Available on IVES Conference Series vine & wine

DOI : https://doi.org/10.58233/4Lx9soLc

GrapeBreed4IPM: A horizon Europe project for sustainable viticulture through multi-actor breeding and innovation

Komlan Avia[1], Marc Dressler[2], Ludger Hausmann[3], Gabriele Di Gaspero[4], Benoit Laurent[5], Mario de la Fuente[6], Pere Mestre[1]

[1] INRAE, Université de Strasbourg, UMR SVQV, 68000 Colmar, France
[2] University of Ludwigshafen, WineCampus, D-67059 Ludwigshafen, Germany
[3] Julius Kühn-Institut (JKI), Institute for Grapevine Breeding Geilweilerhof, 76833 Siebeldingen, Germany
[4] Istituto di Genomica Applicata (IGA), 33100 Udine, Italy
[5] Institut Français de la Vigne et du Vin (IFV), UMT SEVEN, 33290 Blanquefort, France
[6] Spanish Wine Technology Platform – CEIGRAM, Universidad Politécnica de Madrid, 28040 Madrid, Spain

*Corresponding author: komlan.avia@inrae.fr

Abstract. Biodiversity loss and ecosystem degradation are among the greatest challenges of our time, and agriculture's use of pesticides is a major driver. Viticulture, as one of the sectors that utilizes these chemicals most intensively, faces significant pressures to reduce their use, especially in Europe where grape cultivation is economically and culturally important. The Horizon Europe project GrapeBreed4IPM leverages recent breakthroughs in grapevine breeding to address these challenges. The project focuses on developing and deploying varieties with enhanced resistance to key fungal diseases, thereby reducing the need for fungicide applications. By breeding new disease-resistant varieties (DRVs) adapted to diverse European environments, GrapeBreed4IPM offers an eco-friendly alternative to conventional cultivars that rely heavily on chemical protection. Central to the project is a multi-actor co-design approach, actively involving leading research institutions, industry stakeholders, and the broader viticulture community across 7 countries. This collaborative framework ensures that outcomes are practical, user-centered, and directly aligned with winegrowers' needs. In addition to varietal development, GrapeBreed4IPM emphasizes the integration of these innovations into Integrated Pest Management (IPM) systems: disseminating best practices and decision-support tools to optimize pest control while minimizing chemical inputs. By fostering an environment where the exploitation of new resilient varieties is paired with tailored vineyard management and wine marketing strategies, GrapeBreed4IPM aims to drive a transformative shift in European viticulture. The project envisions vineyard ecosystems with preserved biodiversity and improved resilience, aligning grape production with sustainability goals. This paper outlines the key scientific and technical components of GrapeBreed4IPM – including breeding strategies, genomic selection, IPM integration, stakeholder co-design, and regulatory/socio-economic considerations – and discusses how this comprehensive approach is paving the way for a more sustainable future in viticulture.

1. Introduction

Modern viticulture must urgently adapt to mounting environmental and regulatory pressures. Across Europe, there is a strong push to reduce chemical pesticide use in farming to protect biodiversity and human health. Grapevines (*Vitis vinifera*) are especially under scrutiny because they require frequent fungicide treatments to control destructive diseases like downy mildew (DM) and powdery mildew (PM), widespread fungal/oomycete diseases in all EU regions, whose control in the vineyard has economic and environmental impacts [1,2].

Meanwhile, climate change is exacerbating disease pressures and introducing new challenges (e.g. extreme weather, emerging pathogens) to vineyard management [3]. Compounding the issue is the evolutionary lack of the cultivated species' adaptation to the pathogens: although the genus *Vitis* is highly diverse, encompassing wild American and Asian species that evolved in the presence of the pathogens, the wine industry relies predominantly on a few dozen *V. vinifera* cultivars. In the top 15 wine-producing countries, fewer than 10 varieties account for over 60% of vineyard area [4]. This limited use of grapevine biodiversity leaves the sector vulnerable, as it reduces the genetic resources available to confront evolving threats. There is a clear need to broaden the genetic portfolio with new varieties that can better withstand diseases and climate stress, while maintaining wine quality.

The European Union has recognized these challenges and is fostering breeding innovations as part of its sustainable agriculture agenda. In 2023, the EU launched the GrapeBreed4IPM project (Horizon Europe, 2024–2028, €5.6 M) to accelerate the development of disease-resistant grapevine varieties and promote their adoption in Integrated Pest Management systems[1]. GrapeBreed4IPM brings together a consortium covering the main European viticulture value chain, from grape breeders and plant pathologists to growers, advisors, winemakers, and socio-economists. By integrating expertise from multiple disciplines and engaging stakeholders at every step, the project aims to ensure that the resulting innovations are not only scientifically excellent but also practical, acceptable, and economically viable in the real world. The following sections describe the project's approach and objectives in five key areas: (1) breeding strategies for durable disease resistance, (2) application of genomic selection to accelerate breeding, (3) integration of new resistant varieties into IPM, (4) stakeholder co-design and socio-economic analysis, and (5) regulatory considerations and overall expected impact.

2. Breeding Strategies for Durable Disease Resistance

2.1. Developing improved disease-resistant varieties (DRVs)

One of the most direct ways to reduce fungicide use in vineyards is to grow grape varieties that are genetically resistant to diseases. Current data indicate that existing resistant cultivars are adequately protected with up to ~80% fungicide applications cuts [5]. However, the adoption of these disease-resistant varieties has remained limited, due to a number of constraints in breeding and deployment (Table 1). GrapeBreed4IPM addresses these bottlenecks through a comprehensive breeding strategy that combines traditional cross-breeding with advanced molecular tools. The project builds on the successes of past breeding programs in France, Germany, Italy, Spain, Switzerland and others, which in the last two decades have achieved major progress in combining fungal disease resistance with acceptable wine quality [6, 7]. Dozens of new resistant winegrape varieties (some also called "PIWI" varieties in several EU countries) have been released and are now available for planting in EU countries. For example, in France, the INRAE-ResDur program has registered 12 DRVs as of beginning of 2025 and in total ~50 varieties are registered in the national catalogue; in Germany, a few dozens of PIWI varieties have been selected by WBI, JKI, and the Geisenheim University; in Italy, about 40 DRVs bred across Europe are listed into the national catalogue; in Switzerland, a dozen of DRVs are registered in the national catalogue. These achievements demonstrate that high-quality, disease-resistant winegrapes are attainable; nonetheless, several challenges continue to hinder their widespread adoption, ranging from the lengthy breeding cycle to market acceptance issues.

Table 1. Factors hindering the development and adoption of disease-resistant grape varieties. These key obstacles were identified during the planning of GrapeBreed4IPM and highlight the need for coordinated solutions at the European level.

Obstacle	Description
Long breeding cycle and inbreeding depression	Traditional breeding of grapevines is very slow (15+ years per cycle) and prolonged intercrossing of limited lines can cause genetic depression, making progress difficult.
Cultural attachment to traditional varieties	Growers, winemakers, and consumers are strongly tied to emblematic wine grape varieties (e.g. Cabernet, Chardonnay) and are reluctantto replace them with new varieties.
Quality perception issues	Historical direct-producer hybrids and early-generation resistant varieties had poor organoleptic quality, leaving a negative reputation. First wines from some resistant cultivars were of inconsistent quality, fueling skepticism.
Limited trait integration	Breeding programs still struggle to optimally combine all desired traits (disease resistance, high yield, wine quality, climate adaptation) into single varieties; more research is needed to achieve these complex trait packages.
Regional adaptation gaps	Many new DRVs are not yet well-adapted to specific local terroirs or viticultural practices, limiting their performance in certain regions.
Strict regulatory framework	Regulatory constraints (e.g. slow variety registration processes, conservative appellation laws) make it difficult to introduce novel grape varieties into commercial wine production in Europe.
Fragmented efforts in R&D and extension	Breeding and outreach efforts have been fragmented and small-scale. There is a lack of large, coordinated European initiatives and continuous knowledge sharing across the value chain to promote resistant varieties.

Addressing these issues is central to the project's strategy. For example, to overcome the long breeding cycle (often 15+ years for grapevines) and the inbreeding depression brought about by the use of recurrent parents, GrapeBreed4IPM is exploring methods to accelerate breeding (see below on genomic selection) and introducing new genetic diversity into breeding pools. To tackle the *cultural attachment* to "noble" traditional cultivars and lingering skepticism due to past low-quality hybrids, the project emphasizes the need of breeding resistant lines that meet high oenological standards and resemble the profile of classic winegrapes. This includes pyramiding multiple resistance genes into elite genetic backgrounds to achieve durable resistance without compromising wine flavor. Furthermore, by actively involving end-users (growers, winemakers) in defining breeding goals, the project ensures that new varieties correspond to regional tastes and traditions, facilitating their eventual acceptance. GrapeBreed4IPM also explicitly targets secondary diseases: notably black rot (BR, *Guignardia bidwellii* syn *Phyllosticta ampelicida*) and Botrytis bunch rot (BBR, *Botrytis cinerea*) are included as breeding targets, since these are now raising major concerns in some European regions. By extending resistance breeding to a broader set of pathogens (downy mildew, powdery mildew, black rot, and Botrytis), the project will deliver grapevine genotypes that are resilient to multiple diseases (Figure 1). This is especially beneficial for organic and low-input viticulture where it is difficult to control multiple pathogens with a limited number of allowed active substances.

Figure 1. The four diseases targeted in the GrapeBreed4IPM project**.**

2.2. Molecular innovations for resistance durability

In tandem with classical breeding, GrapeBreed4IPM invests in fundamental molecular research to ensure that resistance in new varieties will be durable and effective against the ever-evolving pathogen populations. Most existing resistant grapevine cultivars carry one or few major resistance (*R*) genes introgressed from wild species. These dominant *R* genes can be overcome if pathogens evolve into new virulent strains [8, 9], so it is critical to continually discover additional resistance sources and understand pathogen adaptation. The project is cloning new grapevine *R* genes and the corresponding pathogen avirulence genes (*Avr*) to study their interactions at the molecular level. It also establishes a Europe-wide pathogen monitoring network to track changes in virulence: building upon France's OSCAR observatory for downy mildew resistance breakdown, GrapeBreed4IPM will monitor virulence in downy mildew populations across diverse experimental vineyards in multiple countries. Putative resistance-breaking strains detected will be analyzed and cross-tested on grapevines with different resistance gene makeups. This knowledge guides breeders on how to deploy resistance genes in combinations (gene pyramids) and across regions to outpace the pathogens. Furthermore, the project searches beyond the traditional dominant *R* genes, investigating recessive resistance mechanisms such as "loss-of-susceptibility" genes and RNA interference pathways as novel avenues for durable disease resistance [10, 11]. For example, while exogenous application of double-stranded RNA has shown some success in grapevine pest control (spray-induced gene silencing) [12], no stable resistance via RNA interference (RNAi) has yet been bred into grapevines. GrapeBreed4IPM will explore the grapevine genome for susceptibility (*S*) genes that could be edited or silenced to confer durable resistance.

2.3. New Genomic Techniques (NGTs): cisgenesis and genome editing

The project is also exploiting the use of emerging biotechnologies to complement conventional breeding. NGTs (*cisgenesis* and *genome editing*) offer a means to create resistant grapevines much faster than traditional breeding and without the chromosome reshuffling brought about by sexual reproduction. Unlike transgenic genetic modification (which introduces foreign genes from non-crossable species and is tightly regulated in the EU), cisgenesis transfers genes between sexually compatible grapevines and preserves the original genetic background (and thus the unique varietal traits). Genome editing (e.g. via CRISPR/Cas9) can precisely modify or knock-out specific native genes (for instance, restraining a plant gene product that the pathogen exploits), without otherwise altering the vine's genome [13]. These NGT approaches can drastically reduce the time needed to develop new plant varieties while maintaining a product safety similar to the one delivered by traditional breeding. This is especially relevant for grapevine, a long-lived, vegetatively propagated and highly heterozygous crop where maintaining clonal identity is desirable. In high-quality wine regions, being able to retain an existing famous grape variety (such as Chardonnay) but endow it with disease resistance would be a game-changing innovation, something conventional breeding cannot achieve, since crosses create entirely new genotypes.

GrapeBreed4IPM is studying the feasibility of using cisgenesis and genome editing to obtain resistant clones of emblematic *vinifera* cultivars (targeting resistance to downy and powdery mildew) in a controlled research setting. In the project's lab trials, selected disease resistance genes from within *V. vinifera* or crossable *Vitis* species will be inserted into elite winegrape clones, and/or key susceptibility genes will be knocked out. These modified experimental lines will then be rigorously analyzed at the molecular level to characterize the exact changes and ensure no off-target effects. Through this effort, the project will generate concrete evidence on how minimal and precise NGT-induced genetic changes can impart resistance. The aim is to provide policymakers, growers, and consumers with science-based information on the safety and benefits of NGT-derived grapevines. This is timely, as the EU is currently revisiting its legislation on new genomic techniques. Although NGT vines will not be released in vineyards as part of this project, by working on them in anticipation of regulatory shifts, GrapeBreed4IPM is preparing a basis for potential future solutions that could meet the demand of many European winegrowers for resistant versions of their traditional grape varieties. In doing so, the project will help ensure Europe does not lag behind other global competitors in grapevine innovation

3. Marker-Assisted Selection and Genomic Selection to Accelerate Breeding

Marker-Assisted Selection (MAS) has been proven successful in helping resistance breeding for DM and PM and it will be implemented for resistances to BR and BBR, targeting newly identified QTLs. While MAS can accelerate traditional breeding, grapevine improvement through conventional crossing and field selection remains slow and resource-intensive, particularly for complex traits like wine quality or climate resilience, which are difficult to measure, highly influenced by environmental factors, and poorly suited for MAS. In recent years, genomic selection (GS) has emerged as a promising approach to speed up plant breeding by predicting an individual's performance from its DNA profile [14]. GS uses genome-wide molecular markers and statistical models to estimate the breeding values of seedlings for target traits, allowing breeders to make selection decisions at the seedling stage, long before a vine matures or field tests are completed. This approach can greatly increase the efficiency of selecting for traits that are costly or slow to evaluate phenotypically. Over the last two decades, GS has revolutionized breeding in crops like cereals; in grapevine, its application is more recent but initial studies have validated GS for traits such as berry composition and yield components. For example, Brault et al., [15] demonstrated that genomic prediction across populations is feasible for certain quantitative traits in grapevine, opening the door to more widespread use of GS in grape breeding. GrapeBreed4IPM will develop and implement genomic selection pipelines tailored to grapevine breeding for disease resistance and sustainability traits. High-density genotyping (e.g. SNP arrays or sequencing) and trait data (both conventional traits like yield and quality, and new traits like specific disease ratings or climate tolerance indicators) will feed into GS model development. By testing various statistical models and cross-validation schemes, the project aims to optimize prediction accuracy for grapevine. Once validated, these GS models will be applied to upcoming breeding progenies to select the most promising seedlings carrying desirable combinations of resistance and quality traits. This will significantly increase the number of seedlings that can be scrutinized and rated at a very early stage (in the greenhouse or nursery) instead of committing all of them for years of field trials. As a result, breeders can discard inferior lines sooner and focus resources on a smaller subset of elite candidates, effectively shortening the breeding cycle. Overall, integrating genomic selection with traditional breeding is expected to reduce breeding costs and time, while also enabling more precise accumulation of favorable alleles for complex traits.

4. Integrated Pest Management for New Resistant Varieties

Introducing resistant grape varieties into vineyards is not a silver bullet unless accompanied by appropriate management practices. Integrated Pest Management (IPM) strategies must improve hand-in-hand with varietal innovation to fully capitalize on the resistance traits and ensure sustainability. GrapeBreed4IPM therefore dedicates significant effort to designing and evaluating tailored IPM strategies optimized for the new resistant genotypes. These strategies consider the entire agroecosystem context to recommend how to grow and protect the resistant vines with minimal inputs. First, the project will conduct field data collection on experimental and commercial vineyards where resistant varieties are grown, across different European regions, including monitoring disease incidence on the new varieties under various treatment regimes, recording agronomic performance (yield, phenology, etc.), and assessing environmental factors. For each specific resistant genotype (or group of genotypes), GrapeBreed4IPM is developing IPM protocols that indicate the optimal practices, such as the adjusted spray schedules, canopy management according to the variety's growth habit and disease susceptibility, and complementary use of biological controls or soil health measures. These protocols will be built into or alongside existing viticultural Decision Support Systems (DSS). By tailoring guidelines to each variety's profile, the project ensures that growers can achieve the maximum benefit from resistance traits while avoiding situations that could, on the one extreme, jeopardize durability of resistance or, on the other extreme, provide too little reduction of environmental impact.

Crucially, GrapeBreed4IPM will evaluate the performance of these integrated strategies through multidisciplinary assessments. Trials will compare the new IPM regimes against conventional practice, measuring not only disease control and yield, but also environmental indicators and economic outcomes. Environmental monitoring will cover metrics like the reduction in fungicide active ingredient use, impacts on non-target biodiversity (e.g. beneficial insects or soil microbiota), and overall ecosystem services in the vineyard. On the economic side, the costs of inputs, labor, and any changes in wine quality or market value will be analyzed. This comprehensive evaluation across different European production systems will provide solid evidence of how resistant varieties can contribute to sustainable production in real-world conditions. The knowledge gained will be returned to breeders (to understand if certain resistances require certain management) and to growers (to refine best practices), thereby creating a positive feedback loop to maximize the adoption and impact of resistant cultivars.

5. Stakeholder Co-Design and Socio-Economic Considerations

Successful innovation in viticulture, especially the introduction of new grape varieties, requires more than just technical advancement; it also depends on human factors like grower adoption, consumer acceptance, economic viability, and supportive policies [16-18]. GrapeBreed4IPM adopts a multi-actor co-design approach to address these socio-economic dimensions in parallel with the scientific work. From project inception, a diverse array of stakeholders has been engaged to ensure that the outcomes align with market needs and societal expectations. The consortium includes not only researchers and breeders, but also nurseries, winegrowers, winemakers, advisors and distributors. By involving these groups as partners, the project leverages their insights and facilitates early approval for the project's innovations [6, 19]. A core activity is the formation of national stakeholder panels or expert working groups in each participating country. These groups, composed of representatives along the entire grape and wine value chain, meet to discuss the project's challenges and opportunities for implementation. Through surveys, workshops, and interviews, GrapeBreed4IPM collects data on stakeholder perceptions, economic constraints, and incentives regarding disease-resistant varieties. This includes analyzing current awareness levels about DRVs, perceived advantages or drawbacks, and the readiness of different market segments to embrace wines from new varieties. Such socio-economic research is critical, as previous studies have shown that consumer acceptance of resistant grape varieties is not guaranteed and can be influenced by how benefits are communicated [20, 21]. GrapeBreed4IPM tackles this by devising a comprehensive communication and marketing strategy as part of its outreach.

The project aims to raise consumers' awareness of the sustainability and quality of wines from resistant varieties, and lift earlier prejudice on consumers' perception of wines from brand new varieties. For example, blind tasting events are planned where industry professionals and consumers taste wines from resistant vs. classic varieties without bias; past blind tastings have often shown that resistant variety wines can "hold their own" or even excel, dispelling notions of inferior quality [22]. By publicizing such results and highlighting success stories of growers who have adopted DRVs, the project hopes to build a positive image and demand for these sustainable wines. Another pillar of the co-design approach is education and training. GrapeBreed4IPM will implement two levels of capacity-building for end-users. The first focuses on growers and vine nursery managers: it provides training on the specific agronomic management of resistant plant material (for instance, pruning or canopy techniques if they differ, understanding the resistance traits, and how to monitor for any disease breakthroughs). The second is aimed at winemakers, merchants, and marketers: it centers on enology best practices for the new varieties (e.g. any needed adjustments in winemaking process) and strategies to effectively market and narrate the wines' unique sustainability value. By bolstering knowledge and skills, these trainings will ensure that practitioners can fully exploit the potential of the new varieties and confidently promote their products. In addition, peer-to-peer exchange is encouraged: the project will facilitate networks of pioneering grape growers who are trialing resistant varieties, so they can share experiences, vineyard management tips, and even vine material with others.

Socio-economic analysis is another major component: economists in the project are evaluating the business case for resistant varieties. This involves comparing the long-term costs and benefits for a grower to replant a vineyard with a new DRV versus keeping a traditional one (considering factors like reduced spray costs, potential yield or quality differences, and market price of the wine). Beyond the improvement of the regulatory framework and the removal of trade and market barriers, the reduction of input costs and the consumer's willingness to pay more for organic or environmentally-friendly wines could make a strong financial incentive for adoption [6]. To identify leverage points and remove weaknessess, GrapeBreed4IPM also examines the regulatory landscape and proposes improvements. For instance, appellation rules in many European regions currently do not allow to use new grape varieties for the production of quality wines; the project's dialogue with policymakers and wine authorities will explore avenues to open such regulations to innovation and accommodate proven sustainable varieties.

6. Conclusion

Climate change, more restrictive pesticide regulations, and evolving consumer expectations are converging to accelerate the need for innovation in viticulture. The GrapeBreed4IPM project represents a proactive and comprehensive response to this need, aiming to secure the future of European grape and wine production in an environmentally and economically sustainable way. By combining cutting-edge genomic tools (marker- assisted breeding, genomic selection, cisgenesis, genome editing) with agroecological practices (integrated pest management, biodiversity monitoring) and participatory research (stakeholder co-design, on-farm trials, knowledge transfer), GrapeBreed4IPM is developing a blueprint for resilient viticultural systems. A key strength of the project is its interdisciplinarity: plant geneticists, pathologists, agronomists, economists, and sociologists are working together to address the problem of vineyard sustainability from all angles. The disease-resistant grapevine varieties emerging from the impulse of this project, whether through traditional breeding or new genomic techniques, will provide growers with viable alternatives to pesticide-intensive cultivars. In turn, the adapted IPM strategies and socio-economic insights will help ensure these new varieties are practically adopted and meet with market success.

7. Acknowledgements

GrapeBreed4IPM project has been funded by the European Union through the Horizon Europe Research and Innovation Programme (grant number 101132223). Views and opinions expressed are, however, those of the authors only. Neither the European Union nor the granting authority nor the European Commission can be held responsible for them. GrapeBreed4IPM has also received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) Nr. 24.00152.

8. References

1. Pertot, I., et al., *A critical review of plant protection tools for reducing pesticide use on grapevine and new perspectives for the*

implementation of IPM in viticulture. Crop Protection, 2017. **97**: p. 70-84.

2. Koledenkova, K., et al., *Plasmopara viticola the causal agent of downy mildew of grapevine: From its taxonomy to disease management.* Frontiers in Microbiology, 2022. **13**: p. 889472.
3. van Leeuwen, C., et al., *Climate change impacts and adaptations of wine production.* Nature Reviews Earth & Environment, 2024. **5**(4): p. 258-275.
4. OIV, *Focus OIV 2017: Distribution of the world's grapevine varieties*. 2017: Paris. p. 54.
5. Miclot, A.-S., et al. *Four years of monitoring of disease-resistant grapevine varieties in French vineyards*. in *BIO Web of Conferences*. 2022. EDP Sciences.
6. Montaigne, E., A. Coelho, and S. Zadmehran, *A comprehensive economic examination and prospects on innovation in new grapevine varieties dealing with global warming and fungal diseases.* Sustainability, 2021. **13**(23): p. 13254.
7. Dressler, M., *Meeting Market and Societal Ambitions with New Robust Grape Varietals: Sustainability, the Green Deal, and Wineries' Resilience.* Agriculture, 2024. **14**(12): p. 2138.
8. Paineau, M., et al., *The characterization of pathotypes in grapevine downy mildew provides insights into the breakdown of rpv3, rpv10, and rpv12 factors in grapevines.* Phytopathology, 2022. **112**(11): p. 2329-2340.
9. Peressotti, E., et al., *Breakdown of resistance to grapevine downy mildew upon limited deployment of a resistant variety.* BMC plant biology, 2010. **10**: p. 1-11.
10. Halder, K., et al., *RNA interference for improving disease resistance in plants and its relevance in this clustered regularly interspaced short palindromic repeats-dominated era in terms of dsrna-based biopesticides.* Frontiers in plant science, 2022. **13**: p. 885128.
11. Engelhardt, S., R. Stam, and R. Hückelhoven, *Good riddance? Breaking disease susceptibility in the era of new breeding technologies.* Agronomy, 2018. **8**(7): p. 114.
12. Marcianò, D., et al., *RNAi of a putative grapevine susceptibility gene as a possible downy mildew control strategy.* Frontiers in Plant Science, 2021. **12**: p. 667319.
13. Cardi, T., *Cisgenesis and genome editing: combining concepts and efforts for a smarter use of genetic resources in crop breeding.* Plant Breeding, 2016. **135**(2): p. 139-147.
14. Crossa, J., et al., *Genomic selection in plant breeding: methods, models, and perspectives.* Trends in plant science, 2017.
15. Brault, C., et al., *Across-population genomic prediction in grapevine opens up promising prospects for breeding.* Horticulture research, 2022. **9**: p. uhac041.
16. Golicic, S.L., *Changes in sustainability in the global wine industry.* International Journal of Wine Business Research, 2021.
17. García-Cortijo, M.C., et al., *The Drivers of the Sustainability of Spanish Wineries: Resources and Capabilities.* Sustainability, 2021. **13**(18): p. 10171.
18. Ouvrard, S., S.M. Jasimuddin, and A. Spiga, *Does sustainability push to reshape business models? Evidence from the European wine industry.* Sustainability, 2020. **12**(6): p. 2561.
19. Calliera, M., et al., *Multi-actor approach and engagement strategy to promote the adoption of best management practices and a sustainable use of pesticides for groundwater quality improvement in hilly vineyards.* Science of the Total Environment, 2021. **752**: p. 142251.
20. Espinoza, A.F., et al., *Resistant grape varieties and market acceptance: an evaluation based on experimental economics.* OENO one, 2018. **52**(3): p. 247-263.
21. Vecchio, R., et al., *Consumer acceptance of fungus-resistant grape wines: Evidence from Italy, the UK, and the USA.* Plos one, 2022. **17**(4): p. e0267198.
22. Pedneault, K. and C. Provost, *Fungus resistant grape varieties as a suitable alternative for organic wine production: Benefits, limits, and challenges.* Scientia Horticulturae, 2016. **208**: p.57-77.