	Germany	White	Reference for resistance breeding.
Termantis	Germany	Red	Modern resistant variety (less widely known).
Julius	Germany	Red	Resistant variety included in PIWI listings.
Merlot Kanthus	Germany	Red	Hybrid resistant variety discussed in research.
Sauvignon Rytos	Germany/Italy	White	Resistant variety referenced in Italian context.
Soreli	Germany/Italy	White	Another resistant variety referenced in Italian PIWI lists.

The unresolved issue of copper-based products in organic viticulture

Copper-based products are the main tool to control downy mildew in organic vineyards, but their use presents several challenges. First, as a contact protectant, copper requires reapplication after any rainfall exceeding 12 mm if infection conditions persist, which is

common during spring in most European wine regions. In northern Italy, organic vineyard protection required 17 to 24 applications in the 2024 season alone. In this way, copper accumulates in vineyard soils over time, potentially reaching toxic levels that affect soil health and microbial communities. High copper residues can negatively impact beneficial soil organisms, reducing biodiversity. This is a clear issue for organic viticulture relying on soil organic matter and its regular microbial mediated mineralization (Ghiglieno et al. 2025). Additionally, repeated copper applications increase labor and costs for growers. Notably, copper can persist in the environment, contaminating runoff and nearby ecosystems. Excessive use may also lead to regulatory limits on application rates, constraining disease management. In EU the limit for copper-based products application is 28 kg of copper per hectare over 7 years, an average of 4 kg per year. Finally, climate change, with more frequent heavy rains, may further increase the need for copper, exacerbating its environmental impact (Dagostin et al. 2011).

Limits

Fungus-resistant grapevine varieties (PIWIs) offer a promising route to reduce fungicide use and improve vineyard sustainability and represent a powerful tool, especially for organic viticulture. However, their adoption faces several challenges. First, the wine produced from these varieties often differs in aroma, flavor, and mouthfeel compared to traditional *Vitis vinifera* cultivars, limiting market acceptance (Frioni et al. 2021). Moreover, their resistance is typically specific to certain pathogen strains, and emerging fungal variants may overcome it (Peressotti et al. 2010). Many resistant varieties are still being evaluated for agronomic performance under diverse climates and soils. In this framework, legal recognition and registration of these varieties vary across countries, complicating widespread use. Additionally, many of these varieties have been bred in northern Europe and perform poorly when brought to warmer environments, where they display anticipated phenology, extremely early ripening and excessive grape sugars and low acidity at harvest (Frioni et al. 2021). Finally, consumer perception and regulatory frameworks in organic and traditional wine sectors may restrict adoption, despite clear environmental benefits, and restrictions in appellations (PGI/PDO) can be an additional barrier. As a matter of fact, a pathogen resistant variety obtained by traditional breeding requires 15 to 30 years to take some space in the market. The currently most common PIWI varieties are coming from the Freiburg Federal Institute of Viticulture breeding program in the 70s-80s (e.g. Souvignier Gris, Bronner, Solaris).

New breeding techniques and organic viticulture

New breeding techniques (NBT), such as CRISPR-Cas, offer unprecedented precision in developing grapevine varieties with desirable traits (Magon et al. 2023). They allow for targeted introduction of resistance genes against fungal diseases, pests, and phytoplasmas without altering the rest of the genome. Unlike traditional breeding, NBT can significantly shorten the time required to produce resistant varieties. They also enable the improvement of existing noble varieties such as Cabernet Sauvignon or Chardonnay, while preserving their sensory properties and enological traits alike popular varieties like Chardonnay or Cabernet Sauvignon (Agnoli et al. 2025). NBT can potentially reduce or eliminate the need for chemical treatments, including copper, benefiting both the environment and human health. These techniques can address climate change challenges by enhancing drought tolerance and phenological adaptation. Consumer acceptance and regulatory approval remain key challenges for their adoption. If integrated responsibly, NBTs could revolutionize sustainable viticulture. Ultimately, they represent a promising strategy to balance

productivity, quality, and environmental stewardship in modern vineyards (Magon et al. 2023).

In this context, organic agriculture associations will need to decide whether to allow the use of NBTs within organic standards. Indeed, organic viticulture could greatly benefit from their introduction, as NBTs are specifically designed to reduce the need for pathogen-control sprays, particularly copper-based products. However, many organic associations currently equate NBTs with GMOs, which would prevent their adoption in organic systems. The risk here is that if the currently valid principles continue to be applied, organic viticulture will miss the opportunity to enhance its environmental sustainability, improve consumer perception, and expand market share. Balancing the preservation of core values with innovation will be crucial to maintain both credibility and competitiveness in the evolving wine sector (Agnoli et al. 2025).

Phytoplasms and other emerging diseases

Breeding grapevine varieties resistant to vascular pathogens is emerging as a key strategy for sustainable viticulture. Flavescence dorée, transmitted by leafhoppers, is severely impacting European vineyards, and no curative treatments exist, making resistant varieties essential. Notably the control in organic vineyards located in affected regions rely on compulsory non-selective pyrethrins sprays that affect the entire vineyard entomofauna (Bene et al. 2025). Esca complex, a wood disease caused by multiple fungi, leads to chronic vine decline and reduced yields, with limited control options (Di Marco et al. 2022). *Xylella fastidiosa*, an invasive bacterium, threatens southern European vineyards, especially in Italy, with devastating economic and ecological consequences. Traditional breeding for resistance is slow due to the complex inheritance of tolerance traits. Marker-assisted selection and genomic approaches can accelerate the identification of resistant genotypes. Introgression of resistance from wild Vitis species shows promise, though maintaining wine quality remains a challenge (Dimaglie et al. 2025). Developing multi-disease resistant varieties is a long-term goal to reduce chemical inputs. These efforts could safeguard vineyard productivity under climate change and pathogen pressure.

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