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Pesticide – Free viticulture: towards agroecological wine-producing socio-ecosystems

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Abstract. Is it possible to cultivate grapevines without pesticides? Minimizing pesticide use is a huge challenge for the production of this emblematic crop, which currently heavily depends on chemical-intensive pest and disease management strategies. Given this challenge, which research avenues could lead to the elimination of pesticides in viticulture? Effectively removing pesticides requires integrating multiple management strategies, each typically only partially effective, and a shift from curative to agroecological vineyard management based on prevention and improved agrosystem resistance. Consequently, a thorough and in-depth understanding of agrosystem functioning is necessary in order to identify new reliable approaches and to optimize available methods (i.e., technical innovations). It is also essential to identify the most effective combinations of management strategies and the critical paths to pesticide-free systems. Research must also address any barriers and incentives that could hinder or accelerate this agroecological transition (i.e., systemic innovations). The VITAE research project brings together researchers from INRAE, the universities of Bordeaux and Bourgogne, and the Institut Agro Montpellier. Using an interdisciplinary approach that integrates findings in biology, physiology, ecology, oenology and economic sciences, the VITAE project tackles research areas that have not yet been sufficiently explored, while investigating the extent of the social changes needed to promote this agroecological revolution.

1. Introduction

Towards the end of the 19th century, several bio-aggressors that originated in North America were unintentionally introduced into vineyards throughout Europe, causing significant damage. Scientific advancements at the time led to some understanding of the associated diseases and to the adoption of control methods, such as grafting grape varieties onto resistant rootstocks (Phylloxera), the use of copper (grapevine downy mildew) and sulfur (grapevine powdery mildew) treatments, and eventually synthetic plant protection products. After 1945, the intensification of agriculture resulted in a significant increase in pesticide use and dependance on chemical inputs (Figure 1).

Starting in the 21st century, growing awareness regarding the negative impacts of such products forced a reevaluation of conventional wine-growing systems environmental and socio-economic sustainability. However, because the modern agri-food sector relies on pesticides, substantially reducing their use is a very complex issue.

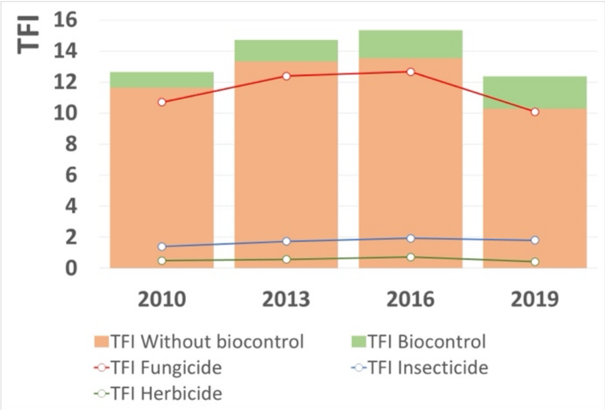

Figure 1. Pesticide use in viticulture has several particularities: high usage on a relatively small area (average TFI of 15 on 3 % of the agricultural area) and the predominant use of fungicides to address powdery and downy mildews and representing more than 80 % of total treatments. Insecticide use is mainly explained by mandatory treatments against the leafhopper, vector of flavescence dorée (73 % of the French wine-growing area).

Most current research programs aim to facilitate the progressive reduction of pesticides using substitute solutions [1] (Fouillet *et al.*, 2022). Analyses from the DEPHY network spanning the last 10 years show that it is possible to reduce phytosanitary product use by 25 % by optimizing their application and substituting with other, less detrimental products [2] (Nefti *et al.*, 2024), [1, 3] (Fouillet *et al.*, 2022, 2024). However, there is a limit to what can be achieved using these levers alone.

Agricultural research must play a major role in developing original research frontiers that could lead to pesticide-free viticulture. This imperative explains several research initiatives, in particular the French Priority Research Program entitled “Growing and protecting crops differently”, and the European Research Alliance program called “Towards a Chemical Pesticide-Free Agriculture” (https://www.era-pesticidefree.eu). These initiatives push agricultural researchers to produce the knowledge needed to enable pesticide-free agriculture by 2040. The VITAE research project is part of this research imperative, incorporating both cutting-edge scientific innovation and better understanding the socio-economic change necessary to facilitate such a monumental agricultural shift.

2. Strategies

The VITAE project brings together French research teams that share a common interest in vineyard agroecology. Using an interdisciplinary approach, the VITAE consortium organizes an integrative research program to reach pesticide-free viticulture.

The project is organized into six work-packages (Figure 2) addressing viticultural management options at varying spatial scales and the socio-economic factors for the ecological transition. The project also includes a foresight study to generate scenarios leading to zero-pesticide viticulture.

Eliminating pesticide use in viticulture requires shifting from a curative disease management approach to one incorporating prevention and multiple alternative methods.

The partial efficacy of alternative protection methods necessitates their coordinated integration into new, broader protection strategies that maximize each method’s impact and their potential synergistic interactions. Management strategies combining these methods will have to be adapted to specific climates and socio-economic contexts.

Achieving zero-pesticide viticulture is only possible using both technical and systemic innovations. It is also necessary to rethink wine-growing systems as a whole while optimizing the quality of the wines that reach the market. Furthermore, any alternative policy regulating pesticides must take into consideration the fundamental economics of market receptivity if, for example, wine characteristics changed as a result, and of maintaining (or even strengthening) the competitiveness of farms and businesses. A thorough understanding of the economic and cultural obstacles to drastically changing agricultural practices is also necessary, bearing in mind that factors other than monetary incentives can induce winegrowers to radically change their cultivation methods.

Finally, research supporting the transition to zero-pesticide viticulture requires close collaboration between scientific disciplines. Disruptive and innovative research axes are made possible by sharing knowledge, combining expertise, and collaborating across disciplines. The VITAE project therefore proposes a multidisciplinary approach to building sustainable wine-growing systems.

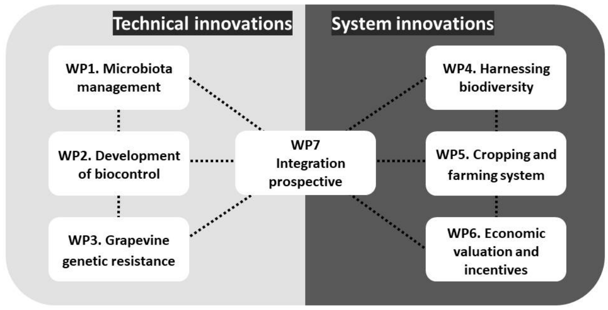

Figure 2. Organization of the VITAE project. The results obtained for technical (WP1-WP2-WP3) and system (WP4-WP5-WP6) innovations will feed the foresight study.

3. Main advances

Work is in progress within each WP shown in Figure 2. The first key results obtained by the midpoint of the project are presented below. The next challenge is to integrate these results together and highlight the benefits of VITAE’s multidisciplinary approach to help drastically reduce pesticide use in vineyards.

3.1. Identifying microbial consortia that interfere with grapevine pathogens

After comparing the microbiomes of vineyards with low or high susceptibility to downy mildew [4] (Fournier *et al.*, 2023), it was found that several species of fungi and bacteria are more abundant in the less susceptible plots. These key fungal and bacterial species were found in large numbers in the soil surface in the spring. They were also present on the surface of young leaves but rarely in leaf tissues. Foliar microorganisms from vineyards less susceptible to downy mildew were isolated and cultured to then assess their effect on the development of the disease. Microorganisms present in leaf tissues that remained healthy even during downy mildew epidemics were also identified to supplement the list of key species potentially involved [5] (Barroso-Bergadà *et al.*, 2022). A simplified microbial community (SynCom) composed of a mixture of forty-two key species showed promising results against downy mildew under controlled conditions. These key microorganisms could be used in biocontrol strategies [6] (Fournier *et al.,* 2022).

3.2. Developing new biocontrol methods with original targets and/or modes of action

3.2.1. Identification of two new biocontrol solutions

Black rot (BR), and downy mildew (DM) are two major grapevine diseases for which effective biocontrol solutions are necessary in order to replace conventional fungicides. Among the potential solutions are biocontrol agents (BCAs) and the active molecules they secrete. We focused on two *Bacillus* strains previously shown as effective BCAs against gray mold: *Bacillus velezensis* Buz14 and *B. ginsengihumi* S38.

A test to evaluate the effectiveness of biocontrol solutions against black rot under semi-controlled conditions was developed. This test assesses disease expression on leaves (i.e., symptom scoring) and fungal development (i.e., a cytological approach). Next, we have demonstrated the effectiveness of the culture medium supernatants of both bacterial strains against black rot (using the newly developed test) and grapevine downy mildew (Figure 3). These two new polyvalent biocontrol solutions combine a direct antimicrobial effect with a plant defense-stimulator (PDS) (Figure 4) [7] (Raveau *et al.*, 2024).

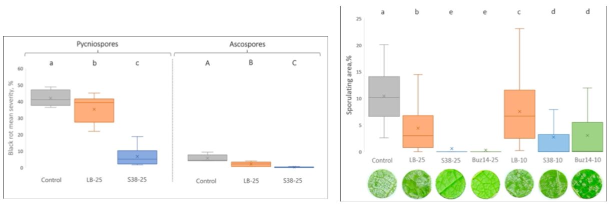

Figure 3. Mitigating effect of the two bacterial supernatants assessed for black rot (left) and downy mildew (right).

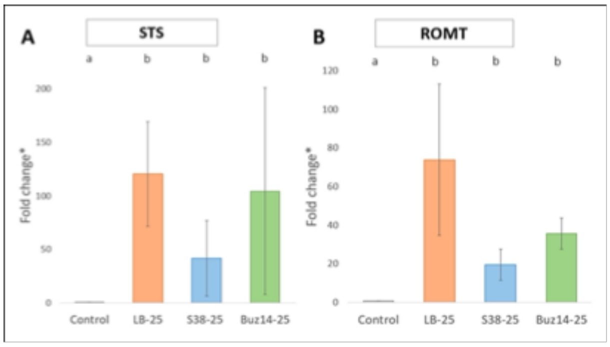

Figure 4. Activation of defense gene expression in cv. Marselan leaves treated by the bacterial supernatants (STS: stilbene synthase, *ROMT*: resveratrol-*O*-methyl transferase).

3.2.2. Enhancing PDS efficacy through preliminary disinhibition of plant defense responses

PDS efficacy is often variable in field conditions and to the quantities applied must be increased. In tobacco, it has been shown that histone deacetylase enzymes negatively regulate defense responses; their inhibition by compounds (called de-inhibitors, or DIs) counteracts this negative regulation. In grapevines, we have demonstrated that applying a DI before applying a PDS leads to a more intense and prolonged activation of some defense genes compared to PDS application alone. Interestingly, this strategy also leads to increased protection against downy mildew and powdery mildew.

3.3. Towards sustainable deployment of resistant varieties

Host plant resistance is generally thought to be the most favorable disease control method in viticulture for environmental, economic, and social reasons. Grapevine breeding programs are carried out by research institutes in countries around the world in order to create disease-resistant varieties targeting powdery and downy mildews. The VITAE project expands this approach by also targeting resistance to black rot and flavescence dorée (pre-breeding). As a first step, tests have been developed to assess grapevine resistance to these two diseases in controlled conditions. Observations from tests conducted in the vineyard and in semi-controlled conditions have led to the identification of *Vitis* species that are resistant to black rot. The next step is to transfer these resistances to an intermediate set of materials that breeders can then use to produce new grapevine varieties.

As for powdery and downy mildew, the VITAE project focuses on the sustainable management of grapevine resistances that are already deployed. Our objective is to better characterize pathogen adaptation by identifying the genes responsible for the breakdown of resistance and monitoring the emergence of virulence in natural populations. To that aim, we have identified a chromosomal region of the *P. viticola* (downy mildew) genome responsible for the breakdown of the *Rpv3.1* resistance and found that at least three genes are recognized by the *Rpv3.1* genes of the plant. These findings allow for the development of a first epidemiological monitoring tool of pathogen virulence in order to support the deployment of resistant varieties [8] (Paineau *et al.*, 2022), [9] (Paineau *et al.*, 2024).

3.4. Mobilizing biodiversity and ecosystem services

Designing viticultural systems that promote the ecosystem services provided by biodiversity would go a long way in increasing agroecosystem resilience in the context of global change. The VITAE project's work on biodiversity has highlighted the key role of certain arthropod taxa (e.g., spider families) in the natural control of insect pests, and the importance of implementing certain farming practices (e.g., diversification of plant covers) at field or landscape scales to promote pest regulation. For instance, we demonstrated that landscapes composed of small vineyard plots and high amounts of semi-natural habitats favor the natural control of grapevine pests and limit the need for insecticides [10] (Etienne e*t al.*, 2023), [11] (Stemmelen *et al.*, submitted). In addition, studies have demonstrated that combining management strategies at both local and landscape scales promotes greater biodiversity overall and bundles of ecosystem services that can enhance the overall sustainability of viticultural systems without harming crop productivity [12] (Beaumelle *et al.*, 2023). These results suggest paths for designing vineyard systems that promote synergies between biodiversity conservation, limited environmental impacts, and crop productivity [13] (Rusch *et al.*, 2021).

3.5. Sustainable growing systems

Research on promising innovations conducted in input-efficient vineyards zeroed in on fifty more sustainable management options currently in use (technical, organizational, and economic). From this research, it is possible to better understand how to integrate these practices into farm management systems, taking into consideration production trade-offs related and any downstream effects. Vineyards surface area is also a promising lever in mitigating obstacles to the implementation lower-pesticide management, compensating for the resultant increased technical and organizational complexity [14] (Merot *et al.*, 2024). In addition, monitoring “minimally treated” plots will allow us to assess the impacts of various management strategies, including on enological characteristics of the final wine product. Furthermore, our results showed that farmers are changing their management approach from plot to farm scale.

3.6. Identifying economic and regulatory incentives

Research has been conducted on an experimental market in order to assess how consumers value environmental labeling, specifically as it relates to biodiversity. The creation of a “biodiv-score” for wines resulted in a general consumer willingness to pay more for such products and a more value placed on an organic certification. In addition, a choice experiment conducted to assess the willingness of Champagne winegrowers to integrate resistant varieties into their vineyards showed that winegrowers are interested in collective approaches to reduce cost and increase knowledge diffusion.

The VITAE project is also working on projects related to insurance policies that cover crop loss and damage. A choice experiment conducted among four hundred winegrowers aimed to assess growers’ preferences for a “product” insuring crop losses due to downy and powdery mildew, while at the same time incentivizing growers to use very low chemical input levels. The results of this experiment show a genuine interest in such “green insurance”, which can be designed as “incentive menus”.

4. Foresight study

The VITAE project includes a foresight study that will develop interdisciplinary scenarios for phasing out pesticides at the territory scale. Initial scenarios are currently being drafted (2024) and will be shared with wine industry organizations. Taking into account the sector's socio-economic context, the VITAE project will then generate practical recommendations for winegrowers, technical institutes, and policy makers.

5. Conclusions

The VITAE project has thus far cultivated an interdisciplinary framework for the research community to develop pesticide alternatives in the wine and vineyard sector. This collaborative structure facilitates the elaboration of interdisciplinary research proposals that align with French and European research programs. This collective expertise must now be combined with that of stakeholders and winegrowers to accelerate the design of new sustainable viticultural production systems.

6. Funding

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7. References

1. E. Fouillet, L. Deliere, N. Chartier, N. Munier-Jolain, S. Cortel, B. Rapidel, A. Merot, European Journal of Agronomy 136, pp. 126503 (2022) Reducing pesticide use in vineyards. Evidence from the analysis of the French DEPHY network
2. O. Nefti, N. Chartier, A. Merot, T. Peyrard, L. Delière, OENO One 58 (2) (2024) To what extent can a phase-out of pesticides in viticulture be

achieved? Learning from the efforts of a large farm network after 10 years

3. E. Fouillet, M. Gosme, A. Metay, B. Rapidel, C. Rigal, N. Smits, A. Merot, European Journal of Agronomy 158, pp. 127199 (2024) Lowering pesticide use in vineyards over a 10-year period did not reduce yield or work intensity

4. P. Fournier, A. Jaswa, L. Pellan, J. Vallance, E. Chancerel, O. Bonnard, I. Masneuf-Pomarède, G. Martins, M. Raynal, C. Debord, S. Labarthe, L. Delière, F. Delmotte, P. This, C. Vacher, IVES Conference Series Vine & Wine, Proceedings of the 22nd GiESCO International Meeting, Towards microbiota-based disease management: analysis of grapevine microbiota in plots with constrasted levels of downy mildew infection (2023)

5. D. Barroso-Bergadà, F. Delmotte, J. Faivre d'Arcier, M. Massot, E. Chancerel, I. Demeaux, S. Guimier, E. Guichoux, D. Bohan, C. Vacher, PhytoFrontiers™ 3, pp. 477-483 (2023) Leaf microbiomedata for European cultivated grapevine (Vitis viniferaL.) during downy mildew (Plasmopara viticola) epidemics in three wine-producing regions in France

6. P. Fournier, L. Pellan, D. Barroso-Bergadà, D. A. Bohan, T. Candresse, F. Delmotte, M.-C. Dufour, V. Lauvergeat, C. Le Marrec, A. Marais, G. Martins, I. Masneuf-Pomarède, P. Rey, D. Sherman, P. This, C. Frioux, S. Labarthe, C. Vacher, Advances in Ecological Research 67, pp. 27-99 (2022) The functional microbiome of grapevine throughout plant evolutionary history and lifetime

7. R. Raveau, C. Ilbert, M.-C. Héloir, K. Palavioux, A. Pébarthé-Courrouilh, T. Marzari, S. Durand, J. Valls-Fonayet, S. Cluzet, M. Adrian, M. Fermaud, Journal of Fungi 10, 471 (2024) Broad-spectrum efficacy and modes of action of two bacillus strains against grapevine black rot and downy mildew

8. M. Paineau, I. D. Mazet, S. Wiedemann-Merdinoglu, F. Delmotte, F. Fabre, Phytopathology 112 (11), pp. 2329-2340 (2022) The characterization of pathotypes in grapevine downy mildew provides insights into the breakdown of Rpv3, Rpv10 and Rpv12 factors in grapevines

9. M. Paineau, A. Minio, P. Mestre, F. Fabre, I. D. Mazet, C. Couture, F. Legeai, T. Dumartinet, D. Cantu, F. Delmotte, New Phytologist 243, pp. 1490-1505 (2024) Multiple deletions of candidate effector genes lead to the breakdown of partial grapevine resistance to downy mildew

10. L. Etienne, A. Rusch, C. Lavigne, E. Fouillet, L. Delière, P. Franck, Agricultural Systems 204, 103553 (2023) Less field-level insecticides, but not fungicides, in small perennial crop fields and landscapes with woodlands and organic farming

11. A. Stemmelen, G. Le Provost, B. Giffard, A. Rusch, submitted to Journal of Applied Ecology, Pesticide use and large pacth size reduce natural pest control potential in vineyards

12. L. Beaumelle, B. Giffard, P. Tolle, S. Winter, M. H. Entling, E. Benítez, J. G. Zaller, A. Auriol, O. Bonnard, Y. Charbonnier, O. Fabreguettes, B. Joubard, S. Kolb, N. Ostandie, J. M. Reiff, S. Richart-Cervera, A. Rusch, Agriculture, Ecosystems & Environment 351, 108474 (2023) Biodiversity conservation, ecosystem services and organic viticulture: A glass half-full

13. A. Rusch, L. Beaumelle, B. Giffard, A. A. Ugaglia, Advances in Ecological Research 65, pp. 305-335, Academic Press, (2021) Harnessing biodiversity and ecosystem services to safeguard multifunctional vineyard landscapes in a global change context

14. A. Merot, T. Etchepare, E. Fouillet, IFSA conference, 30th June-4th July, Trapany, Italy, Dealing with complexity to reduce pesticides: the case of vineyard cropping systems (2024)