The French grapevine breeding program ResDur: state of the art and perspectives

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THE FRENCH GRAPEVINE BREEDING PROGRAM RESDUR: STATE OF THE ART AND PERSPECTIVES

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Abstract:

The French grapevine breeding program for durable resistance to downy and powdery mildew (INRAE-ResDur) was initiated more than 20 years ago to help reduce the heavy use of plant protection products and provide a durable mean to cope with a strong pathogen pressure. This program has now proved to be effective, with about ten new varieties already officially registered. However, there is still a lot to be done (1) to reduce the duration of each breeding cycle, (2) to diversify disease factors' pyramiding and anticipate emerging diseases, (3) to work towards larger adoption of the new resistant varieties. New breeding schemes incorporating for example genomic prediction of breeding values are being evaluated to accelerate genetic gains, saving cost and time while handling complex traits.

Here we will present the current state of the INRAE-ResDur program as well as the perspectives towards an optimal integrated pest management.

Keywords: Grapevine, INRAE-ResDur, disease resistance, genomic prediction, IPM

1. Introduction

European viticulture in the 21st century is faced with important challenges, including, in the one hand, an increasing need for disease resistance in a context of global pressure for reducing pesticide use, and in the other hand, a need for adapting to climate change. During the past few decades, European countries, have made significant progress in breeding new grapevine varieties with resistant factors mainly against powdery mildew (PM, caused by the obligate biotrophic ascomycete *Erysiphe necator*) and downy mildew (DM, caused by the heterothallic oomycete *Plasmopara viticola*).

Breeding innovation has been limited in grapevine. Despite the long history of resistance breeding, major progress in combining disease resistance and wine quality has only been achieved in the past couple of decades (Montaigne *et al.*, 2021). To control PM and DM with minimal use of agrochemicals, genetic improvement through the interspecific introgression of resistance genes (*R* genes) has been the most straightforward approach. These genes play a significant role in plant defense (Chisholm *et al.*, 2006). A few of them conferring protection against PM and DM have been identified in grapevine while several others are known as quantitative trait loci (QTLs) and are used in introgression breeding as resistance haplotypes (Merdinoglu *et al.*, 2018; Possamai & Wiedemann-Merdinoglu, 2022). The donors of those resistance factors are wild relative species, with a few exceptions. Gene pyramiding, the combination of multiple R genes or haplotypes, provides broader and more durable resistance against pathogens, compared to resistance based on a single resistance factor (Mundt, 2018).

The French grapevine breeding program INRAE-ResDur, is one of the European national breeding programs. The INRAE-ResDur program targets an ideotype that exhibits high resistance to major diseases, intermediate resistance to secondary diseases, and berry composition suitable for producing high-quality wines in a changing climate. The adopted strategy includes combining several resistance sources in parents with a predominantly cultivated genetic background, and implementing a selection scheme that combines marker-assisted selection

(MAS) with multi-site experimentation for agronomic and oenological traits. In collaboration with the German Julius Kuhn Institute (JKI) and Weinbau Institute Freiburg (WBI), as well as the Swiss institute Agroscope, the INRAE-ResDur program has been implemented through three successive series of crosses (ResDur1; ResDur2 and ResDur3), with resistance gene pyramiding to ensure a durable resistance against DM and PM (Schneider *et al.*, 2019).

2. INRAE-ResDur program: where are we now?

The selection scheme used in the INRAE-ResDur program (Schneider *et al.*, 2019) consists of three stages: i) early selection with marker assisted selection (MAS) to identify offspring with combined resistance loci; ii) intermediate selection, involving a preliminary evaluation of resistance, production, and wine quality traits through a comprehensive performance assessment, and iii) final selection, with Value for Cultivation, Use and Environment(VCUE) trials, a mandatory step before registration in the official catalog. In this scheme, starting with 1,000 seeds, 50% germination rate yields 500 seedlings for the early selection. About 50 candidate varieties will be retained for intermediate selection and then 10 for the final selection (VCUE). This selection process reduces the time for registering a new grape variety to 15 years, compared to 25 years in the late 1990s.

The ResDur1 and ResDur2 series have completed their final selection, with four varieties registered in 2018 (Floreal, Voltis, Artaban and Vidoc; see Schneider *et al.* (2019)), and five additional varieties from the second series registered in early 2022 (Figure 1). Three more will be submitted for registration in 2023. These varieties exhibit strong resistance to PM and DM, and good production potential and wine quality.

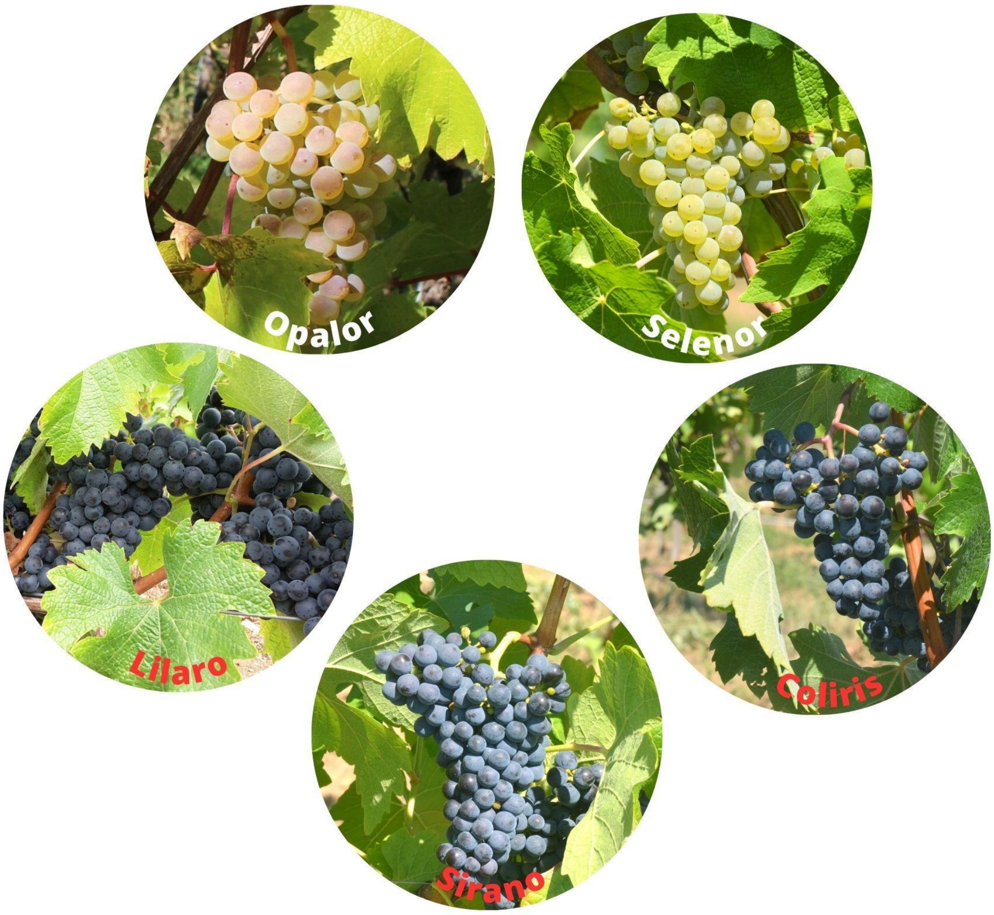

Figure 1. INRAE-ResDur2 disease resistant varieties registered in early 2022.

Schneider *et al.* (2019) described the INRAE-ResDur1 varieties. The new INRAE-ResDur2 varieties combine the resistance factors *Rpv1, Rpv10* (see Merdinoglu *et al.* (2018)), giving them very high levels of resistance to downy mildew on both leaves and clusters. They also have significant resistance to black rot (based on *Rgb1*; see Rex *et al.* (2014)), providing some protection, although insufficient when the disease pressure is high. Based on our current knowledge, potential savings in phytosanitary inputs reach 90% (Miclot *et al.*, 2022). Productivity is satisfactory to good for all these varieties, with yields ranging from 10 to 12 T/ha, on average over 3 years, comparable to the reference grape varieties used for comparison (Gamay, Pinot Blanc, Chardonnay, Merlot, Cabernet Franc). Their maturity periods, ranging from Chardonnay to Merlot, make them suitable for several French wine-growing regions. The quality of the wines has been judged equivalent to the same reference varieties in numerous blind tastings conducted during the registration trials, which involve 100-liter mini-vinifications. Coliris is characterized by its early ripening, allowing it to produce complex, rich with high color intensity, and structured wines with very fine tannins in northern regions. Sirano also is characterized by a high color intensity, it has a maturation precocity comparable to Syrah and allows to produce full-bodied red wines with fine tannins and freshness suitable for aging. Lilaro can produce fruity, balanced red wines with fine tannins and an average color intensity. It is particularly suitable to produce rosé wines, that are fine and expressive, with a pleasant acid structure. For the white types, Selenor is suitable for making slightly aromatic white wines with floral notes while Opalor is suitable to produce white wines with a bouquet of white fleshy fruit aromas, well balanced by acidity.

The ResDur3 series, with an even higher level of resistance (combining three resistance factors against downy mildew: *Rpv1, Rpv3, Rpv10* and three against powdery mildew: *Run1, Ren3, Ren9*), is currently in its final selection stage, with the first catalog presentations expected in 2025.

Overall, the INRAE-ResDur program has produced 50 different crosses, 20,000 seeds, and 9 registered varieties so far, with an additional 5 to 10 expected in the coming years.

3. INRAE-ResDur: perspectives

a- Towards new resistant varieties adapted to regional conditions

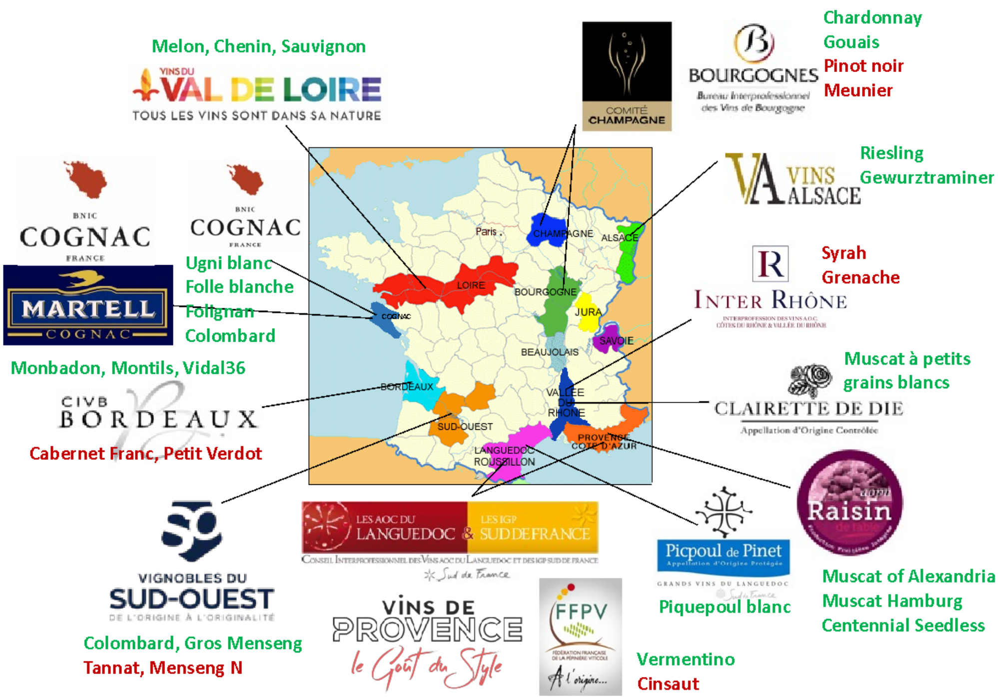

Figure 2. The regional breeding programs derived from the INRAE-ResDur program, based on INRAE and IFV pyramided elite progenitors.

The success of the INRAE-ResDur breeding program has led to the initiation of regional breeding programs in collaboration with IFV (the French grapevine and wine institute) and major wine trade associations, based on the elite resistance progenitors of IFV and INRAE. The main goal of these programs is to obtain new disease resistant varieties with regional typicalities. Crosses have already been made with a short list of emblematic varieties from each grapevine production region, selected by the regional trade associations.

Besides, to diversify the pyramiding of disease resistance factors and anticipate emerging diseases, new introgression and backcrossing activities are ongoing at INRAE Colmar. Future elite progenitors with different pyramiding combinations and an extension to new diseases will be made available for IFV and the major wine trade associations. Main current resistance factors that are being evaluated are presented in Table 1.

Table 1. Resistance factors considered in current pre-breeding programs.

Disease	Resistance factor	Origin
Downy mildew	*Rpv2*	*V. rotundifolia*
	Rpv8	*V. amurensis*
	Rpv12	Kunleany
Powdery mildew	*Run2*	*V. rotundifolia*
	Ren1	Kishmish Vatkana
	Ren4	*V. romanetii*
	Ren6	*V. piasezkii*
	Ren7	*V. piasezkii*
Black-rot	*Rgb2*	Börner
Pierce's disease	*Pdr1*	*V. arizonica*

b- Genomic selection

Although the INRAE-ResDur breeding program has significantly reduced the time needed to register a new variety, 15 years is still a long term for a breeding program especially in the face of challenges linked to climate change and the European Union important objective of drastic reduction in the use of plant protection products. Genomic selection (GS) offers a good opportunity to predict breeding values based on a reference panel without waiting for multiple years mandatory in conventional phenotypic selection, hence allowing breeders to accelerate their breeding schemes efficiently (Meuwissen *et al.*, 2001; Heffner *et al.*, 2009). Although GS has been recently developed in grapevine for several berry composition and yield components' traits (Brault *et al.*, 2022), its extension to a more comprehensive prediction of the overall breeding value of each seedling and its application in routine breeding schemes is still lacking. INRAE has planted a reference panel for genomic selection at multiple sites in France (French National Research Agency project "SelGenVit") and prediction optimization in the framework of a breeding program is being evaluated for a future implementation, with the goal to better orientate crosses and cut the time of future breeding schemes to at least 9 years instead of the 15 years currently required (Figure 3).

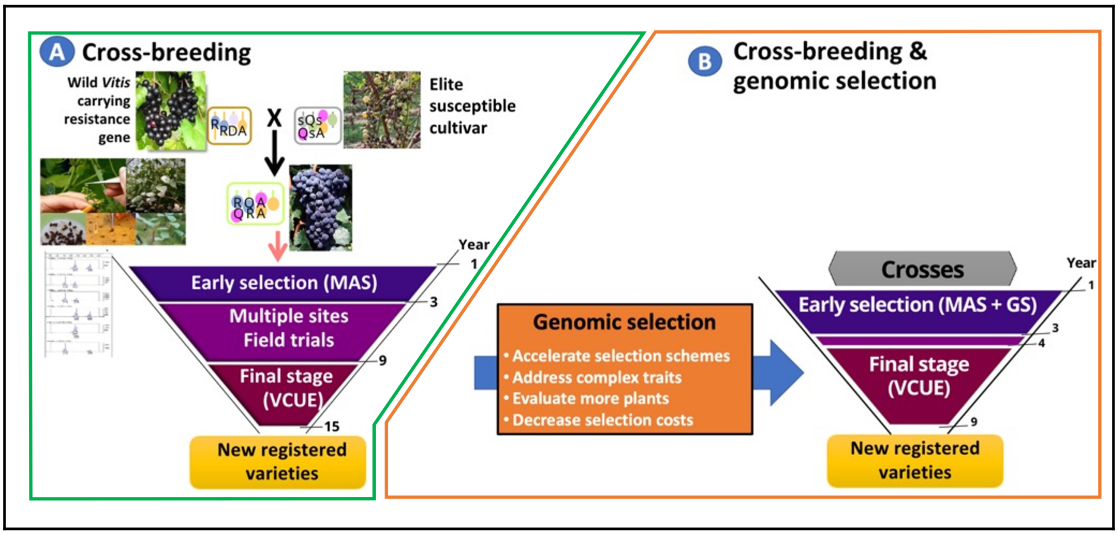

Figure 3. Expected gains based on genomic selection compared to current conventional cross-breeding schemes.

4. Conclusions

Given the deep cultural attachment to traditional grape varieties, adoption of new disease resistant varieties will take time. Currently, less than 1% (about 1000 ha end of 2022) of vineyards are planted with these varieties, despite data suggesting that they have the potential to reduce fungicide use by up to 90%. Yet, with the EU aiming to reduce pesticide use by 50% by 2030, it is crucial for viticulture to develop and adopt disease-resistant grapevine varieties. Historical data indicate that, among all crops in the EU-15 region between 1994 and 2003, vineyards had the highest pesticide use (Muthmann & Nadin, 2007). In France, consumption of plant protection products (PPPs) for viticulture reached about 25% of all crops (inorganic sulphur excluded), for only 3% of the agricultural land used. Viticulture and the wine industry must comply with the overall ambitious objective of the EU to reduce the use of PPPs by 50% by 2030. However, this will require further context-specific adjustments to EU policies, as labels, appellations, and winegrower attitudes play a significant role in achieving broader adoption. The European Common Agricultural Policy has now lifted the ban on the use of *Vitis* spp. x *Vitis vinifera* varieties and their introgression lines to produce Protected Designation of Origin (PDO) wines in the EU. In France, resistant varieties are now authorized in some PDOs, but at a maximum rate of 10% for the blend and 5% for the acreage (Montaigne *et al.*, 2021). Vineyards have a natural renewal rate of 2-3% annually, making variety choices crucial in the long run and varietal replacement critical, and the modification of individual PDO production guidelines, including the authorized varieties for grape production, takes time to be agreed among producers. Developing new resistant varieties to compete with established varieties will take time, and without regulatory intervention, change will likely be limited. The canton of Vaud in Switzerland has recently decided to provide winegrowers with financial support up to 40,000 CHF per ha, for planting disease resistant or robust varieties (list and exact definition are being validated). Such a move could become one of the strategies to acceleration a broader adoption.

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