OSCAR, a national observatory to support the durable deployment of disease-resistant grapevine cultivars

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Abstract

The cultivation of disease-resistant grapevine cultivars makes it possible to reduce considerably the number of pesticide treatments applied in viticulture. The recent, but increasingly widespread deployment of these cultivars raises several important issues. The first concerns the qualitative potential of the cultivars and their marketing. The second issue is more generally important and concerns the management of durability of resistance. Several cases of erosion or breakdown of resistance have already been reported in Europe. The evolution of pathogen populations targeted by varietal resistance should therefore be closely monitored, to ensure that grapevine resistance remains effective in the long term. Another key issue is the design of the cropping system, which should be adapted to resistant cultivars so as to maintain production objectives, promote the durability of resistance and minimize the use of pesticides. INRA has set up the National Observatory for the Deployment of Resistant Cultivars (OSCAR; http://observatoire-cepages-resistants.fr) to meet these challenges. OSCAR is a participative network based on plots in production situations planted by growers. The participative dimension of the network promotes the sharing of experiences relating to agronomic behavior, the potential for mechanization, ease of cultivation and wine quality. This observatory also monitors the emergence of new diseases or of virulent strains. Powdery and downy mildew (diseases targeted by varietal resistance) isolates are collected and tested under laboratory conditions, to monitor changes in population aggressiveness. We present here the first results obtained for the 34 plots of OSCAR monitored in 2017. This observatory is currently being extended to a larger number of plots in France and other European countries. The data obtained will be fed into mathematical models to determine the effects of deployment strategies and landscape features on the epidemiological dynamics of resistance erosion.

Keywords: disease resistance, observatory, downy mildew, powdery mildew

INTRODUCTION

Controlling plant pathogens is a major challenge in agriculture, given the considerable losses they cause (Oerke, 2006). One of the main alternatives to pesticides for controlling pathogens is the use of resistant cultivars. This strategy presents three main advantages: cost effectiveness, absence of negative side effects on human health and environment, and high specificity (Crute and Pink, 1996), preventing side effects on non-target organisms. Resistant cultivars are widely used for arable crops (DEPHY, 2014), but remain rarely considered for perennial crops, such as apple and grapevine, which are still heavily treated with pesticides. The mean treatment frequency index in viticulture is high, at 14.7 (Agreste, 2013). Fungicides account for 80% of these treatments, and most treatments target downy and powdery mildew (Agreste, 2013).

The breeding of perennial plants, such as grapevines, for disease resistance has a long

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history. Fourteen factors conferring resistance to downy mildew (Rpv) and 11 conferring resistance to powdery mildew (Run or Ren) have been identified in wild American and Asian *Vitis* species (Merdinoglu et al., 2018). Following the introduction of downy and powdery mildew in Europe in the late 19th century, breeders used American *Vitis* species as a source for resistance, to create new interspecific hybrids resistant to these diseases. In 1958, these hybrids accounted for more than 30% of the grapevines in French vineyards. However, the poor enological and agronomic quality of these hybrids, together with unfavorable regulations (ICV, 2013), resulted in their gradual eradication. Breeding efforts nevertheless continued in Germany, Switzerland, Italy, Hungary and France. In Germany, the cultivar 'Regent', which is nowadays the most planted resistant cultivar in Europe (2000 ha in 2015, according to the German Wine Institute), was created by the JKI in 1967, and the WBI Freiburg obtained various resistant cultivars in the 1970s and 1980s. In France, a first research initiative in 1974 aimed to incorporate resistance factors from *Vitis rotundifolia* into the European vine (*Vitis vinifera*) (Bouquet, 1980). This resulted in the creation of a series of genotypes called 'Bouquet', which were released after 25 years of backcrossing to the *V. vinifera* parent. Each genotype carries one single gene conferring quantitative resistance to downy mildew (*Rpv1*; Merdinoglu et al., 2003) and another single gene conferring qualitative resistance to powdery mildew (*Run1*; Pauquet et al., 2001). This effort was followed by the "ResDur" program, which was initiated in 2000, with the aim of pyramiding resistances from 'Bouquet' genotypes with those of German cultivars (Merdinoglu et al., 2009; Mundt, 2014). Four resistant cultivars are now typecast in France ('Floreal', 'Voltis', 'Vidoc', 'Artaban'), and several German, Swiss and Italian cultivars are also available (Figure 1). This situation has enabled French vine growers to cultivate this new generation of resistant cultivars in France and use them for wine production.

Varieties	Resistance factors	Breeding institute	Vineyard ID number
3159-2-12 B	Rpv1, Run1	INRA*	9
3160-11-3 N	Rpv1, Run1	INRA*	9
3176-21-11 N	Rpv1, Run1	INRA*	9
3184-1-9 N (G14)	Rpv1, Run1	INRA*	9
3197-81 B (G5)	Rpv1, Run1	INRA*	9
Artaban	Rpv1/Rpv3, Run1/Ren3	INRA**	1, 9, 13
Floreal	Rpv1/Rpv3, Run1/Ren3	INRA**	3, 5, 9, 13
Vidoc	Rpv1/Rpv3, Run1/Ren3	INRA**	11, 13
Voltis	Rpv1/Rpv3, Run1/Ren3	INRA**	5
Col-50#83	Rpv1/Rpv10, Run1/Ren3.2	INRA**	14
Cabernet cantor	unknown	WBI Freiburg	6, 7
Cabernet cortis	unknown	WBI Freiburg	6, 10
Monarch	unknown	WBI Freiburg	8, 10
Muscaris	unknown	WBI Freiburg	4, 6, 8
Souvignier gris	unknown	WBI Freiburg	6, 10
Cabernet jura	unknown	V. Blattner	2
Cal 6-04	unknown	V. Blattner	2, 4
Cabernet kretos	unknown	IGA Udine	12
Cabernet volos	unknown	IGA Udine	12
Soreli	unknown	IGA Udine	11, 12

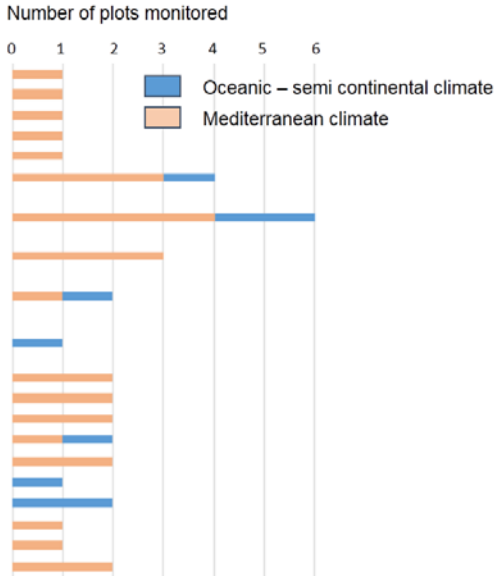

Figure 1. Characteristics and location of the cultivars monitored by OSCAR in 2017. Resistant genes, breeding institute of origin. Each of the 34 plots monitored is planted with a single cultivar. Mediterranean climate, 25 plots located in Languedoc, Provence and Rhône; Oceanic climate, nine plots located in Bordeaux, Bergerac, the southwest; Semi-continental climate, one plot located in Alsace.

In practice, the implementation of disease-resistant grapevine cultivars remains challenging because, for any newly registered cultivar, many agronomic parameters must be assessed in the vineyard. More specifically, protection goals and protection strategies must be adapted to complement the partial genetic resistance achieved and to control the secondary diseases that might re-emerge following the decreased use of fungicides. Long-term cropping system experiments have already been conducted with disease-resistant grape cultivars at INRA (Petit-Genet et al., 2016), but further evaluations of these innovative cultivars are now required in more diverse agro-climatic situations. The use of disease-resistant cultivars is also challenging for farmers for socioeconomic reasons (Hochereau et al., 2015), concerning more particularly the economic valorization of the wine produced. In France, cultivars derived from interspecific crosses cannot be used for the production of wines under a protected designation of origin (PDO) (European regulations EU1308/2013).

The second major challenge concerns the management of the genetic resistances used so as to ensure their durability (i.e., the maintenance of resistance efficacy in the long term). Resistance genes do not remain effective forever (McDonald and Linde, 2002; Zhan et al., 2015), and their scarcity, together with the very long periods of time required for their introduction into a new cultivar, requires careful management to ensure that they will remain effective for as long as possible (Merdinoglu et al., 2018). Pathogens evolve to adapt to resistant cultivars (McDonald and Linde, 2002), through evolutionary mechanisms resulting in the total breakdown of qualitative resistance and/or a gradual erosion of quantitative resistance. Downy and powdery mildews respond rapidly to directional selection, as demonstrated by the rapid evolution of resistances to almost all fungicides deployed (Chen et al., 2007; Fontaine et al. 2013; Delmas et al., 2016). In their native area (northeastern America), the downy and powdery mildew agents can infect an extensive range of *Vitis* species (Brewer and Milgroom, 2010; Rouxel et al., 2014), including the cultivars that have provided the resistance genes introgressed into *V. vinifera*. Moreover, several cases of resistance breakdown have been reported, even though resistant grapevine cultivars are not widely cultivated: in Europe, the *Rpv3* resistance factor present in 'Bianca' and 'Regent' has been overcome by a virulent strain of *Plasmopara viticola*, the causal agent of downy mildew (Peressotti et al., 2010; Delmotte et al., 2014; Delmas et al., 2016). Similarly, *Erysiphe necator* strains from *V. rotundifolia* can break the total resistance to powdery mildew conferred by the *Run1* gene (Feechan et al., 2013). The new French cultivars currently being developed are designed to ensure the durability of resistance through the pyramiding of several resistance factors for each target disease. This approach should slow down the erosion and limit the breakdown of resistance. More generally, agricultural practices for pathogen control, such as preventive cropping practices, fungicide treatments, and biological control, should be combined with varietal resistance to increase overall resistance durability (Mundt, 2014). However, such combinations of control methods are constrained by financial, organizational and environmental factors that must be assessed in practical situations (Delmotte et al., 2016).

INRA has launched the national observatory for the deployment of disease-resistant grape varieties (OSCAR) to meet these challenges. OSCAR monitors the initial deployment of resistant grape cultivars in France. The objective of this observatory is i) to set up large-scale monitoring of the efficacy of resistance to downy mildew, ii) to monitor the emergence of new plant health issues and iii) to favor the sharing of experiences with cropping systems based on resistant grape cultivars. We describe here i) the major features of OSCAR and ii) the first results obtained by this observatory in 2017.

MATERIALS AND METHODS

Network of plots

Plots must fulfill several conditions for inclusion in OSCAR. They must cover an area of at least 0.2 ha (700-1500 vines), be planted with a single cultivar and be subject to similar cropping practices to those used elsewhere in the vineyard (pruning, cropping operations, harvest). OSCAR is designed to establish a network of plots characterized by diverse practices and agro-climatic conditions. Each plot is described in terms of location, size, cultivar, year of plantation, density, rootstock, pruning method, and target yield. Data concerning the socioeconomic characteristics of the vineyard and its products are also collected (organic vs. conventional; type of wine produced).

Data collection

We use standardized protocols to collect data concerning the properties (A1-A7), cropping practices (A8-A10), and disease epidemics (A11-A12) of grape cultivars:

A1. Assessment of phenological stages: dates of budburst, flowering and ripening.
A2. Growth habit (erect, intermediate, procumbent).
A3. Cane fragility (on a scale of 1-4).
A4. Cluster compactness (loose, normal, compact).
A5. Ease of mechanical harvest (on a scale of 1-3).
A6. Yield (kg ha^{-1}).
A7. General evaluation of the quality of the cultivar (on a scale of 1-3).
A8. Prophylactic operations (leaf removal, removal of disease inoculum, bud removal).
A9. Irrigation (yes, no).
A10. Plant protection: dates of treatment, target, product name and active ingredients, dose, decision rules used. These data are used to calculate the treatment frequency index (TFI). For each disease, the amount of fungicide used is expressed by the TFI, which is calculated as follows: $TFI_{field} = \Sigma$ treatment(applied rate/recommended rate) (OECD, 2001; Pingault et al., 2009).
A11. Assessment of disease dynamics for six major grapevine diseases: downy mildew due to *P. viticola*, powdery mildew due to *Erysiphe necator*, black rot due to *Guignardia bidwellii*, anthracnose due to *Elsinoë ampelina*, erineum due to the mite *Colomerus vitis*, and phylloxera due to *Daktulosphaira vitifoliae*. Five observations are made per year, at five stages: preflowering, flowering, fruit set, veraison, harvest (Coombe, 1995). For each disease, we assess incidence at the scale of the vine, and incidence and severity on leaves and clusters, on a scale of 0 to 5 (Table 1).
A12. A qualitative assessment of local disease pressure is performed for downy mildew, powdery mildew and black rot on susceptible *V. vinifera* cultivars growing adjacent to the plot (no disease; low; intermediate; high levels of disease).

Table 1. Rating scales used to characterize diseases observed on OSCAR plots. Six variables are evaluated: incidence on leaves and clusters at the vine scale (frequency of vines with at least one diseased leaf and frequency of vines with at least one diseased cluster); incidence on leaves (frequency of diseased leaves in the plot); incidence on clusters (frequency of diseased clusters in the plot); severity on leaves; severity on clusters. For each variable, five classes have been defined.

Incidence (vines)	Incidence (leaves/clusters)	Severity
5. Generalized (>80%)	5. Very high (>50%)	5. Very high (>50%)
4. Very high (50-80%)	4. High (10-50%)	4. High (10-50%)
3. High (25-50%)	3. Moderate (5-10%)	3. Moderate (5-10%)
2. Regular (5-25%)	2. Low (1-5%)	2. Easily visible (1-5%)
1. Rare (<5%)	1. Rare (<1%)	1. Traces (<1%)
0. Absent	0. Absent	0. Zero

Monitoring of virulence

Pathogen adaptation to resistant grape cultivars is monitored with *P. viticola*. Across the observatory, isolates of *P. viticola* are collected annually from the plots planted with resistant cultivars and from adjacent plots planted with susceptible *V. vinifera* cultivars. These isolates are stored in liquid nitrogen, to constitute a collection of *P. viticola* populations that have faced resistant grape cultivars. Every 3 years, bioassays are conducted under laboratory conditions as described by Delmas et al. (2016). The life-history traits recorded for the pathogen include its sporulation dynamics, number of sporangia per leaf area, latency period, and sporangium size. The *P. viticola* isolates are then genotyped with microsatellite and single nucleotide polymorphism (SNP) markers (Delmotte et al., 2006, 2011).

Management

OSCAR is managed by a coordination team responsible for the various activities of the observatory: coordination, training, data management and analysis, and virulence monitoring. The team is supported by a multidisciplinary advisory committee of plant pathologists, breeders, agronomists, and sociologists. Data are collected by professional partners [extension workers from chambers of agriculture, the Institut Français de la Vigne et du Vin (IFV), and interprofessional organizations].

RESULTS

Network development

In 2017, the network consisted of 34 plots located in 14 vineyards covering a total area of 17 ha distributed in seven French wine-producing regions: Languedoc (*n*=17), Provence (*n*=3), Rhône (*n*=5), Bordeaux (*n*=4), Bergerac (*n*=2), the southwest (*n*=2) and Alsace (*n*=1) (Figure 2).

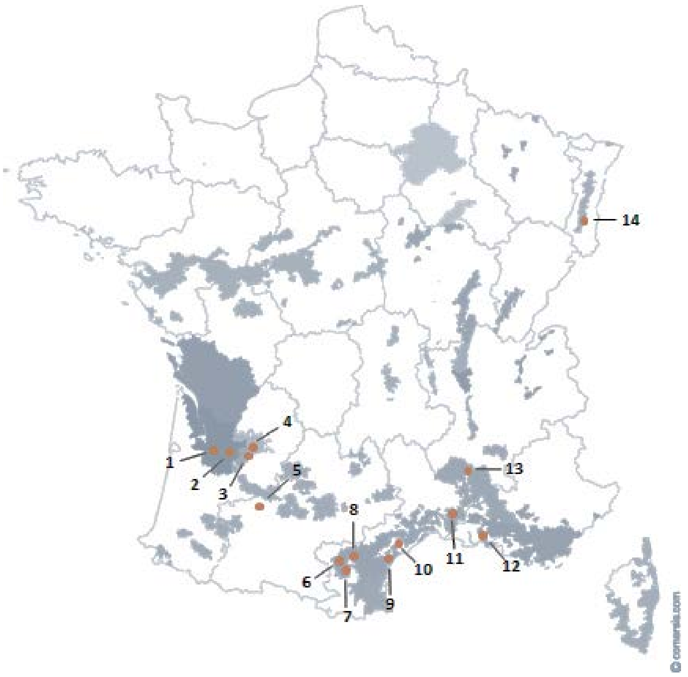

Figure 2. The 14 vineyards participating in OSCAR in 2017. Each farm has an ID number. Wine regions are shown in gray. OSCAR plots are present in seven wine-producing regions: Alsace (vineyard 14), Bordeaux (vineyards 1 and 2), Bergerac (vineyards 3 and 4), the southwest (vineyard 5), Languedoc (vineyards 6-10), Rhône (vineyards 11 and 13) and Provence (vineyard 12).

In total, 17 of these plots are managed according to organic rules, whereas all others are under conventional management. All the plots contain vines grafted onto phylloxera-resistant rootstocks. The plots are quite young, with most planted after 2015. The oldest plot was planted in 2011, and the most recent plots were planted in 2017 (four plots).

The 34 plots are planted with 20 different resistant cultivars. Half of these cultivars were produced in French breeding programs (five 'Bouquet' and five 'ResDur' grape cultivars), and the others were obtained from the Udine Institute ('Cabernet kretos', 'Cabernet volos', 'Soreli'), the Freiburg Institute ('Cabernet cantor', 'Monarch', 'Muscaris', 'Souvignier gris', 'Cabernet cortis') and Valentin Blattner ('Cabernet jura', 'Cal-6-04').

Sampling

In 2017, downy mildew isolates was collected from five grape cultivars: 'Artaban' (31 isolates, from vineyard 1), 'Cabernet volos' (five isolates, vineyard 12), 'Vidoc' (three isolates, vineyard 11), 'Cabernet cortis' (two isolates, vineyard 10), and 'Sauvignon kretos' (one isolate, vineyard 12).

Pesticide use

A number of farming practices were monitored in 2017. We present here the results for pesticide use. The TFI (including fungicide, herbicide and insecticide applications) was determined for the 30 OSCAR plots planted before 2017 (plots planted in the year of assessment were not taken into account) and for a set of 431 plots included in DEPHY (DEPHY, 2018) and distributed across French vineyards (national reference). The average TFI was 2.05 for OSCAR and 10 for the national reference, corresponding to an 80% decrease in pesticide use. For fungicide treatments, the TFI for OSCAR plots was 1.2, an 84% decrease relative to the national reference.

The main target of the fungicides was powdery mildew in the Mediterranean area (22 plots), accounting for 77% of the total fungicide TFI, and downy mildew in the oceanic and semi-continental areas (eight plots), accounting for 60% of the total fungicide TFI (Figure 3). Black rot was the target of 4.5% of fungicide applications in the Mediterranean area (one of 22 plots) and 33% of those in areas with an oceanic climate (three of eight plots).

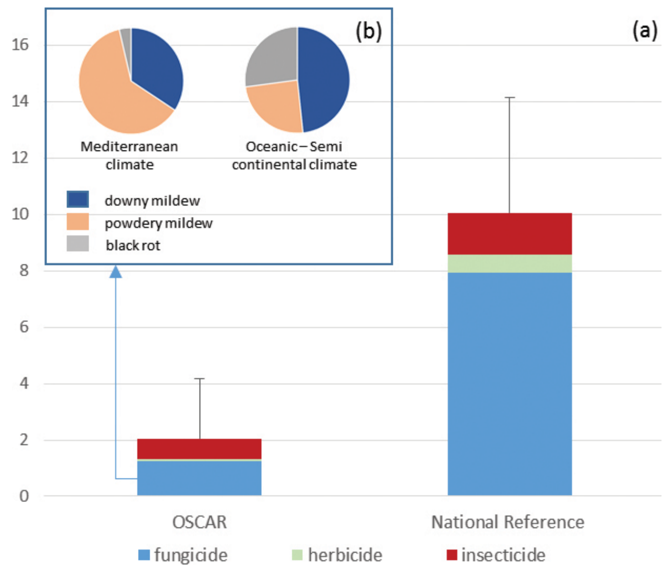

Figure 3. Treatment frequency index (TFI) in the OSCAR network. (a) TFIs for fungicide, herbicide and insecticide applications on OSCAR plots and the national reference in 2017. The standard error between plots is shown. The national reference is calculated from data of the DEPHY network (431 plots distributed over all French wine regions). This network brings together 528 vine growers involved in the reduction of pesticide use (DEPHY, 2018). There are 30 OSCAR plots: the plots planted in 2017 are not taken into account. Fungicide targets for OSCAR plots are shown on pie charts (b). The fungicide targets depend on climate: Mediterranean (*n*=22 plots) or oceanic/semi-continental (*n*=8 plots).

In 2017, the plots received 0 to 2 fungicide applications (Table 2), with an evenly balanced distribution of treatment frequency: 35% of the plots received no fungicide, 35%

received only one fungicide application, and 30% received two applications. All the untreated plots were located in areas with a Mediterranean climate. In this climate, 45% of plots remained untreated, 23% of the plots received one fungicide treatment and 32% two applications. In the oceanic and semi-continental climate, none of the plots remained untreated, 75% of the plots received one fungicide application and 25% received two applications. Overall, 76% of fungicide treatments were applied at or around the flowering stage, a period of susceptibility to disease in grapevine (Lorenz et al., 1995), and 24% were applied at veraison.

Table 2. Number of fungicide applications on the 30 plots of the OSCAR network surveyed in 2017. The percentages of the plots receiving zero, one or two fungicide applications are shown. The columns report data for the entire OSCAR network (n=30), for plots from areas with a Mediterranean climate (n=8), and for plots with an oceanic-semi continental climate (n=22).

Number of applications	OSCAR	Mediterranean climate	Oceanic-semi continental climate
0	35%	45%	0%
1	35%	23%	75%
2	30%	32%	25%

Disease epidemics

The 30 plots planted before 2017 were monitored for diseases on leaves, and 28 of these plots were monitored for disease on clusters. Results were obtained for all plant growth stages considered, but only results corresponding to the veraison stage, which provides a useful snapshot of the plant health status of the vineyards, are shown here.

Downy mildew was found on the leaves in 30% of the plots, regardless of climatic zone. Severity was systematically below 5% on these infected plots, and was mostly <1%. By contrast, this disease was not detected on clusters in any of the 28 plots surveyed. A similar trend was observed for incidence.

Powdery mildew was detected on leaves in 13% of the plots and on clusters in 11% of the plots (Figure 4). Powdery mildew occurred on leaves only in the Mediterranean area. No powdery mildew was detected on varieties carrying the *Run1* resistance gene, which was totally resistant to this pathogen. Both disease incidence and severity were low (class 1 or 2) on all infected plots, with the notable exception of a plot planted in 2016 with the cultivar 'Soreli' (vineyard 11). In this plot, 80% of the vines had clusters infected, but disease severity was low (1-5%).

We also obtained results for a number of diseases not targeted by resistance genes in grapevine: black rot, anthracnose, erineum mite and phylloxera on leaves (Figures 4 and 5). Almost 25% of the plots displayed black rot symptoms on leaves (23%) and clusters (21%) at veraison. The severity was always below 5%. On three plots, black rot incidence on clusters reached 25-50% at vine scale ('Cabernet jura' in vineyard 2, 'Soreli' in vineyard 11 and 'Artaban' vineyard 1) and, on one plot, black rot incidence on leaves reached 50-80% at the vine scale ('Artaban', vineyard 1). For anthracnose, only one plot planted with 'Artaban' in 2011 (vineyard 1) had symptoms on leaves and clusters, with low incidence and severity (incidence at vine scale <5% and severity <1%). For phylloxera, 17% of the plots presented galls on leaves, with low incidence at vine scale and low severity (<1%). Erineum mite galls were observed on leaves in 80% of the plots, but both incidence and severity remained low (<5% of the vines affected, with a severity of <5%). No symptoms were detected on clusters.

DISCUSSION

OSCAR, the national observatory for the deployment of disease-resistant grape cultivars, was launched in 2017. This is the first time that a plant-breeding organization (in this case ENTAV-INRA) has decided to implement a large-scale framework aiming to manage the deployment of resistant grape cultivars. One main objective is the long-term monitoring of downy mildew virulence in response to the deployment of resistant grape cultivars. This approach can be compared with the long-term virulence monitoring systems deployed for other pathosystems, such as that used for the surveillance of *Puccinia striiformis* f. sp. *tritici*, the causal agent of wheat stripe rust, over the last 25 years in France and Europe (de Vallavieille-Pope et al., 2012; Thach et al., 2015; Global Rust Reference Center, 2018) and the international initiative for *Venturia inaequalis*, the causal agent of apple scab (Vinquest). During this first year of monitoring, we detected no cases of erosion/breakdown of the resistance of these cultivars to downy and powdery mildews. Indeed, the severities of downy mildew and powdery mildew remained below 5% on leaves and clusters, despite the low levels of fungicide use. Powdery mildew did not appear on INRA cultivars carrying *Run1* resistance genes, which confer total resistance to the pathogen. For downy mildew, these field assessments should be complemented by the monitoring of aggressiveness and virulence in laboratory conditions. These bioassays will be performed at 3-year intervals, from 2019 on.

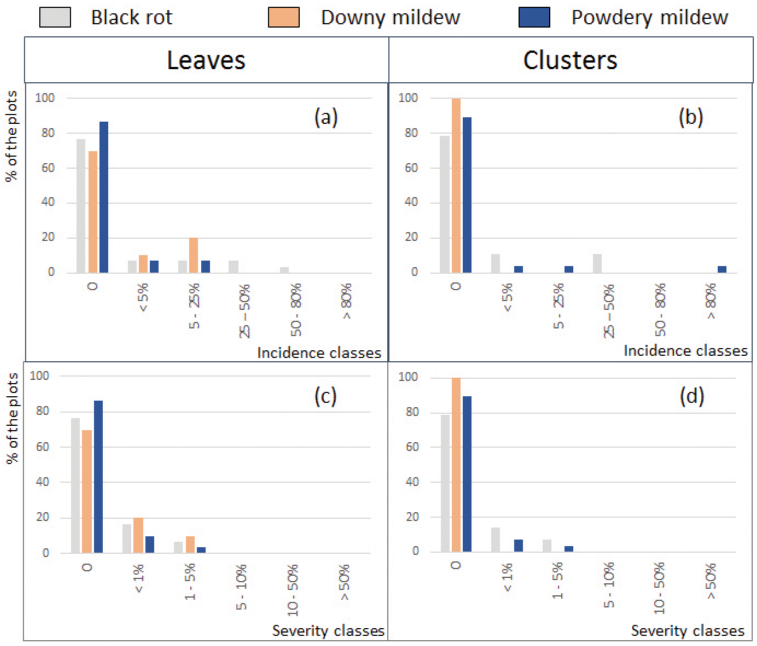

Figure 4. Incidence and severity of black rot, downy mildew and powdery mildew on leaves and clusters in plots of the OSCAR network sampled at the veraison stage in 2017. Disease incidence on leaves: frequency of vines with at least one infected leaf. Incidence on clusters: frequency of vines displaying at least one infected cluster. Incidence and severity were classified into five classes. The histograms report the percentage of the plots in each class (*n*=30 plots for leaves and *n*=28 for clusters). (a) Incidence of the three diseases on leaves. (b) Incidence of the three diseases on clusters. (c) Severity of the three diseases on leaves. (d) Severity of the three diseases on clusters.

In addition to virulence monitoring, the originality of OSCAR consists of the generation of reference data for the cultivation systems used for the new disease-resistant cultivars. The results for this first year of surveillance highlight the tremendous potential of resistant cultivars for reducing pesticide use in grapevine systems. Indeed, pesticide use was 80% lower (84% for fungicides) than the national average across the 34 plots monitored. Despite this strong decrease in fungicide use, all the fungal diseases remained well controlled, whether targeted by the resistance genes or not. These results confirm those previously obtained in long-term cropping system experiments conducted in France with INRA disease-resistant cultivars (Petit-Genet et al., 2016; Delière et al., 2018). However, it should be kept in mind that 2017 was characterized by a low to moderate overall disease pressure in

French vineyards (DEPHY, 2018). Clearly, a full evaluation of the potential of disease-resistant grapevine cultivars will require surveys over several years, under conditions of both low and high disease pressure.

Figure 5. Incidence and severity of erineum mite, anthracnose and phylloxera on leaves and clusters on plots surveyed at veraison in the OSCAR network in 2017. Incidence on leaves: frequency of vines with at least one infected leaf. Incidence on clusters: frequency of vines displaying at least one infected cluster. Incidence (upper part of the figure) and severity (lower part of the figure) are assigned to five classes. The figures shown are percentages of the plots in each class (*n*=30 plots for leaves and *n*=28 for clusters).

The strong decrease in fungicide use has major practical implications, because it may favor the re-emergence of many secondary diseases normally controlled by fungicide treatment. In 2017, the severities of phylloxera, erineum, anthracnose and black rot were below 5% at veraison, suggesting no increased infection by these pathogens on the varieties assessed. However, disease impact may differ between leaves and clusters. Although common on leaves, erineum rarely affects the growth of *V. vinifera* plants (Linder et al., 2009). Erineum was detected on clusters before flowering in two plots (E-L38 stage, i.e., single flowers in compact groups), a situation rarely reported for *V. vinifera*. Anthracnose is rarely observed in European vineyards because it is controlled by fungicide applications against downy and powdery mildew (Viret and Gindro, 2014). Nevertheless, it was detected, at low incidence and severity, on one plot planted with a mildew-resistant cultivar. Black rot, a fungal disease causing sporadic damage in European vineyards (Viret and Gindro, 2014), has generally low incidence and severity in our survey, although its impact on leaves and clusters was high at the vine scale in three of the plots analyzed. The vintners considered local black rot pressure to be low. The results obtained in a 5-year study for 'Artaban' (Delière et al., 2018) indicated that black rot could cause significant harvest losses under conducive conditions if not controlled by specific fungicide applications (50% severity on clusters in 2014). Black rot should therefore be taken into account in the decision rules for pesticide treatment applications on resistant cultivars. Phylloxera is controlled by the grafting of vines onto resistant rootstocks, and is rarely seen on *V. vinifera.* Its incidence and severity were null or very low on the resistant cultivars surveyed in 2017.

The challenge of fungicide treatment management on disease-resistant grape cultivars relies on the capacity of controlling secondary diseases while maximizing the durability of resistance, a major goal of OSCAR. We found that one-third of the plots received no fungicide treatment at all, which might represent a risk for the durability of the resistance factors deployed. Pesticide treatments greatly decrease the size of the pathogen population, therefore decreasing the risk of resistance breakdown (McDonald and Linde, 2002). In orchards, the use of fewer fungicide treatments associated with an adaptation of practices, such as the use of prophylactic methods to decrease primary inoculum levels, has been shown to improve the efficiency of partial resistances and to postpone the breakdown of total resistances by *Venturia inaequalis* (Didelot et al., 2016).

An additional concern is the timing of fungicide applications. In the treated plots of the OSCAR network, treatments were generally applied at or around the flowering stage, as this is a period of susceptibility to pathogens in grapevine, because of the presence of many young receptive organs (leaves, flowers, knotted berries) (Lorenz et al., 1995). However, the question of timing of treatments and its link with the durability of resistance remains: should grape organs be treated when they are most receptive, when the amount of inoculum is the highest, or at other steps of the infectious cycle of the pathogen, such as sexual reproduction, for example (Delbac et al., 2019)? Indeed, 28% of the plots displayed a large increase in downy mildew levels on leaves at harvest, with high incidence (>50% of the vines affected on leaves). Vintners and extension service technicians are used to determine the optimal timing of fungicide treatments according to a decision support system developed for susceptible cultivars (Claverie et al., 2014; Raynal et al., 2002, 2009). These models and decision rules may need to be revised for resistant grape cultivars, taking into account the additional objective of resistance durability management.

Dissemination of the information obtained by the observatory is essential, to support vine growers and other stakeholders. A website (http://www.observatoire-cepages-resistants.fr) has been developed to describe the design and organization of OSCAR and to provide a reliable, unified and updated source of knowledge concerning cropping systems for disease-resistant grape cultivars. The website includes information about cultivars, support for disease identification, large image resources, technical and scientific articles, and evolution of regulations. This tool will make it possible to communicate the annual results to as large a number of vine growers as possible.

In the near future, OSCAR will be extended to additional plots, not only in France, but also in other European countries, including Switzerland, Germany, and Italy, in which disease-resistant grape cultivars have already been planted. Another opportunity for the expansion of OSCAR is the addition of plots located in northeastern America, the native area of the downy and powdery mildew pathogens and the region of origin of many of the *Vitis* species from which resistance genes have been introgressed to generate the new resistant cultivars. This expansion is particularly important for predicting the durability of resistance, as plant-pathogen interactions may evolve more rapidly in areas in which genetic diversity is high for both the pathogen and its hosts (Brewer and Milgroom, 2010; Rouxel et al., 2013, 2014). The increasing number of plots surveyed with time will improve the characterization of the agronomic and socioeconomic durability of these new cropping systems. Furthermore, generating data at an international scale in the frame of OSCAR will make it possible to calibrate mathematical models designed at providing information about sustainable strategies of resistance deployment, with the aim of advising stakeholders concerning the use of resistance genes at the regional scale.

CONCLUSIONS

The national observatory for the deployment of disease-resistant grape cultivars was launched in 2017 by INRA, with three goals: to monitor the evolution of the pathogens targeted by resistance, to produce data on cropping systems for resistant grape cultivars, and to communicate the knowledge acquired. Our principal findings for the first year of the survey were as follows:

- Disease-resistant grape cultivars have considerable potential for reducing pesticide use (-80%).

- No erosion of grape resistances to downy or powdery mildew was detected in 2017.
- Secondary diseases had low overall severity on the plots surveyed. However, under conducive conditions, black rot must be controlled to prevent major yield losses.
- The results were disseminated via the official OSCAR initiative website, http://www.observatoire-cepages-resistants.fr.
- The observatory is currently being expanded to include more plots, both in France and in other countries.

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