INRA-ResDur: the French grapevine breeding programme for durable resistance to downy and powdery mildew

C. Schneider[a], C. Onimus, E. Prado, V. Dumas, S. Wiedemann-Merdinoglu, M.A. Dorne, M.C. Lacombe, M.C. Piron, A. Umar-Faruk, E. Duchêne, P. Mestre and D. Merdinoglu

INRA, Université de Strasbourg, UMR 1131 SVQV, 68000 Colmar, France.

Abstract

The current strategy to control grapevine downy and powdery mildews relies on chemical treatments. The most promising option to reduce the need for fungicides in viticulture is the use of resistant cultivars. This is why a new breeding programme called INRA-ResDur was launched in 2000 to create cultivars with durable resistance to downy and powdery mildews and with berry quality suitable for the production of high-quality wines. Various American and Asian sources of resistance have been known for a long time. During the last decade, intense genetic analyses of some of them have unveiled several resistance loci. However, resistance breakdown has already been observed for the locus *Rpv3* (resistance to *Plasmopara viticola* carried by the resistant cultivar 'Bianca') and for the locus *Run1* (resistance to *Uncinula necator* derived from *Vitis rotundifolia*). To ensure the durability of resistance, the INRA-ResDur programme used marker-assisted selection (MAS) to stack resistance factors derived from multiple sources. Thus, MAS allowed us to follow six resistance loci, *Rpv1*, *Rpv3* and *Rpv10* for downy mildew and, *Run1*, *Ren3* and *Ren3.2* for powdery mildew. This strategy led to the development of candidate cultivars bearing not only one but two or three genes to control each disease. Four new resistant cultivars, 'Artaban', 'Floreal', 'Vidoc' and 'Voltis', were registered in 2018, and a set of about 20 additional cultivars should be released by 2024. This project is a result of collaborations between INRA and IFV, the French Vine and Wine Institute, as well as other European breeding institutes.

Keywords: grapevine, breeding, resistance, marker-assisted selection, pyramiding, durability

INTRODUCTION

In France, as well as other countries in Europe, it is so far not possible to produce wine or table grapes without protection against numerous pests and diseases. The traditional cultivars are highly susceptible to downy mildew (DM; causal agent *Plasmopara viticola*) and powdery mildew (PM; causal agent *Erysiphe necator*) in particular, two biotrophic pathogens introduced from America during the 19th century. Viticulture therefore requires large amounts of plant protection products (PPP) compared with other crops. Considering the period between 1999 and 2009, PPP consumption for viticulture reached about 25% of all crops (inorganic sulphur excluded), for only 3% of the agricultural land used, with no decreasing trend (Muthmann, 2007; Butault et al., 2011).

Because of that particular situation, it is very important to develop other methods to control diseases like DM and PM. Considering possibilities based on natural resistance, we know that some American or Asian *Vitis* species can be used as sources of resistance in grapevine improvement for resistance to pathogens (Boubals, 1959; Staudt and Kassemeyer, 1995; Cadle-Davidson, 2008). That is why the French National Institute for Agricultural

[a]E-mail: christophe.schneider@inra.fr

Research (INRA) decided in 2000 to launch the ResDur breeding programme. The goals of this programme are to create cultivars with high and durable resistance to DM and PM, associated with good agronomic and wine quality performances, and to register a panel of about 20 cultivars offering a wide range of grape maturity period and wine type.

RESISTANCE FACTORS AND BREEDING STRATEGY

Over the last 20 years, a special effort has been made in genetic analysis of pathogen resistance within the *Vitis* germplasm. Quite a number of genetic factors conferring protection against DM or PM have been identified, and the corresponding loci positioned on genetic maps (see compiled list with references at http://www.vivc.de, data on breeding and genetics). However, not all of them are interesting or easy to use for breeding, either because they have weak effects or because they are not available in a sufficiently introgressed genetic background of *Vitis vinifera*. At the end, only a few of them are currently used in European grapevine breeding programmes (Figure 1).

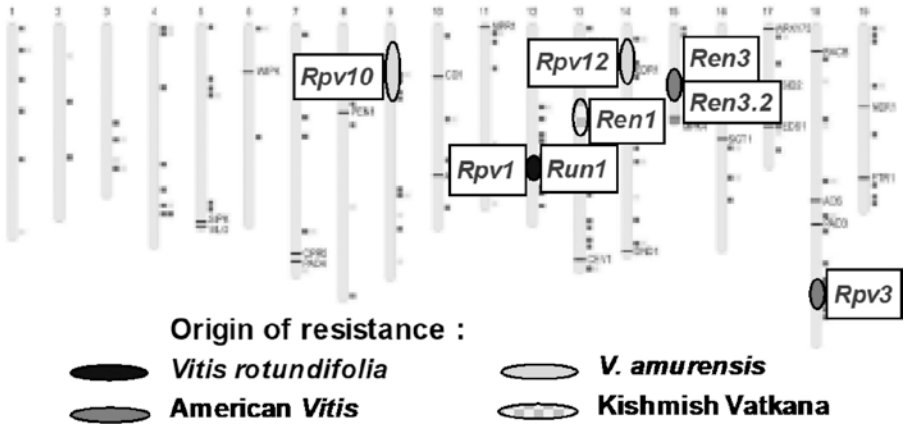

Figure 1. Resistance factors to DM (*Rpv*) and PM (*Run* or *Ren*) currently used in European breeding programmes for grapevine improvement.

Another point is resistance durability, which is very important for a perennial species. We know that disease resistance traits may be overcome by virulent pathogen strains. Such resistance breakdown has already been observed for the cultivar 'Bianca', resistance of which to DM is mainly determined by the *Rpv3* factor (Peressotti et al., 2010). A similar situation was observed for *Run1*, a gene from *Vitis rotundifolia* that confers total resistance to PM, with a naturally occurring PM isolate from Florida (Feechan et al., 2015). Therefore, in order to increase the stability of resistance to a pathogen, the breeding strategy should tend to combine different resistance loci, as recommended by a resolution of the OIV (2013). The development of new selection tools, such as marker-assisted selection (MAS), allows the implementation of such a strategy, leading to new cultivars with so-called polygenic resistance (Eibach et al., 2007).

Consistent with those principles, the INRA-ResDur programme was launched in 2000 and organised in three successive series of crosses, involving partnerships with Julius Kuhn Institute (JKI; Germany), the Weinbau Institute Freiburg (WBI; Germany) and the Agroscope (Switzerland) (Figure 2).

On the basis of introgression lines originating from *V. rotundifolia* by successive backcrosses (BC4, BC5) (Bouquet, 1986; Pauquet et al., 2001), we did a first series of crosses with cultivars bred by JKI. 'Regent' was used for the first cross-breeding, which had the advantage of being both not linked with the previous resistance source and newly registered in the German Catalogue, with very good cultivation and wine quality traits. Those types of crosses ultimately provided progenies combining two resistance loci for DM, *Rpv1* (Merdinoglu et al., 2003) and *Rpv3* (Fischer et al., 2004; Welter et al., 2007), and two resistance loci for PM, *Run1* (Pauquet et al., 2001) and *Ren3* (Welter et al., 2007). We call

these offspring ResDur1 cultivars.

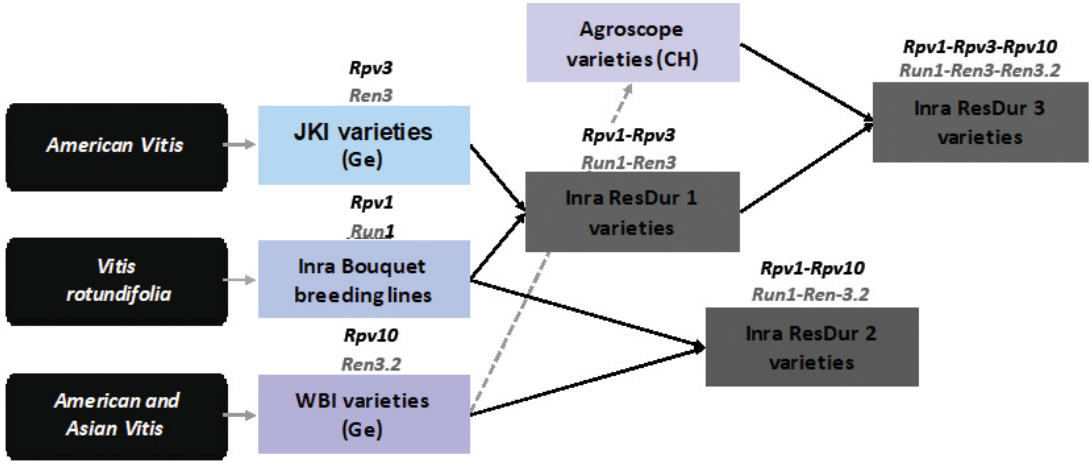

Figure 2. Crossing scheme used in the Inra-ResDur programme.

Continuing the programme on the same basis, in a second series of crosses, we have used cultivars from WBI for combination with *V. rotundifolia* backcrosses. The main cultivars were 'Solaris' and 'Bronner', bred by Norbert Becker (1996), carrying the major loci *Rpv10* for DM resistance (Schwander et al., 2012) and Ren3.2 for PM resistance (Blasi et al., 2010). So, the cultivars of the second series, called ResDur2, also carry two resistance loci for each pathogen, the American source being replaced by an Asian source for DM.

Finally, we completed the programme with a third series of crosses, between the ResDur1 progenies and the cultivars from WBI mentioned above, or offspring of them bred by the Agroscope Institute in Switzerland, such as 'Divico' (Spring et al., 2013). In this way, it was possible to stack up to three resistance loci for each disease in the ResDur3 cultivars.

The ResDur programme is expected to be completed in 2025, with the registration of the cultivars belonging to this last group.

SELECTION PROCEDURE AND PROGRESS OF THE PROGRAMME

A shortened selection scheme

When starting the ResDur programme in 2000, besides the concern for resistance durability, we also considered the possibility of hastening the selection procedure, in order to deploy the new cultivars for sustainable viticulture within a reasonable timeframe. We have therefore integrated both new selection tools such as molecular markers, and new organisation of the field testing trials.

We built up the selection scheme illustrated in Figure 3, comprising three steps: i) early selection, which involves mainly MAS to choose the offspring with stacked resistance loci; ii) intermediate selection, which consists of a first overall performance assessment for resistance, production and wine quality traits. It is based on a so-called INRA network of field trials, spread over the main climatic regions of France, thanks to the experimental facilities provided by the units of Colmar, Bordeaux, Angers and Montpellier. In these trials, the progenies are grafted on a same rootstock and observed under no spray conditions. iii) final selection, which forms the basis of the value for cultivation and use (VCU) examination, a prerequisite for registration in the official catalogue. This third step is conducted in partnership with IFV, the French Institute for Vine and Wines, involving a network of regional partners in charge of extension in the wine regions of France (Figure 4). As in step 2, the trials are not sprayed and are conducted with grafted material. They include, in addition, local cultivars as controls, for which a classical fungicide protection is provided.

The overall duration of this procedure is approximatively 15 years, which is fairly short in comparison with the classical 20- to 25-year timescale in grapevine breeding.

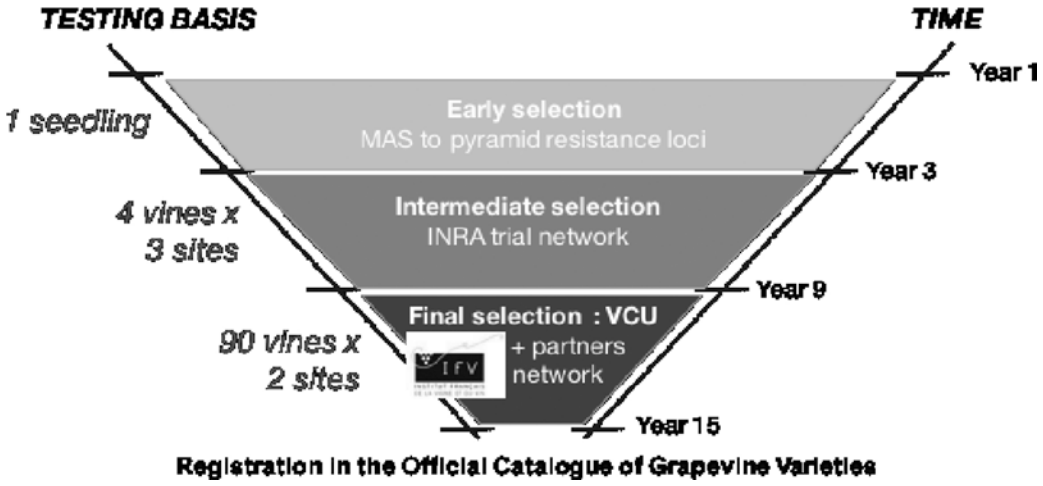

Figure 3. Selection procedure applied to the INRA-ResDur progeny.

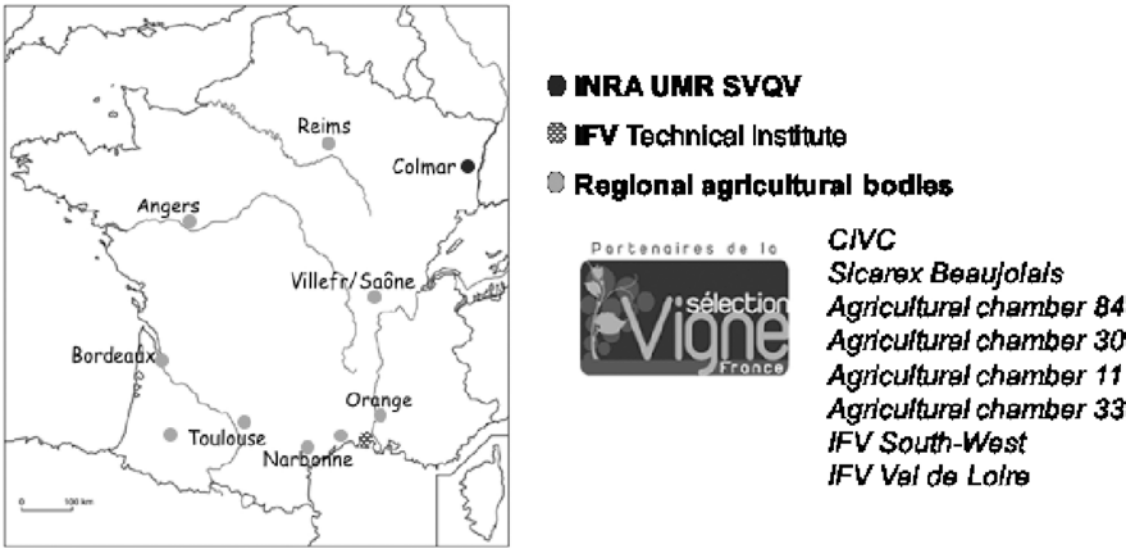

Figure 4. Organization of field trial network for the final selection in the INRA-ResDur programme.

Registration and release prospects

The state of progress of the programme has already led to the first cultivar registrations. The whole selection procedure was achieved in 2017 for the ResDur1 series, and four cultivars were registered in the French Official List in January 2018 (Figure 5). Release could start in spring 2018, with the planting of about 10 ha, mainly in the south of France. In the current state of European regulation, these cultivars can be used for the production of table wines or protected geographical indication (PGI) wines.

The second series, with 24 candidate cultivars, is undergoing the VCU level of experimentation, with a first data set on grape production and wine quality collected in 2018. Registration, expected in 2021, could include about eight cultivars.

The third series, with 35 candidate cultivars, has just been installed in the final selection step, and registration will not occur before 2024.

Main agronomic and oenological traits of the ResDur1 registered cultivars

'Artaban' (Mtp 3082-1-42 × 'Regent') has high resistance to DM and total resistance to PM. It is moderately vigorous, upright growing, with fairly high grape production. The

ripening period is medium, about 1 week after 'Gamay'. The berries are moderate sized, with blue-black skin colour. When ripe, their sugar content remains moderate, in good balance with acidity. The wines are light, silky, with good colour. They are well adapted for fast consumption, type nouveau. The aromas are dominated by fruity notes.

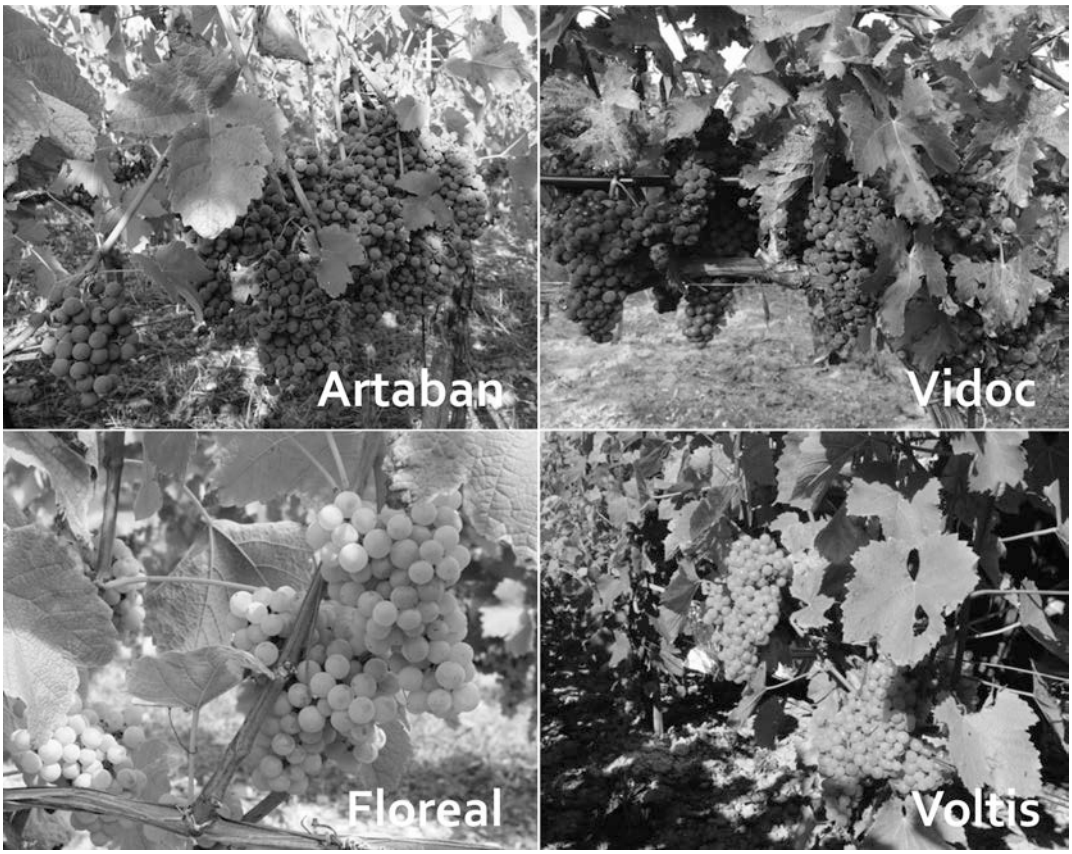

Figure 5. INRA-ResDur1 cultivars, registered in January 2018.

'Vidoc' (Mtp 3082-1-42 × 'Regent') has high resistance to DM and total resistance to PM. Vigorous, with semi-erect shoots, this cultivar requires tying. Grape production is fairly high. The ripening period is medium to late, close to that of 'Grenache'. The berries have blue-black skin colour, small size, with good tolerance to grey rot. At maturity, the sugar content is high, as is the acidity, thanks to a high proportion of tartaric acid. The wines are powerful, robust green and have intense colour. The aromas are complex, dominated by fruity and spicy notes.

'Floreal' ('Villaris' × Mtp 3159-2-12) has very high resistance to DM and total resistance to PM. It is vigorous, with semi-erect shoots requiring tying. Grape production is satisfactory, berry size is moderate and the skin colour is yellow-green. The sugar content remains average, slightly less relative to 'Chardonnay' for instance, well balanced with acidity. The wines are expressive, aromatic, with pleasant notes of exotic fruits and boxwood.

'Voltis' ('Villaris' × Mtp 3159-2-12) has very high resistance to DM and total resistance to PM. It is vigorous and upright growing. Because of the low fruitfulness of base buds, this cultivar should be cane pruned to obtain sufficient production. The berry size is moderate and the skin colour is yellow-green. Sugar content and acidity seem strongly influenced by yield. The wines are supple, ample and persistent where grape production is limited.

More detailed information on these cultivars may be found on the technical sheets, available at http://www.colmar.inra.fr/toutes-les-actualites/vignes-des-varietes-resistantes-au-mildiou-et-a-l-oidium.

CONCLUSIONS

With the inclusion of the first four Inra-ResDur cultivars in the official catalogue, we have proved the concept of grapevine cultivars that combine polygenic resistance to DM and PM with very good vineyard and wine quality performances. An accelerated selection procedure has been applied, based on MAS and multilocation field trials. The total duration of the process was reduced to 15 years, from seed germination to catalogue entry. The ResDur programme has now been extended to regional breeding programmes, in partnership with IFV and the wine industry. The objective is to obtain, by 2030, cultivars that carry multilocus resistance and produce wines of regional character. Among the regions involved are Cognac, Champagne and Burgundy, the Bordeaux area, the Rhone valley and Alsace. As a whole, these initiatives represent the biggest varietal improvement effort for grapevine ever undertaken in France and perhaps even in the world.

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