How to deal with the Green Deal – Resistant grapevine varieties to reduce the use of pesticides in the EU

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Abstract:

With its Farm-to-Fork Strategy, which is a part of the European Green Deal, the European Union aims at reducing the amount of pesticides used in agriculture by 50% until 2030. As viticulture uses around 70% of the fungicides in the EU, there is substantial pressure on winemakers to reduce their pesticide input. On top of the political goal, winegrowers face increased pressure from the public demanding a more sustainable production of wine. Since the introduction of downy mildew, powdery mildew and other pests and pathogens from North America to Europe in the 19th century, substantial breeding efforts were undertaken to develop disease-resistant varieties and reduce the amount of plant protection products needed for harvesting healthy grapes. Today's winegrowers in Europe can choose from many new varieties allowing them to reduce fungicide input by 50-80% and produce high quality wines on par with the valued traditional cultivars. This review will provide an overview on the current situation of disease-resistant varieties in European viticulture. Selected European breeding institutions and private breeders will be introduced and their most important grapevine varieties will be presented. Many resistant varieties are available for winegrowers today, however, even the most robust new varieties will not lead to a more sustainable viticulture if the market does not accept them. The adoption and acceptance of new varieties by winegrowers and consumers is still rather low, but the interest in these varieties is rapidly growing. The production of grafted vines of disease-resistant grapevine varieties allows the estimation that the area of disease-resistant varieties will significantly grow in the next years in Europe.

Keywords: grapevine, breeding, disease tolerant varieties, sustainability, market acceptance

The European Green Deal

In 2020, the European Union (EU) passed the European Green Deal with ambitious goals to overcome the challenges of climate change and environmental degradation and funds the necessary transition of the European economy with 600 million €. The most important part of the European Green for agriculture is the Farm-to-Fork Strategy (European Commission, 2020), which aims to make food production more sustainable. One central goal of the strategy is to reduce (1) the use and risk of chemical pesticides and (2) the use of more hazardous pesticides each by 50% by 2030. EU-level data on the sales of plant protection products will be used for measuring pesticide use and the baseline for the reduction is the average of sales of the years 2015, 2016 and 2017.

Viticulture in Europe

Europe is regarded as the cradle of modern viticulture and is the continent with the largest acreage of grapevines in the world. With around 3.2 million ha planted with vines, the EU constituted around 45% of all the vineyards worldwide in 2020 (Eurostat, 2022). In the EU, 16 countries have more than 500 ha of vineyards and represent 99.97% of the total acreage (see Table 1), whereas eleven countries have a smaller area under vines and account for the rest. Spain (910 859 ha), France (792 565 ha) and Italy (688 985 ha) are the three biggest wine growing countries, followed by Romania (180 683 ha) and Portugal (173 254 ha) and Germany was in 6th position with 103 554 ha in 2020. The average size of a vineyard holding in the EU was relatively small with only 1.43 ha per holding on average and are often family-run businesses. However, holdings in France are an outlier and on average 10.55 ha in size. Generally it is an ongoing trend that smaller holdings are vanishing and the vinyards are bought by bigger businesses. In cool climate countries like Germany, Austria and Hungary, white wine varieties are prevalent, whereas warmer countries grow more red wine varieties. In 2020, the majority (65.3%) of vinyards were used for the production of wines of protected designation of origin, the highest category of quality. The vast majority of cultivars used in Europe are susceptible to the viticulturally important diseases, most prominently the fungal diseases Downy Mildew and Powdery Mildew. In order to harvest healthy grapes, winegrowers need to use high quantities of fungicides in their vineyards. In Europe, around two thirds of all the fungicides used in agriculture are applied in viticulture, although viticulture constitutes only around 4% of the agricultural area (Eurostat, 2007). This highlights the potential to reduce pesticide usage in viticulture in order to fulfill the goals set by the Green Deal and make viticulture more sustainable.

Table 1: The total area under wines of the 16 member states of the EU with more than 500 ha of vinyards in 2020 (Eurostat, 2022).

Rank	Country	Total area under vines (ha)
1	**Spain**	910.859
2	**France**	792.565
3	**Italy**	688.985
4	**Romania**	180.683
5	**Portugal**	173.254
6	**Germany**	103.554
7	**Greece**	103.058
8	**Hungary**	62.108
9	**Bulgaria**	60.169
10	**Austria**	46.273
11	**Czechia**	18.099
12	**Croatia**	17.628
13	**Slovenia**	15.363
14	**Slovakia**	13.108
15	**Cyprus**	7.613
16	**Luxembourg**	1.294

Solutions for Viticulture

Continuous research over the last decades resulted in significant progress in developing methods and materials for sustainable viticulture. Todays winegrowers can use this knowledge and the tools and plants to make their vineyards more environmentally sound in order to reach the ambitious goals set by the EU in the Farm-to-Fork strategy. Of note is for example the development of the VitiMeteo prediction system by the Staatliches Weinbauinstitut Freiburg (WBI) in Germany and Agroscope in Switzerland (Dubuis et al., 2019) . It is used in Germany, Switzerland and other European countries as a tool to predict infection pressure of the most important diseases and pests. The online tool uses weather and monitoring data of a tight network of stations to calculate the risk of infection and therefore helps the winegrower to determine the ideal timepoint for plant protection in the vinyards. It even provides information on how long the plant protection product will be active in the vinyards depending on weather conditions and growth of the vines and is a powerful tool to optimize plant protection throughout the growing season. Progress in viticultural machinery, first and foremost the use of recycling sprayers, can also help to reduce the amount of plant protection products used in viticulture. However, the highest potential for the reduction of pesticides have new, disease-resistant grapevine varieties, the fruits of long-lasting grapevine breeding programs.

Grapevine breeding

Breeding disease-resistant grapevine varieties started in Europe soon after the introduction of Powdery Mildew, Downy Mildew and Phylloxera from North America. Phylloxera was effectively dealt with by developing Phylloxera-tolerant rootstock varieties based on North American Vitis species and grafting traditional European cultivars on top of it. Development of disease-resistant varieties for wine production was initially successful and winegrowers adopted these varieties fast, but doubts concerning their wine quality led to an almost complete disappearance of these varieties in Europe´s vinyards in the middle of the 20th century (Galet, 1988). In Germany, breeding disease-resistant varieties gained momentum in the 1920s and in 1992 the first variety from a resistance breeding program was registered and allowed for quality wine production. The red wine variety ‘Regent’ from the Julius Kuehn Institute (JKI) followed in 1994 and was well received by winegrowers and broke the ice for the new generation of disease-resistant varieties and sparked new interest in breeding disease-resistant varieties throughout Europe.

Resistance loci used in grapevine breeding

For a long time, breeding disease-resistant varieties was a purely empirical endeavour. Progeny of crosses had to be evaluated for their degree of resistance in the greenhouse, in the fields or in lab tests. Due to advances in research of the genetics of grapevine, molecular characterization of genetic loci responsible for the resistances (“resistance loci”) was possible. This knowledge allows the use of molecular markers to trace these resistances in the progeny (“Marker Assisted Selection”, MAS) without the need for time-consuming experiments or field evaluations. Over time a wealth of resistance loci was discovered and characterized. Today, 32 resistance loci against Downy Mildew and 13 resistance loci against Powdery Mildew are described (overview at www.vivc.de/loci), however only a fraction is usable in MAS. Against Powdery Mildew, breeders in Europe use the resistance loci Run1 (Barker et al., 2005), Ren1 (Hoffmann et al., 2008), Ren3 (Welter et al., 2007), Ren4 (Riaz et al., 2011) and Ren9 (Zendler et al., 2017) in MAS. Against Downy Mildew Rpv1 (Merdinoglu et al., 2001), Rpv3.1 (Welter et al., 2007) and its allelic variants Rpv3.2 (Zyprian et al., 2016) and Rpv3.3 (Vezzulli et al.,2019), Rpv10 (Schwander et al., 2012) and Rpv12 (Venuti et al, 2013) are in use. The degree of resistance these loci are exhibiting is of course heavily dependend on the environmental conditions and disease pressure, but in Central Europe Run1, Ren1, Ren4 are regarded as very strong against Powdery Mildew. Ren3 and Ren9 are linked resistances and usually inherited together and exhibit medium strength resistance against the pathogen. Rpv10 and Rpv12 are strong against Downy Mildew, whereas Rpv1 conveys medium resistance. The three allelic variants of Rpv3 (Di Gaspero et al., 2012) exhibit weak to

medium resistances. Additionally, Rgb1 (Rex at al., 2014), a resistance locus against black rot, is traced via MAS. Apart from these well-described loci, breeders in Europe are also using genetic ressources with unkown resistance loci in their breeding programs. In order to increase the degree of resistance and the durability of the resistance, breeder strife to combine several resistance loci in their new varieties, which was only made feasible through the use molecular markers and MAS in the last two decades.

Selected grapevine breeding programs

Today, there are many ongoing grapevine breeding programs in Europe focused on the development of new disease-resistant varieties. Most of them are state-funded but there are also some private breeders with their own programs. As they are too many to list, this overview will only present a select few. A more detailed overview is provided in Reynolds, 2015.
In Germany, the JKI – Institute for Grapevine Breeding Geilweilerhof is breeding disease-resistant varieties and is heavily invested in grapevine research. 'Regent' in 1994 was one of the first varieties the JKI released. 'Regent' carries the Rpv3.1 locus agains Downy Mildew and Ren3 and Ren9 against Powdery Mildew and is considered as having a low resistance by todays standards. However, even with high Downy Mildew pressure in 2021, 'Regent' was still able to reduce fungicide use by 50%. Apart from its success as variety, 'Regent' was often used as resistance donor in subsequent crosses both at the JKI and at other European breeders and is parent to many other important disease-resistant varieties. After the turn of the millennium, the JKI focused on combining resistance loci with the help of MAS in their breeding program. In 2018, Calardis Blanc was released and combined two resistances against Downy Mildew (Rpv3.1 and Rpv3.2), Powdery Mildew resistance (Ren3 and Ren9) together with black rot resistance and beneficial traits facing climate change, like sunburn resistance and a later ripening time than many other disease-resistant varieties. Currently, the JKI evaluates several variety candidates with additional Run1, Rpv1 and also Rpv10 loci.
The WBI in Freiburg, Germany, released several disease-resistant varieties in the 1990s (e.g. Johanniter), but the 2001 released variety Solaris quickly became the most popular disease-resistant white wine variety in Germany and other European cool climate winegrowing areas. Solaris exhibits a strong resistance against Downy Mildew due to the Rpv10 and Rpv3.3 loci, medium resistance to Powdery Mildew (Ren3 and Ren9) and very early ripening time, rendering it well suited for Northern wine growing countries like Denmark, Sweden and Norway. In 2012 the WBI released Souvignier Gris, which was very well received by winegrowers, e.g. due to its similarity to Pinot Gris and is currently the most-sought after disease-resistant variety in Europe. One new variety developed by the WBI ('Fr 628-2005') carrying Run1, Ren3, Ren9, Rpv1, and Rpv10 loci is currently in registration and its release will follow in the near future.
The private Swiss breeder Valentin Blattner developed several varieties in cooperation with a German nursery. Particularlyly the variety 'Cabernet Blanc' resonates very well with winegrowers all around Europe due to its resemblance of Sauvignon Blanc-style wines and has the second highest acreage of disease-resistant varieties in Germany. His new variety 'Sauvignac' is also of note as it features the Downy Mildew resistance loci Rpv3.1 and Rpv12 resulting in a strong resistance against this disease. Additionally, it carries Ren3 and Ren9 against Powdery Mildew. Its fruity Sauvignon-style wines and good resistance properties are reasons this variety is very popular among winegrowers all around Europe.
There are also several ongoing breeding programs in Italy. For example, the University of Udine started a breeding program for disease-resistant varieties around the turn of the millennium. The first batch of ten varieties were released in 2015 and the nursery Vivai Cooperativi Rauscedo (VCR) took over international distribution of the varieties. These varieties carry the Rpv3.1 and/or Rpv12 loci against Downy Mildew and some carry Ren3 and Ren9 against Powdery Mildew. Four further varieties derived from crosses of a disease-resistant breeding line from Hungary with Pinot Noir or Pinot Blanc were recently released and are distributed internationally by VCR, too. The Run1 and Rpv1 resistance loci were introduced into some of their latest disease-resistant varieties, too. Additionally,

the Fondazione Edmund Mach released four disease-resistant varieties ('Charvir', 'Nermantis', 'Termantis', 'Valnosia') in 2021 and they are available for winegrowers in Europe as well.
In France, the INRAE successfully breeds disease-resistant varieties in their ResDur breeding programs. For more information, please refer to the article by Avia et al.

Adoption of disease-resistant varieties

In Europe, the deep cultural attachment to traditional grape varieties is an important obstacle to a broader adoption of disease resistant varieties. Nevertheless, when 'Regent' was introduced to the German market in 1995, winegrowers were very interested and eager to plant this new disease-resistant variety. The acreage of 'Regent' rose up to 2 183 ha in 2006 in Germany and other European countries showed interest in the variety, as well. The variety paved the way for many new disease-resistant varieties in Germany. However, the area under disease-resistant wines in Germany only grew slowly the following years and was almost stagnating between 2005 and 2015. Since 2016, the area is slowly increasing again and the disease-resistant varieties currently sum up to 3 - 3,5% of the viticultural acreage (Table 2). Despite the advantages of disease-resistant varieties, many winegrowers are still hesitant to plant these varieties as they still have unfounded doubts about the wine quality, the resistance properties or how to sell wines of new cultivars the consumers do not know. German wine drinkers in particular prefer varietal wines of varieties they are familiar with and wines of disease-resistant varieties with new, unknown names are at a disadvantage. However, the general public developed a rising awareness for environmental issues and demands more sustainability, also for the production of food and drinks. Therefore the interest in wines from more sustainable production is growing and many people, especially younger generations, are eager to try wines from disease-resistant wines.In France, there even were several cases of conflicts between neighboring populations and winegrowers linked to heavy pesticide sprays, leading to an increasing pressure towards reduction of pesticide use, especially in populated areas.

Table 2: Area of selected disease-resistant grapevine varieties in Germany in 2022 in comparison to 2012
The table shows the acreage of selected varieties in 2012 and 2022. Many of the varieties planted today were not yet introduced in 2012, or no data was available ("-"). The category "Others" also includes traditional varieties of minor interest, but is mostly constituted by disease-resistant varieties prior to registration or shortly after registration (Source: German Federal Office of Statistics).

Rank	Disease-resistant Variety	Acreage 2012 in ha	Acreage 2022 in ha
1.	Regent	2.047	1.618
2.	Cabernet Blanc	-	260
3.	Solaris	102	207
4.	Souvignier Gris	-	204
5.	Johanniter	94	141
6.	Muscaris	-	117
7.	Cabernet Cortis	34	60
8.	Phoenix	48	46
9.	Pinotin	-	36
10.	Helios	-	22
11.	Prior	-	21
12.	Cabertin	-	19
13.	Monarch	-	13

14.	Saphira	-	11
15.	Rondo	11	10
16.	Cabernet Carbon	-	7
17.	Hibernal	1	8
18.	Cabernet Carol	-	5
19.	Piroso	-	5
20.	Bronner	4	6
21.	Merzling	4	3
22.	Staufer	1	0
23.	Villaris	-	0
	Others*	418	699
	Total	**2.764**	**3.518**

Winegrowers in Germany faced very difficult years with extremely high pressure of Downy Mildew in 2016 and 2021 and became more open to planting disease-resistant varieties in the last years. In fact, the interest in disease-resistant varieties grew up to the point that the production of grafted vines cannot keep up with the demand and vines of the most popular disease-resistant varieties are mostly sold out one year in advance.

In France, similarly to Germany, things are evolving slowly and the consumers' awareness to the environmental benefits of such varieties is rising, with the hope that the young generation will push the change forwardThe aforementioned public pressure together with the ambitious EU-goals are playing a significant role in the positive trend. The EU Green Deal regulations have been translated into national laws with a government financial program called "Plan Ecophyto" launched in 2009 that has funded several projects in all crops including grape. Although very limited for now, national regulations concerning the cultivation of disease-resistant varieties are also evolving despite strong restraints in the PDOs (Protected Designation of Origin) and PGIs (Protected Geographical Indication) in France. Thanks to recent changes, it is now possible to use disease-resistant varieties in some PDOs at a maximum rate of 10% for the blend and 5% for the acreage. In the famous Champagne production region, the INRAE-ResDur1 variety 'Voltis' has just been authorized and planting will start from 2023. This is a significant push for disease-resistant varieties. Overall, in France, further modifications of the national regulations are needed to induce a broader adoption of disease-resistant varieties. In fact, although there are reasons to be optimistic, adoption rate is overall still very limited, albeit with a rapid progress. As of 2022, 45 varieties mainly resistant to PM and DM were registered in the French national catalog of varieties: 20 of them are considered historical and include varieties such as Baco blanc, Chambourcin noir, Maréchal Foch or Seyval blanc; 12 are foreign varieties registered in 2017 and include varieties such as Bronner, Cabernet Cortis, Solaris, Soreli or Souvignier Gris; 4 INRAE-ResDur1 varieties; 5 INRAE-ResDur2 varieties, and Sauvignac. Additionally there are 3 varieties for distillation (Coutia blanc, Luminan blanc and Vidal blanc). The number of these disease resistant varieties has doubled during the last 2 decades but their total acreage is limited. The latest detailed data showed that in 2021 altogether they reached about 1 200 ha, with Souvignier Gris being the most planted (365 ha), followed by two ResDur1 (Floreal, 250 ha and Artaban, 150 ha). The limited number of available graftings for ResDur1 varieties at that time must be taken into account however. Indeed, the planted acreage of the ResDur1 varieties grew from 550 ha in 2021 to about 900 ha in 2022, an indication of great interest in them. But compared to the almost 800 000 ha of viticulture land in France, these acreages are far from being significant for now.

Production of grafted disease-resistant grapevine varieties

The current data on the area planted with disease-resistant varieties does not directly reflect the current trend of viticulture but lags a few years behind the winegrowers decision on what to plant. A look at the production of grafted vines in the nurseries is a way to have a more up-to-date look at the current developments:

In 2022, German nurseries grafted around 24 million vines, of which 5.3 million (22.1%) were made with disease-resistant varieties (see Table 3). In 2017 and 2018, disease-resistant varieties only made up around 9.6% of the graftings, showing a significant increase in the production of disease-resistant grafted vines. A look at the relative amount of planted disease-resistant varieties, however, reveals that in 2022 only 9.5% of the annually planted grapevines were disease-resistant. This in turn means many grafted vines of disease-resistant varieties are exported into other European countries. In France, total grafted vine production amounted to 220 M in 2021, half a million smaller than that of 2020. Production of disease-resistant varieties is progressing rapidly with 4.25 M graftings (1.9%) in 2021 compared to 2.79 M (1.3%) in 2020.

Taken together, the data leads to the conclusion that in the coming years the area under disease-resistant vines in Europe, and in particular in Germany, is going to grow significantly.

Table 3: Data on the production of grafted vines in Germany and annually planted disease-resistant grapevine varieties.

	2017	2018	2019	2020	2021	2022
Total graftings (M)	**27,4**	**28**	**23,3**	**22**	**23,3**	**24**
Disease-resistant varieties grafted (M)	**2,6**	**2,7**	**3,3**	**3,5**	**4**	**5,3**
Disease-resistant graftings (%)	**9,6**	**9,6**	**14,2**	**16**	**17,3**	**22,1**
Disease-resistant new plantings (%)	**1,8**	**2,7**	**3,4**	**4,4**	**6,6**	**9,5**

Conclusion

Disease-resistant grapevine varieties offer great potential to reduce the amount of pesticides used in viticulture and to fulfill the goals for pesticide reduction set by the European Commission in their Green Deal. Due to the long lasting breeding efforts of European grapevine breeders, todays winegrowers have a wealth of disease-resistant varieties to choose from which allow the reduction of fungicide treatments by 50 – 80 %. However, even the most robust new varieties will not lead to a more sustainable viticulture if the market does not accept them. After years of hesitation from winegrowers and consumers, the tide seems to turn: Winegrowers are aware of the reduction goals and the high-quality alternatives that disease-resistant varieties are. Additionally, the public expresses a rising demand for sustainable production of their consumed products and puts pressure on the producers. Therefore, the interest in disease-resistant grapevine varieties and their wines grows in every step of the value chain. Together with other advances in vineyard management, prediction tools and viticultural machinery, the reduction goals st by the Green Deal will be achievable.

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