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Classification of wine grape cultivars in Chile and France according to their susceptibility to *Botrytis cinerea* related to fruit maturity

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Keywords:	Botrytis bunch rot, Grape maturity, Resistant, Susceptibility Index, <i>Vitis vinifera</i>

Reviewer 1

Comment	Answer
The authors did a good job for classification based on climate, phenology and their observations as well as others authors observations already published. However, there is nothing in the index concerning the yield of the production for each variety that should be taken into account as well as the thickness of the skins of each grapes variety. In my opinion this 2 parameters should be also taken into account if the authors want to be closer to the reality and to the different conditions that can apply for each vines variety growing. Can the authors add elements on this aspect and in the new index?	We agree with the reviewer that these two parameters are important to be closer to the reality under the different conditions. In our study, we did not measure the yield or thickness of the berry skins. Therefore, unfortunately, we were not able to add and analyse more data related to these two parameters. However, after considering the importance of some bunch morphological aspects, such as the compactness (more compact clusters may be associated with higher yields and thinner berry skins, thus increasing berry susceptibility to *B. cinerea*), we have added in the discussion (lines 522-545) a new paragraph on the possible relationships among BBR intensity, cluster compactness and other key agronomic factors. Thus, future field investigations should be conducted to better determine the relationships between these parameters and the classification of cultivars according to the susceptibility to the disease.
There is different type of *Botrytis cinerea* strains and some of them can conduct to more severity than some others. How the authors deals with these aspects ? They should include possible modulation concerning the index on this aspect.	Yes, there are different types of *B. cinerea* strains, notably based on the transposon genotypes differing in virulence in grapevine, and this might have affected the results to a certain extent. In our study, we did not consider the phenotypic variability of the pathogen. Thus, we cannot include this aspect in the index, as suggested by the reviewer. Nevertheless, it has been demonstrated that the two major sympatric transposon genotypes in *B. cinerea sensu stricto* (excluding *B. pseudocinerea*) are present similarly in vineyards in Chile and France. Moreover, they seem to have similar key phenotypic features in both countries. A paragraph on this aspect was added to the Discussion (lines 465-482).

Reviewer 2

Comment	Answer
The main objective of the study was to set up a procedure to classify the wine grape cultivar according to the susceptibility to *B. cinerea* despite contrasting climatic conditions and cropping. The idea is good but no evidence on the "validation" of the method are reported.	The main goal of this work was not only to set up a procedure to classify the cultivars but also to compare the susceptibility of different wine-grape cultivars to *B. cinerea* under contrasting climatic and cropping conditions. For this purpose, it was necessary to objectively group and classify the cultivars and then to question the already published classifications, which were made based on experience rather than experimental data. Our method used to classify the cultivars was based on a methodological reference, the index calculated by Boso et al. (2014) (see Materials and methods lines 161-164). It should also be noted that an overall validation of our cultivar classification is the fact that most of the cultivars were finally classified in accordance with the literature (even if there are a few discrepancies). Furthermore, a secondary objective of our study was to demonstrate how a key potential explanatory factor, *i.e.,* fruit maturity, supports the observed differences in susceptibility to *B. cinerea.* This is clarified in the text (see the Abstract, lines 7-9, and the Introduction, lines 83-87).
English must be improved and also the Authors must apply all the standard detailed in the guidelines for the authors (i.e. citation in the text and references).	English editing was performed by a professional from the "American Journal Experts" service.
The results herein presented are sometimes conflicting with those reported in other researches and it is not well supported.	Our results come from experimental fields in which the measurement protocols (e.g. numbers of sampled vines, assessment stages/dates, and observation form) were standardized; thus, the results are as objective as possible. In contrast, the classifications reported in the literature are mostly based on professional experience rather than experimental data, as stated in the introduction (see lines 58-64). Thus, it may be expected, to a certain extent, that our results differ from some previously reported ones. Even the data from different sources in the literature may also be in conflict, and some of them differ in cv ranking, occasionally to a large extent (Table 1). When our results were very different from those reported in the literature, a possible explanation has been put forward in the discussion section (see Discussion, lines 391-426).
No sprays to control downy mildew are reported. Is it true?	The main viticulture areas in Chile (located at the centre of the country) are usually not favourable to downy mildew development; thus, no specific spray was included in the

	phytosanitary program. This is the case at the Panguilemo experimental station, where no specific fungicide spray to control downy mildew was applied in any year. In contrast, in France, four fungicide applications were used to control downy mildew. A paragraph addressing this issue has been added to the Materials and methods section (see Materials and methods, lines 132-139)
No canopy and bunch management is detailed. Is it true?	Neither in Chile nor in France were leaf-removal or bunch thinning performed during the studied seasons. This information has been added to the Materials and methods section (see Materials and methods, lines 130-131).
BBR was assessed observing the "surface" of the clusters. Is it true? No information on BBR inside the cluster? Can it twist the result?	Yes, BBR was assessed by observing the surface of the clusters, and it was confirmed by looking more precisely, if possible, within the grapevine bunches. BBR developing within the cluster could possibly affect the results, but only slightly. Usually, both parts of the clusters, *i.e.,* the surface and the inside part, are attacked by the pathogen, and there are generally no BBR attacks that affect only the bunch surface. We also preferred evaluating the surface because this methodology has been used in most of the works reported in the literature (e.g. Valdés-Gómez et al., 2008, González-Domínguez et al., 2015). This allowed us to better compare all of the available results. A paragraph addressing this issue has been added to the Materials and methods section (see Materials and methods, lines 154-157).
None relation with morphological and structural aspects has been reported by the Authors. All them can contribute to the assessed result	We agree with the reviewer, but identifying the various relationships with morphological and structural aspects was not the main objective of the present study. A paragraph addressing this issue has been added to the discussion section (see the Discussion, lines 522-545).

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(vii) Diclosure statement:

We declare the absence of any conflict of interest in the submitted manuscript.

(viii) Short running title:

Susceptibility of wine grape cvs to *Botrytis cinerea*

Classification of wine grape cultivars in Chile and France according to their susceptibility to *Botrytis cinerea* related to fruit maturity

Abstract

Background and Aims: The susceptibility of wine-grape cultivars (cvs) to *Botrytis cinerea* is a debated topic, and the available classifications are based on professional experience rather than experimental data. The main aim of this study was to compare and classify the susceptibility of different wine-grape cvs to *B. cinerea* and its relation to fruit maturity under two contrasting climatic and cropping conditions.

Methods and Results: Between 2011 and 2015, three field trials were performed in Chile and France, including 13 common cvs. Both the incidence and severity of the disease were evaluated at harvest, and indices of susceptibility (SI) and maturity (F_{Mat}) were calculated on a per site basis. The significant differences in incidence and severity observed among cvs led to a similar susceptibility classification in both countries. Cabernet Sauvignon, Cabernet Franc, Grenache Noir and Petit Verdot were the most resistant cvs, whereas Gewürztraminer and Sauvignon Blanc were the most susceptible ones. Moreover, an exponential and positive relationship was established between SI and maturity.

Conclusions: The cultivar classification according to the susceptibility to *B. cinerea* was similar in both countries, despite the contrasting climatic conditions and cropping practices.

Significance of the Study: These findings might be of interest for choosing cvs that are more resistant to *B. cinerea* to reduce the number of fungicide applications.

Keywords: Botrytis bunch rot, Grape maturity, Resistant, Susceptibility Index, *Vitis vinifera*.

Introduction

Botrytis cinerea is a polyphagous fungus that infects more than 1400 species of cultivated plants (Elad et al. 2016). On grapevine, this fungus causes one of the most serious diseases, namely, Botrytis Bunch Rot (BBR). The pathogen can reduce drastically both the yield and quality of wine (Ribéreau-Gayon et al. 1998), especially sensory qualities such as colour, taste and odour (Pszczolkowski et al. 2001). Important organoleptic negative consequences are perceived in the wine from a threshold of 5% fruit infection at harvest (Ky et al. 2012). Thus, this fungus causes substantial economic losses in grapevines, which have been estimated to be approximately 2 billion $US per annum (Elmer and Michailides 2004).

To control this disease, fungicides have long been used (Rosslenbroich and Stuebler 2000), leading to the generation of site-specific fungicide resistant strains (Hahn 2014) and harm to both human health and the environment (Damalas and Eleftherohorinos 2011). Therefore, new control strategies that allow growers to reduce the application of pesticides should be developed based on the principles of Integrated Pest Management (IPM) (IOBC 2007). In this context, some cropping practices aiming at BBR control should contribute to decrease the favourable conditions for the pathogen's development. This development depends on three major factors: i) climatic and microclimatic conditions, ii) the presence/amount and characteristics of the pathogen inoculum, and iii) the susceptibility of the host, i.e., grapevine. Climatic and microclimatic conditions, specifically temperature and humidity, are key factors for *B. cinerea* infection, notably in grapevine (Savage and Sall 1984, Thomas et al. 1988, English et al. 1989, Nair and Allen 1993, Broome et al. 1995, Fermaud et al. 2001, Valdés-Gómez et al. 2008, Ciliberti et al. 2016). Favourable climatic conditions are temperatures between 15 and 25°C and wetness duration between 12 and 24 h (Thomas et al. 1988). Concerning the pathogen, the population genetic structure is also a key factor to consider in the epidemiological development (Giraud et al. 1997, 1999, Levis et al. 1997, Beever and Weeds 2004, Martinez et al. 2003, 2008, Walker 2016). Regarding the host, the disease development depends on various genetic and phenotypic traits, such as the cluster compactness and morphological, anatomical, and chemical features of the berry skin (Latorre 2015), which are highly dependent on the grapevine cultivar.

Grapevine cultivar susceptibility to *B. cinerea* can be considered an essential management indicator in IPM. Although different cultivar classifications according to their susceptibility to the pathogen are available in the literature (Orffer 1979, Brocuher-ACTA-ITV 1980, Robinson 1986, Jackson and Schuster 1987, Galet 1988, Dry and Gregory 1990, Marois et al. 1992, Dubos 2002), they sometimes differ greatly from one another (Table 1). This situation may have come to be because the proposed classifications are based mostly on professional experience rather than experimental data. Additionally, there are some gaps in these classifications: i) few studies compare the cultivars under the same environmental and management conditions, and ii) no study has proposed a cultivar susceptibility ranking that considers contrasting climatic and cropping conditions, e.g., northern *vs* southern hemisphere.

The cropping conditions include agronomic factors, such as the canopy and/or foliar density, water and mineral nutrition, grape training systems and winter pruning, which also predispose grapevine berries to *B. cinerea* infection (Latorre 2015). Several studies have investigated the relationship between *B. cinerea* development and these factors (Barbetti 1980, Savage and Sall 1984, Marois et al. 1986, Gubler et al. 1987, English et al. 1989, Vail and Marois 1991, Zoecklein et al. 1992, Percival et al. 1994, Ferree et al. 2003, Mundy 2007, Valdés-Gómez et al. 2008, Hed et al. 2009, Molitor et al. 2011, Pereira de Bem et al. 2015), but most often by taking into account and investigating only one model cultivar. Similarly, some works have studied the correlation between maturity and disease infection (Kosuge and Hewitt 1964, Blakeman 1975, Coley-Smith et al. 1980, Doneche 1986, Padgett and Morrison 1990, Vercesi et al. 1997, Mikota et al. 2003, Deytieux-Bellau et al. 2009), but none of them have related a classification of many cultivars with an explanatory factor of sensibility to the pathogen, such as the grape maturity.

Thus, the main objective of this work was to compare and classify the susceptibility to *B. cinerea* between different grapevine cultivars in two contrasting climatic and cropping conditions, in Central Chile and Western France. Additionally, the fruit maturity was simulated, and we analysed the extent to which this factor may account for the susceptibility rankings.

Materials and methods

This study evaluated the susceptibility to Botrytis Bunch Rot (BBR) of different *Vitis vinifera* L. cultivars under contrasting conditions. The analysis was performed in three grapevine collections, two of them located in France and one in Chile. A total of 33 and 22 cultivars were evaluated in both grapevine collections located in Aquitaine Region in France, in the sites “Tour Blanche” (Bommes 44°32′33.81″ N, 0°21′02.17″ W, 57 m.a.s.l) and “Grande Ferrade” (Villenave d’Ornon 44°47′15.4″N, 0°34′37.43″W, 22 m.a.s.l), respectively (Table 2). In contrast, 19 cultivars were evaluated in Maule Region in Chile, in the site "Panguilemo" (Panguilemo, 35°22.24' S, 71°35.62' W, 125 m.a.s.l). A total of 13 common cultivars were evaluated in both countries. The experimental trials were performed during three seasons in the "Tour Blanche" site (2011, 2012, 2014), one season in the "Grande Ferrade" site (2011) and two seasons in Panguilemo site (2013-14, 2014-15).

Climatic characterization

The climatic conditions are different in the two regions. The sites located in France are characterized by an Oceanic climate with mild temperatures and annual rainfall of 890 mm, with approximately 55 and 45% falling during the autumn-winter and spring-summer periods, respectively. In contrast, the site in Chile has a Dry Mediterranean climate with an annual rainfall of 600 mm, with more than 500 mm (80%) falling during the autumn-winter period. To characterize the climatic conditions for the study seasons of both sites, an automatic weather station (AWS) (Adcon Telemetric, A730, Klosterneuburg, Austria in Chile and Cimel Electronique S.A.S, CimAGRO, Paris in France) were installed 50 m from the trial plots and provided data about the air temperature, relative humidity and precipitation at 15-min intervals.

Since Chilean climatic conditions were not favourable to *B. cinerea* development, we moistened the vines during the second season (2014-15) to promote the pathogen development. For this, the vines were water sprayed using a knapsack sprayer (Solo 435). At two consecutive days, close to harvest (approximately 25°Brix), a total of 2 L of water was applied per vine, every 2 hours from 8 pm (day 1) to 9 pm (day 2), resulting in the fruit being moistened for a period of 36 hours.

Experimental conditions

The characteristics of the experimental fields are summarized in Table 3. The main differences between experimental sites are the irrigation and rootstock. The use of irrigation is typical in vineyards in central Valley in Chile but not in Western France. In contrast, vines were grafted in French sites, but in Chile, the vines were planted on their own roots. Concerning disease management and with the aim to study the cultivar susceptibility to *B. cinerea*, no fungicide was applied to control this pathogen. For the others crop managements, conventional agricultural practices as used in commercial vineyards in Central Chile and Western France were used throughout the study period. Neither in Chile nor in France were leaf removal and/or cluster thinning performed during the studied seasons. The vineyards were protected against European Grapevine Moth, and sulphur sprays were applied to control Powdery Mildew in both countries. Additionally, one application of quinoxyfen (Legend ®), one of tebuconazol (Corail ®) and one of trifloxystrobin (Natechez ®) were used to control Powdery Mildew in France, whereas one application of flusiolazol (Nustar ®) and one of penconazol (Topas ®) were performed in Chile. Downy Mildew was controlled only in France with four fungicide applications per season, corresponding to two applications of cymoxanil (Option ®) and two copper applications. In Chile, due to the unfavourable conditions for grapevine Downy Mildew, no sprays were applied in any season and site.

Regarding the experimental design at both sites, in the "Tour Blanche" site (France), each cultivar was replicated two times in a random design, and each replication consisted of a total of 6 adjacent vines. For the site "Grande Ferrade" (France), the cultivars were repeated in a randomized block design (4 blocks), and each block consisted of a total of

10 vines. Finally, in “Panguilemo” (Chile), each cultivar was replicated four times in a randomized block design (to remove the effect of the soil slope), and each block consisted of a total of 15 vines.

Disease susceptibility assessment

To determine the susceptibility of the different cultivars, the incidence and severity of BBR were evaluated at harvest (approximately 25° Brix) in each study season. In France, the surface of all clusters from 3 vines per cultivar, corresponding to environ 70 clusters, was visually evaluated. In Chile, 5 and 20 vines per cultivar, corresponding to approximately 110 and 500 clusters, were evaluated in 2013-14 and 2014-15, respectively. BBR was assessed by observing the surface of the clusters because this methodology has been used in most published works (e.g., Valdés-Gómez et al., 2008, González-Domínguez et al., 2015), thus allowing more direct comparisons of the results from different sources. The incidence was obtained by dividing the number of clusters infected by the total number of clusters. The severity was calculated in each cluster as the percentage of the rotted and/or sporulating area. Both the incidence and severity were expressed as percentages.

Additionally, to classify the 13 common cultivars in both countries, a susceptibility index (SI) was calculated using the severity data. The SI was calculated using as reference the index calculated by Boso et al. (2014). Thus, the SI values were calculated for all cultivars at each season and site as specified in equation (1):

$$SI = \frac{Severity\ (\%) for\ cultivar\ in\ question}{Highest\ severity\ (\%) recorded\ in\ the\ season\ and\ in\ the\ most\ rotted\ cultivar} X\ 100 \quad (1)$$

The cultivars were then classified into 5 categories of susceptibility: Highly Resistant (HR) = 0-3.5%; Resistant (R) = 3.51-10%; Intermediate (I) = 10.1-25%; Susceptible (S) = 25.1-50% and Highly Susceptible (HS) = 50.1-100%.

Maturity assessment

A maturity index (F_{Mat}) was calculated to relate the berry maturity to the disease susceptibility of the 13 common cultivars in France and Chile. The index was calculated for each season and site using the Grapevine Flowering Veraison model (GFV) of Parker et al. (2011, 2013) and weather data for each study season, as indicated in equation (2). This phenological model was chosen because it was developed under similar conditions as observed in France and it was calibrated at the Panguilemo site, Chile (data not shown).

$$F_{Mat} = F_{B.c\ assessment} - F_{veraison} \qquad (2)$$

where $F_{B.c\ assessment}$ is the timing of the *B. cinerea* assessment in each study season and $F_{veraison}$ is the timing of veraison for each cultivar, using the model proposed by Parker et al. (2011, 2013). Both variables were estimated as the critical degree-day sum (above 0°C) calculated from the 60th and 242th day of the year in France and Chile, respectively, to the dates of *B. cinerea* assessment ($F_{B.c\ assessment}$) and veraison ($F_{veraison}$). In Chile, the $F_{veraison}$ was corrected according to the results of calibration process by subtracting 100 from the $F_{veraison}$ value proposed by Parker et al. (2013).

Finally, to prevent the effect of the different dates of assessment depending on the season, the F_{Mat} was adjusted (F_{Mat_adj}) in both countries by removing the value of F_{Mat} of the latest cultivar, i.e., Petit Verdot, among the 13 cultivars studied, as shown in equation (3):

$$F_{Mat\_adj} = F_{Mat} for\ each\ cultivar - F_{Mat}\ Petit\ Verdot \quad (3)$$

Statistical analyses

To determine differences of disease incidence and severity among the cultivars, an analysis of variance (ANOVA) was performed using the PROC GLM procedure for each experimental site. The variable "Cultivar" was considered as a fixed factor, whereas the variable "season" was considered as a random factor. When significant differences were found, a least significant difference (LSD) test at a significance level of 95% ($p = 0.05$) was used to compare cultivars. Additionally, a cluster analysis was performed for each site using the disease severity data. In this analysis, the furthest neighbour method and the squared euclidean distance metric were used. Furthermore, to establish a classification for the 13 common cultivars according to their susceptibility to *B. cinerea*, a box plot analysis was performed using together the SI data from all sites and all studied seasons. Moreover, a Kruskal-Wallis analysis and a Student-Newman-Keuls test at a significance level of 5% ($p = 0.05$) were performed on the SI data to compare the cultivar susceptibility. Finally, for the 13 common cultivars, the relationship between maturity of cultivars and their susceptibility to the pathogen was studied and modelled using the SI, F_{Mat} and F_{Mat_adj} data in all sites and study seasons. To build this relationship, a nonlinear model based on the equation $SI = a*(F_{mat\_adj})^b$ was chosen. In both analyses using SI data (Box Plot and modelling), we did not include the values of cv. Roussanne in 2011 because the disease was difficult to assess due the presence of sour rot. All statistical analyses were performed using the Statistical Software Statgraphics Plus 5.1 (StatPoint Inc., Warrenton, Virginia, USA).

Results

Climatic conditions

In all years studied in France, spring and summer were characterized by humid and temperate conditions, which favoured the growth and development of *B. cinerea* (Figure 1a, c). From budbreak to harvest, the mean air temperature fluctuated between 8 and 27 °C and was rather similar in all seasons, except in 2011, which was characterized by slightly higher temperatures. From April to October, i.e., during spring and summer in France, a total rainfall of 418 mm and 439 mm were recorded in 2012 and 2014, respectively, whereas a total rainfall of only 240 mm was registered in 2011. However, in the last year, half of this total rainfall fell from veraison to harvest, notably in August and September (124 mm), leading to favourable conditions for disease development. Chilean conditions were characterized by dry and temperate spring and summer periods, in both studied seasons, which were not conducive to disease development (Figure 1b, d). From budbreak to harvest, the mean air temperature in both seasons ranged from 10 to 27 °C, similar to France. However, the total rainfall was much lower than in France: from October to April, only 22 and 36 mm were recorded in 2013-14 and 2014-15, respectively (Figure 1b). In the 2014-15 season, the rain periods were mostly concentrated before veraison.

Disease incidence and severity under field conditions

Experiments in France

In the "Tour Blanche" site for the different *Vitis vinifera* cultivars evaluated, the mean values of disease incidence and severity for the three studied years fluctuated from 0 to 98% and from 0 to 66%, respectively (Table 4). In contrast, for disease incidence, in 2011, the cultivars Riesling, Semillon, Muscat Petit Grain, Chenin, Folle Blanche, Roussanne and Negrette showed the highest values (> 83%). In contrast, Gros Manseng, Petit Verdot, Petit Manseng and Cabernet Franc showed the lowest values (< 16%). In 2012, the cultivars Sauvignon Blanc, Chardonnay, Folle Blanche, Riesling, Muscadelle, Muscat Petit Grain, Grenache Blanc and Semillon showed the greatest incidence values (> 84%). However, Grenache Noir, Carignan, Tannat, Cabernet Sauvignon, Petit Verdot, Merlot, Cabernet Franc and Petit Manseng showed the lowest values (< 18%). In 2014, the cultivars Semillon, Folle Blanche and Pinot Noir showed the highest incidence values (> 74%), whereas Cabernet Franc, Syrah, Grenache Noir, Gros Manseng and Petit Manseng showed the lowest values (< 14%).

In contrast, for disease severity, in 2011, Riesling showed the highest value (66%), followed by Semillon and Chenin (39%), consistent with the incidence levels. Moreover, the cultivars Gros Manseng, Petit Manseng, Cabernet Franc, Colombard, Cabernet Sauvignon, Tannat, Merlot and Petit Verdot showed the lowest severity values (< 1.3%). In 2012, Riesling again was the most rotted cv, with a severity value reaching 47%, followed by Folle Blanche and Sauvignon Blanc (approximately 31%). Grenache Noir, Petit Verdot, Gros Manseng, Carignan, Cabernet Sauvignon, Petit Manseng, Cabernet Franc, Rolle, Tannat, Mourvèdre, Colombard, Ugni Blanc and Merlot were the least attacked, showing the lowest severity values (< 1.2%). In 2014, Folle Blanche showed the highest disease severity (30%), followed by Pinot Noir (22%). Gros Manseng, Petit Manseng, Cabernet Franc, Grenache Noir, Petit Verdot, Tannat, Cabernet Sauvignon, Carignan, Mourvèdre and Alicante Bouchet showed the lowest severity values (< 1.2%).

In the “Grande Ferrade” site, mean incidence and severity values, for the studied season, fluctuated from 65 to 100% and from 5 to 51%, respectively (Table 5). The cultivars

Cabernet Franc, Cot, Muscadelle, Petit Verdot, Roussanne, Sauvignon Blanc, Semillon, Tempranillo and Touriga Nacional showed the highest disease incidence, greater than 98%. However, Mourvèdre showed the lowest value (65%). The cultivar Roussanne showed the highest disease severity value (51%), whereas the cultivars Marselan and Mourvèdre showed the lowest values (< 8%).

Experiments in Chile

The *V. vinifera* cultivars evaluated showed disease incidence and severity values lower than in France in both years (Table 6). The cultivars Cabernet Franc, Cabernet Sauvignon, Cot, Merlot, Mourvèdre and Petit Verdot did not develop any BBR symptom in any year, even when the vines were sprayed with water in the 2014-15 season in Chile. Thus, these cultivars are considered not susceptible to the pathogen under Chilean conditions. In addition to these cultivars, Carménère, Grenache, Syrah and Tempranillo were not affected by the disease in 2013-14. In this season, the cultivars Gewürztraminer and Sauvignon Blanc showed the highest incidence values, reaching 5 and 8%, respectively. In 2014-15, the cultivars Sauvignon Gris, Sauvignon Blanc and Gewürztraminer exhibited the greatest incidence, with values fluctuating between 12 to 38%.

Regarding the disease severity, in 2013-14, the cultivars Gewürztraminer and Sauvignon Blanc showed the highest values (approximately 0.2%), followed by Pinot Gris (0.12%). In 2014-15, the cultivar Sauvignon Gris exhibited the highest disease severity (9.8%), followed by Sauvignon Blanc and Gewürztraminer, with 3.9 and 2.3%, respectively.

Classification of cultivars according to the disease severity

Situation in France

In the "Tour Blanche", the cluster analysis classified the cultivars tested into 7 groups according to the disease severity (Figure 2a). The groups obtained were classified as follows: resistant-intermediate "R-I" (group 1), susceptible "S" (groups 2 to 4) and highly susceptible "HS" (groups 5-7) cultivars. The first group comprised 17 cultivars (Alicante Bouschet to Syrah) that showed a mean severity value of 1.6% for all of the three seasons. The disease severity for these cultivars was stable between seasons, i.e., the mean severity fluctuated from 0.1 to 5.3% through the 3 years. The second group from the cluster analysis included 3 cultivars (Gamay to Viogner) presenting a mean severity value of 9.8%. The third group was composed of 6 cultivars (Chenin to Negrette) presenting a mean severity value of 13.8% for the three seasons. The severity values for these cultivars were similar in 2011 and 2012 but lower in 2014. The fourth group, with a mean severity value of 17.4%, included 3 cultivars (Chardonnay through Gewürztraminer). The fifth group comprised 2 cultivars (Pinot Noir and Semillon), which showed a mean severity value of 23.3%. Finally, the cultivars Folle Blanche and Riesling were classified in the sixth and seventh categories showing mean severity values of 30.7 and 39.3%, respectively. A particular case was the cultivar Riesling, which was classified in the most susceptible category and presented a very high severity for the 2011 and 2012 seasons but a relatively low severity value in 2014.

Furthermore, a classification was established based on all the databases from France. A cluster analysis was performed with the common cultivars present in La Tour Blanche and Grande Ferrade sites. The groups obtained in this analysis were classified as follows: resistant-intermediate (group 1), susceptible (group 2) and highly susceptible (groups 3 and 4) cultivars (Figure 2b). The first group was composed of 9 cultivars (Cabernet Franc through Mourvèdre), with a mean severity value of 6.8%. The disease severity for these cultivars was similar in the "Tour Blanche" site during all the three seasons but higher at the "Grande Ferrade" site. The second group included 8 cultivars (Chardonnay through Roussanne), which were characterized by a mean disease severity value of 21%. Similarly, the severity results were higher at "Grande Ferrade". Finally, the cultivars Pinot Noir and Riesling were classified in the third and fourth categories, showing mean severity values of 22.2 and 36%, respectively.

Situation in Chile

In Chile, the cultivars were grouped into 6 groups (Figure 3) according to disease severity. The groups obtained were classified as follows: resistant-intermediate (group 1), susceptible (groups 2 to 5) and highly susceptible (group 6) cultivars. The first group was composed of 12 cultivars (Cabernet Franc through Sangiovese). Within this group, 6 cultivars did not present any rot symptom in any season. However, the other cultivars showed a very low mean severity value of 0.1%. The second group comprised 3 cultivars (Chardonnay through Roussanne) that presented a mean rot severity value of 0.2%. The cultivars Pinot Gris and Gewürztraminer were classified in the third and fourth groups with mean disease severity values of 0.4 and 1.3%, respectively. Finally, the cultivars Sauvignon Blanc and Sauvignon Gris were ranked in the fifth and sixth groups with mean severity values of 2.0 and 4.9%, respectively.

Classification of common cultivars in Chile and France according to the susceptibility index

According to the susceptibility index (SI), we classified the common cultivars evaluated in Chile and France in 5 categories: i) highly resistant (HR), ii) resistant (R), iii) intermediate (I), iv) susceptible (S) and v) highly susceptible (HS) cultivars (Figure 4). Five cultivars – Grenache Noir, Cabernet Franc, Petit Verdot, Cabernet Sauvignon and Mourvèdre – were highly resistant (SI ≤ 3.5). Three cultivars were included in the resistant category (Merlot, Syrah and Cot). Only Roussanne was classified as an intermediate cultivar. Finally, the cultivars Chardonnay and Pinot Noir were identified as susceptible, whereas Gewürztraminer and Sauvignon Blanc were highly susceptible (SI > 50). This classification was corroborated with a non-parametric statistical analysis. This analysis demonstrated that the cultivars classified as HR and HS were stable between seasons and sites, in contrast with the R, I and S cultivars, which showed significant variability.

Relationship between the cultivar susceptibility ranking and fruit maturity

An exponential relationship between the susceptibility to the pathogen, as indicated by the SI value, and the fruit maturity (F_{Mat}) of cultivars studied in France and Chile was observed (Figures 5 and 6). For every combination "country x season" (experimental condition), the relationship between the two variables was positive, thus showing clearly that the cultivars with more mature berries were the most susceptible. This pattern was very similar in all experimental conditions, but it was noticeable that the F_{Mat} values differed to a large extent from one experimental condition (combination "country x season") to the next (Figure 5).

To prevent the effect of the different dates of assessment depending on the season, the F_{Mat} was adjusted (F_{Mat_adj}) in both countries by removing the value of F_{Mat} of the latest cultivar among the 13 cultivars studied. The relationship between F_{Mat_adj} and the SI value was positive and exponential in both countries (Figure 6). In France (r^2 = 0.73), the equation was y = 3.2 E-4 * x $^{2.1}$ (Figure 6a), whereas in Chile (r^2 = 0.55), it was y = 4.6E-11*$x^{4.78}$ (Figure 6b), with "y" representing the SI value and "x" the F_{Mat_adj} value. This pattern was quite similar in both sites, but with a steeper slope in Chile. Note that a change in cultivar susceptibility occurred for adjusted F-Maturity values of greater than approximately 250. In France, for higher F_{Mat_adj} values, the cultivars were classified as susceptible with an SI value higher than 25 (Figure 6a). In Chile, the cultivars with F_{Mat_adj} > 250 corresponded to those developing disease symptoms to some degree, whereas below this value, mostly no disease or very few rot symptoms were recorded (Figure 6b). The Roussanne cultivar was the exception in both sites, presenting a higher disease susceptibility in the 2012 and 2013-14 seasons, despite its low maturity (Figure 6a, b).

Discussion

Cultivar classification according to disease susceptibility

The results of this study showed that the cultivar classification according to the susceptibility to *B. cinerea* was generally similar in the two countries, despite the contrasting climatic conditions and cropping practices. Thus, on the one hand, the two *V. vinifera* white cultivars Sauvignon Blanc and Gewürztraminer were classified as the highest-susceptibility cultivars, followed by Chardonnay and Pinot Noir. On the other hand, the four wine black cultivars – Petit Verdot, Cabernet Sauvignon, Mourvèdre and Syrah – were identified as resistant or highly resistant. These classification features confirm various previously published findings (Orffer 1979, Brocuher-ACTA-ITV 1980, Robinson 1986, Jakcson and Schuster 1987, Galet 1988, Dry and Gregory 1990, Marois et al. 1992, Dubos 2002) (Table 7). However, for the other cultivars tested, our results differ greatly from those published in the literature. We have classified the two black cultivars, Grenache Noir and Cabernet Franc, as highly resistant, yet they were considered as susceptible or highly susceptible by other authors (Robinson 1986, Galet 1988, Dry and Gregory 1990, Dubos 2002). Similarly, both the Merlot and Cot cultivars, which were identified as resistant in this study, appear in the literature as susceptible cultivars. Finally, we classified Roussanne as a cultivar intermediate in susceptibility, whereas it had been identified previously as a highly susceptible cultivar (Table 6).

These differences observed between our results and those from the literature could be accounted for by possible changes in agronomic conditions that could affect the plant, the pathogen, the environment and/or the interactions between these epidemiological factors. Diverse studies have demonstrated the relationship between *B. cinerea* infection and/or BBR development and various environmental/agronomic factors, such as the following: first, climate and microclimate within the canopy (Savage and Sall 1984, Thomas et al. 1988, English et al. 1989, Fermaud et al. 2001, Pieri and Fermaud 2005, Valdés-Gómez et al. 2008, Ciliberti 2015, 2016); second, canopy density and leaf removal after flowering (Gubler et al. 1987, English et al. 1989, Zoecklein et al. 1992, Valdés-Gómez et al. 2008, Molitor et al. 2011); third, cluster compactness and thinning (Barbetti 1980, Marois et al. 1986, Vail and Marois 1991, Percival et al. 1994, Ferree et al. 2003, Hed et al. 2009, Molitor et al. 2011); fourth, mineral and water nutrition (Mundy 2007, Valdés-Gómez et al. 2008); fifth, grape training systems (Pereira de Bem et al. 2015); sixth, winter pruning (Savage and Sall 1984); seventh, cracks caused by biotic (insects, birds, snails, other plant pathogens) and abiotic (rain, hail, frost, sunburn, rapid water intake) factors (Nair et al. 1988, Fermaud and Le Menn 1989, Coertze and Holz 1999, Becker and Knoche 2012a, b); and eighth, clone and rootstock (Bernard and Leguay 1988, Vail and Marois 1991, Derckel et al.1998, Vail et al. 1998).

An important source of variation may be the clone effect, which may cause important susceptibility differences within one considered cultivar. From this point of view, Pinot Noir is a model cultivar of interest. Significant differences in susceptibility to *B. cinerea* between Pinot Noir clones have been attributed to variations in cluster compactness (Bernard and Leguay 1988). Additionally, Derckel et al. (1998) also detected differences in susceptibility to *B. cinerea* amongst the four Pinot Noir clones, suggesting that some grape berry defences may play an important role in this interaction. Similarly, within the Chardonnay cultivar, variability in the susceptibility of different clones to *B. cinerea* has also been shown, although the variability attributable to the clone may be considered lower than the variability explained by the cultivars (Vail and Marois 1991, Vail et al. 1998).

The rootstock may also play an important role in the observed variability in the susceptibility to the pathogen among and within cultivars. For example, the SO4 rootstock induces higher disease infection in Pinot Noir cultivar because it promotes vine vigour, which is conducive to the disease (Dubos 2002). Additionally, the rootstock, by affecting depth of the root system and vine vigour, can influence significantly the cluster compactness, berry size and fruit maturity, which are known factors that modify the susceptibility to *B. cinerea* (Cordeau 1998).

As a first conclusion, despite all the variations and differences possibly due to agronomic factors, the cultivar effect *per se* seems to be the most important for the extreme susceptibility groups of cultivars (highly resistant and susceptible), as defined and demonstrated in the present work.

Stability of cultivar classification between years, sites and literature

Our results suggest that the susceptibility of some cultivars is not stable and changes depending on environmental, seasonal or management conditions. To compare the differences in susceptibility and to know the stability of the cultivar classification, we calculated the standard deviation corresponding to the literature results (Sdlit) and that from our experimental data (Sdres) (Table 6). The susceptibility classification of Cabernet Franc cultivar was not stable, neither in the literature nor in our study (Sdlit = 1.5; Sdres =1.6). This could be due to the use of different clones because a great variability among Cabernet Franc clones has been demonstrated to be related to key susceptibility factors, notably, maturity, berry size, yield and tannin content (Van Leeuwen et al. 2013). However, in our case, this difference appears to be due to the vegetative growth because this cultivar was classified differently only at the "Grande Ferrade" site, at which the vigour was higher. For the other cultivars, Petit Verdot and Grenache Noir, their susceptibility rank was rather stable in the literature (Sdlit = 0.3 and 0.5), but it differed according to the season and country in our work (Sdres = 1.6 and 1.0). For the cultivars Merlot, Cot and Roussanne, the classification was the same in all other works (Sdlit = 0), but it differed significantly under our conditions (Sdres = 1.5 and 1.2). Interestingly, the four cultivars Grenache Noir, Petit Verdot, Merlot and Cot are susceptible to flower abortion (Reynier 2011); consequently, they may present very different cluster compactness depending on seasonal climatic conditions during bloom, leading to more or less flower abortion (Keller 2015). Such a difference in compactness should account for great variations in the susceptibility to *B. cinerea*, as has been often demonstrated in the literature (Marois et al. 1986, Vail and Marois 1991, Percival et al. 1994, Ferree et al.

2003, Hed et al. 2009, Molitor et al. 2011). Regarding the susceptibility classification, the cultivars Grenache Noir, Cabernet Franc, Merlot, Cot and Roussanne showed significant differences between literature works and our study (Table 6). To understand this difference, further studies about the clone and the vegetative growth related to the rootstock are necessary.

It is important to note the effect of Chilean data, which decrease the average of the Susceptibility Index (SI) in the cultivars classification due to the existence of climatic conditions unfavourable to disease development. Even if the grapevines were water sprayed in Chile, this effect was temporary and did not allow the pathogen to develop to a large extent, as may occur under natural wet conditions such as e.g., under oceanic conditions. Finally, it may be discussed whether these results could have been affected by the phenotypic variability among *B. cinerea* strains, particularly in terms of difference in virulence. It has been demonstrated that the virulence of the two *B. cinerea* genetic types, *vacuma* and *transposa*, differed significantly in terms of disease incidence and severity, with *transposa* strains being more virulent than *vacuma* ones. This virulence on leaves or on berries was significantly and negatively correlated with the mycelial growth rate (Martínez et al. 2005). Moreover, the mechanism involved in this pathogenicity could be explained by the presence of transposable elements, which is a characteristic feature of *transposa* isolates. Thus, Baulcombe (2013) explained that transposon small RNA (sRNA) molecules are associated with the suppression of host defences, which may have important implications for the pathogen arms race. This idea is supported by Weiberg et al. (2013), who founded that transposon sRNA molecules derived from *B. cinerea* can act as effectors to suppress host immunity and play a positive role in pathogenicity. Thus, although we did not consider the high phenotypic variability in this study, it has been demonstrated that the two major sympatric transposon genotypes (*transposa* and *vacuma*) are present similarly in Chile as in France (Martinez et al. 2003, 2008). They also tend to have similar characteristics in both countries (Muñoz et al. 2002); consequently, this variability should not affect the results to a great extent.

Effect of grape maturity on disease susceptibility

The fruit maturity was identified as a major factor determining the cultivar susceptibility to *B. cinerea*. Several studies, often based on one selected model cultivar, have demonstrated that increasing sugar concentration with the phenological stage in maturing grape berries promotes infection and colonization by *B. cinerea*. Some of these studies also demonstrated that the presence of sugar in berry exudates stimulates the germination and mycelium growth of *B. cinerea* (Kosuge and Hewitt 1964, Blakeman 1975, Coley-Smith et al. 1980, Doneche 1986, Padgett and Morrison 1990, Vercesi et al. 1997, Deytieux et al. 2009). Despite several authors having demonstrated the relationship between sugar concentration and pathogen infection, few works have revealed a correlation between increasing maturity and progress of disease severity, and they mostly used a single cultivar (Fermaud et al 2011), not a set of different cultivars. Studies related to the infection by the pathogen and the solid soluble contents of grapes have been conducted, in particular by Mundy and Beresford (2007), who established clearly a significant and positive linear regression between berry sugar concentration and the percentage of rotted berries. Furthermore, regarding the maturity effect, the susceptibility of berries increased during ripening (Kretschmer et al. 2007), and, more precisely, a positive, close and sigmoid relationship between maturity variables and *B. cinerea* susceptibility was established by Deytieux-Belleau et al. (2009). This last study demonstrated that severity of *B. cinerea* increases regularly during berry maturity, reaching a maximum at the over-maturity stage: then, this relationship can be represented by a sigmoid curve. In our study, these relationships were exponential, showing that the most mature grapevine cultivars were the most susceptible to the pathogen. These cultivars were mostly white cultivars, in which the sugar content is, generally, higher than in black ones (Doneche 1986). If we had measured the disease severity of cultivars in a more advanced state of maturity, these results may have been similar. Moreover, the most mature cultivars correspond to the earliest cultivars. They could also have been more attacked because they were exposed, in a susceptible, mature stage, for a longer time under favourable conditions for infection and disease development.

In addition to the maturity, other factors may account for the variability in susceptibility. For example, the less-susceptible cultivars, according to the disease incidence and severity, were in both countries black cultivars. In contrast, the most susceptible cultivars were white and pink ones. This relationship between susceptibility and berry colour was expected because it has been shown that the susceptibility of grapes may be affected by the concentration of phenolic compounds in grapes (Frankel et al. 1995, Goldberg et al. 1995), and particularly, the tannin content within the berry skin (Deytieux-Belleau et al. 2009). These results confirmed previous studies (Goetz et al. 1999, Xie and Dixon 2005) that demonstrated that black cultivars are less susceptible to *B. cinerea* than white or pink cultivars. In addition, the compactness of clusters has been shown to be an important morphological feature that affects the susceptibility to *B. cinerea* by affecting the microclimate and the thickness and wax content of the berry cuticle (Marois et al. 1986, Vail and Marois 1991, Percival et al. 1993, Fermaud et al. 2001). In this study, we observed a clear trend in the vineyard conditions that the cvs with more compact clusters were more severely attacked and more susceptible to the pathogen. In contrast, we noted that the less-attacked cvs presented looser clusters and were classified as less susceptible to *B. cinerea*. This corroborates a previous study that showed a positive correlation between BBR development and cluster compactness (Hed et al. 2009). Lastly, and in addition to the fruit maturity, berry skin colour and cluster compactness, which also may affect the susceptibility to BBR, there are other predisposal factors, such as genetic (morphological, anatomical and chemical features of the berry skin), physical (wounds), environmental (climate and weather conditions) and agronomic (cultural practices) (Latorre et al. 2015). For agronomic factors, after the climate influence, vegetative growth and canopy development are considered the second most important factors favouring *B. cinerea* development (Valdés-Gómez et al. 2008). Then, some morphological factors related to cluster architecture, e.g., the bunch mass and berry number, also have an important influence on BBR epidemics (Vail and Marois 1991, Valdés-Gómez et al. 2008). The bunch mass has been positively and significantly correlated with the BBR incidence and considered more relevant than the yield to account for disease development. This factor contributes largely to cluster compactness; thus, it can be considered as a key morphological feature that increases *B. cinerea* susceptibility (Valdés-Gómez et al. 2008). Although in this work we did not consider any of these factors, they should be further studied in future works addressing cv susceptibility to the pathogen.

Main findings and implications for IPM and climatic change adaptations

As previously reported, our results also confirmed that environmental conditions are a main factor in the disease epidemiological development (Savage and Sall 1984, Thomas et al. 1988, English et al. 1989, Fermaud et al. 2001, Valdés-Gómez et al. 2008, Ciliberti

2015, 2016). The contrasting climatic conditions in the two regions studied led to different levels of disease infection, due principally very different amounts and distributions of rainfall. Rainfall, which is predominantly at the origin of increased relative humidity and wetness duration in the vineyards, was found to be of primary importance in disease development (Ciliberti 2015, 2016). Thus, in France, all cultivars were attacked by *B. cinerea*, and they presented more advanced disease development than in Chile. Although under Chilean conditions, no cultivars seemed to be very susceptible, considering the low disease severity values, it was possible to classify them according to their susceptibility. This classification was similar to that in France, thus demonstrating that climate does not change the susceptibility of cultivars. However, when the climatic conditions are not favourable to the pathogen development, it is difficult to differentiate resistant from intermediate cultivars because the latter do not develop the disease at all. This situation was observed, in particular, in grapes that were not sprayed with water in Chile (data no shown). Thus, the decision to apply a fungicide to these cultivars based on their susceptibility classification to BBR would be more difficult. Furthermore, it is interesting to note that future climatic conditions in the Bordeaux region could be relatively similar to the current climatic conditions characterizing the Chilean region considered in the present study (Pañitrur-De la Fuente et al. 2016). Under this context of climate change, strategies may be orientated by adapting the cultivar choice to future possible climatic scenarios, considering both the potential disease development and the associated cultivar susceptibility.

Further investigation should be conducted to better understand the relationships between the classification of cultivars according to their susceptibility to *B. cinerea* and other variables (e.g., clone, vigour, and rootstock) to develop management and integrated pest management strategies.

Conclusions

The results of this study demonstrated that the classification of different wine cultivars according to their susceptibility to *B. cinerea* was generally similar in both countries, despite the contrasting climatic conditions and management practices. Sauvignon Blanc and Gewürztraminer were the most-susceptible cultivars, whereas Petit Verdot, Cabernet Sauvignon, Mourvèdre and Syrah were rather resistant or highly resistant. These results are in accordance to previous studies; however, for the other cvs that we evaluated, their ranking differed to some extent compared with data from the literature. This difference is presumably caused by variations in the agronomic and/or environmental conditions under which the field experiments were performed. The interfering effects of various factors, such as clone, rootstock, and cluster compactness related to flower abortion are discussed in detail and should be considered in further studies aiming to compare cultivar susceptibility to the pathogen.

The maturity of cultivars seems to be a major determining factor in the susceptibility to *B. cinerea*. In our study, the relationship between fruit maturity and susceptibility to the pathogen was positive and exponential, indicating that the most mature grapevine cultivars were the most susceptible. This could be explained by the increasing sugar concentrations in ripening berries, which promote fungal colonization, and by the longer time during which later grapevine cultivars are exposed to favourable conditions for disease development.

The cultivar is a principal and permanent factor affecting the susceptibility to *B. cinerea*, which could be modified by climate and agronomic management, which are considered as variable factors. Thus, the cultivar remains a key parameter in decision support systems, and the fruit maturity could be used to support this. Further investigation should be conducted to better understand the relationship between susceptibility to *B. cinerea* and other variables (e.g., clone, vigour, and rootstock) to develop management and integrated pest management strategies.

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Tables

Table 1. Susceptibility to *B. cinerea* of 13 grapevine cultivars according to different literature sources.

Cultivar	a	b	c	d	e	f	g	h
Grenache Noir	4	3	-	-	4	-	3	4
Cabernet Franc	3	-	-	-	-	-	4	1
Petit Verdot	0-1	-	-	-	-	-	1	1
Cabernet Sauvignon	2	-	0	1	1	0	1	1
Mourvèdre	-	-	-	-	-	-	1	-
Merlot	3	-	-	-	-	-	3	3
Syrah	2	-	1	3	3	-	-	2
Cot	3	-	-	-	-	-	3	3
Roussanne	4	-	-	-	-	-	-	4
Chardonnay	4	-	2	2	3	-	3	3
Pinot Noir	3	4	2	3	4	-	-	3
Gewürztraminer	4	-	-	-	-	-	1	4
Sauvignon Blanc	4	-	4	3	4	-	1	4

a = Dubos (2002), b = Dry and Gregory (1990), c = Orffer (1979), d = Jackson and Schuster (1987), e = Robinson (1986), f = Marois et al. (1992), g = Galet (1988), h = ACTA (1980); 0 = highly resistant, 1 = resistant, 2 = intermediate, 3 = susceptible, 4 = highly susceptible.

Table 2. Cultivars evaluated at each experimental site in France and in Chile

Tour Blanche (France)	Grande Ferrade (France)	Panguilemo (Chile)	Common cultivars (France and Chile)
Alicante Bouschet	Cabernet Franc	Cabernet Franc	Cabernet Franc
Cabernet Franc	Cabernet Sauvignon	Cabernet Sauvignon	Cabernet Sauvignon
Cabernet Sauvignon	Carignan	Carménère	Chardonnay
Carignan	Chardonnay	Chardonnay	Cot
Chardonnay	Chenin	Cot	Gewürztraminer
Chenin	Cot	Gewürztraminer	Grenache Noir
Cinsault	Gamay	Grenache Noir	Merlot
Colombard	Grenache Noir	Marsanne	Mourvèdre
Cot	Marselan	Merlot	Petit Verdot
Folle Blanche	Merlot	Mourvèdre	Pinot Noir
Gamay	Mourvèdre	Petit Verdot	Roussanne

Gewürztraminer	Muscadelle	Pinot Gris	Sauvignon Blanc
Grenache Blanc	Petit Verdot	Pinot Noir	Syrah
Grenache Noir	Pinot Noir	Roussanne	
Gros Manseng	Riesling	Sangiovese	
Melon	Roussanne	Sauvignon Blanc	
Merlot	Sauvignon Blanc	Sauvignon Gris	
Mourvèdre	Semillon	Syrah	
Muscadelle	Tempranillo	Tempranillo	
Muscat Petit Grain	Touriga Nacional		
Negrette	Ugni Blanc		
Petit Manseng	Viogner		
Petit Verdot			
Pinot Noir			
Riesling			
Rolle			
Roussanne			
Sauvignon Blanc			
Semillon			
Syrah			
Tannat			
Ugni Blanc			
Viogner			

Table 3. Field characteristics of the experimental fields.

	France		Chile
Property	**Tour Blanche**	**Grande Ferrade**	**Panguilemo**
Experimental Period	2011, 2012, 2014	2011	2013-14, 2014-15
Vineyard planting year	1995	2009	2006
Rootstock	3309	SO4	Own-rooted
Location (WGS84)	44°32′ N, 0°21′ W	44°47′N, 0°34′ W	35°22’ S, 71°36’ W
Spacing (m x m)	1.8 x 0.9	1.8 x 1.0	2.0 x 1.0
Trellis/Pruning system		VSPSystem[a]/ Two-bilateral	
Irrigation system	Non-irrigated	Non-irrigated	Drip irrigation (one dropper per plant with a flow rate of 4 L / h)

891 **Table 4.** Mean disease incidence and severity values (%) for each cultivar under field
892 conditions in the "Tour Blanche" site (France) over three seasons.
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Cultivar	Disease incidence (%)			Disease severity (%)		
	2011	2012	2014	2011	2012	2014
Alicante Bouchet	30.7cdef	35.8bcd	33.4bcdefg	3.3ab	3.1abc	1.2a
Cabernet Franc	13.2abc	16.4ab	7.1a	0.4a	0.4a	0.2a
Cabernet Sauv.	27.6bcde	10.7ab	26.6abcde	0.9a	0.3a	0.5a
Carignan	37.9def	10.5ab	25.8abcde	1.9ab	0.3a	0.6a
Chardonnay	79.5klmn	93.1j	51.9fghijk	11.5abcde	26.4fgh	10.2defg
Chenin	94.5mn	49.4cdef	37.0cdefgh	39.0i	7.4abcd	1.7ab
Cinsault	54.9fghijk	29.8abc	55.6ghijk	5.9abcd	2.3ab	3.2abc
Colombard	18.8abcd	29.2abc	36.4cdefgh	0.7a	1.0a	1.3ab
Cot	41.2defg	46.3cde	40.5defghi	4.7abc	2.5ab	2.0abc
Folle Blanche	89.2lmn	92.8j	81.8lm	29.3ghi	32.6h	29.7i
Gamay	51.0efghi	25.6abc	51.7fghijk	13.7bcdef	3.9abc	11.1efg
Gewürztraminer	64.8ghijkl	63.5efghi	68.4jklm	19.3efg	23.3efgh	11.7fg
Grenache Blanc	65.8hijkl	86.0ij	33.4bcdefg	17.1def	17.1def	2.9abc
Grenache Noir	34.9cdef	5.6a	11.8ab	4.0abc	0.2a	0.2a
Gros Manseng	0a	15.1ab	12.4ab	0a	0.3a	0.1a
Melon	42.9defgh	73.7fghij	67.6jklm	4.5abc	10.3abcd	14.5g
Merlot	33.1cdef	15.6ab	51.3fghijk	1.2a	1.2a	3.3abcd
Mourvèdre	21.8abcd	22.5abc	26.4abcde	1.8ab	0.9a	0.7a
Muscadelle	75.9jklmn	88.2ij	51.4fghijk	17.7def	14.4bcdef	5.3abcdef
Muscat petit grain	97.2n	86.7ij	46.9efghij	29.8ghi	12.0abcde	4.4abcde
Negrette	83.8lmn	57.3defg	58.1hijk	24.4fgh	8.6abcd	7.0abcdef
Petit Manseng	12.6abc	18.1ab	13.6abc	0.3a	0.3a	0.2a
Petit Verdot	3.3ab	13.4ab	22.3abcd	1.3a	0.2a	0.4a
Pinot Noir	77.8jklmn	70.2efghij	74.0klm	32.7hi	15.6cdef	21.7h
Riesling	97.7n	91.2j	61.5ijkl	65.7j	47.1i	5.1abcdef
Rolle	48.5efghi	24.3abc	31.0bcdef	3.3ab	0.9a	2.7abc
Roussanne	88.6lmn	63.2efghi	43.1defghi	31.2ghi	7.3abcd	2.1abc
Sauvignon Blanc	71.3ijklm	96.2j	61.8ijkl	15.3cdef	30.6gh	8.3bcdefg
Semillon	96.2n	84.6hij	86.7m	39.2i	19.3defg	11.6fg
Syrah	37.0cdef	58.0defgh	11.5ab	2.6ab	11.8abcde	1.4ab
Tannat	22.4abcd	10.5ab	24.2abcde	1.1a	0.9a	0.4a
Ugni Blanc	43.3defgh	32.5abcd	56.1ghijk	2.8ab	1.1a	1.9abc
Viogner	53.5fghij	80.4ghij	53.6fghijk	8.4abcde	13.2abcde	8.7cdefg

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Table 5. Mean disease incidence and severity values (%) for each cultivar under field conditions in the "Grande Ferrade" site (France) in the 2011 season.

Cultivar	Disease incidence (%)	Disease severity (%)
Cabernet Franc	100.0e	36.8efg
Cabernet Sauvignon	83.3bc	15.8abc
Carignan	96.3de	25.9bcde
Chardonnay	92.4cde	39.5efg
Chenin	96.4de	33.9def
Cot	100.0e	37.1efg
Gamay	93.7cde	28.8cde
Grenache Noir	91.7cde	10.1ab
Marselan	71.3ab	7.3a
Merlot	97.7de	28.6cde
Mourvèdre	65.0a	5.1a
Muscadelle	100.0e	47.7fg
Petit Verdot	98.8e	34.6def
Pinot Noir	85.4cd	18.9abcd
Riesling	95.9cde	26.0bcde
Roussanne	98.6e	51.2g
Sauvignon Blanc	98.8e	40.5efg
Semillon	100.0e	30.3cde
Tempranillo	100.0e	48.0fg
Touriga Nacional	98.8e	33.8def
Ugni Blanc	93.8cde	14.8abc
Viognier	97.5de	42.1efg

Table 6. Mean disease incidence and severity values (%) for each cultivar under field conditions in Chile over two seasons.

Cultivar	Disease incidence (%)		Disease severity (%)	
	2013-14	2014-15	2013-14	2014-15
Cabernet Franc	0a	0a	0a	0a
Cabernet Sauvignon	0a	0a	0a	0a
Carménère	0a	0.3a*	0a	0a
Chardonnay	1.07a	2.7ab	0.05ab	0.30a
Cot	0a	0a	0a	0a
Gewürztraminer	8.11c	12.0cd	0.24d	2.25ab
Grenache Noir	0a	0.25a*	0a	0a
Marsanne	0.01a	0.18a*	0.01ab	0a
Merlot	0a	0a	0a	0a
Mourvedre	0a	0a	0a	0a
Petit Verdot	0a	0a	0a	0a
Pinot Gris	2.33ab	9.75bcd	0.12bc	0.78a
Pinot Noir	0.72a	3.93ab	0.06ab	0.30a

Roussanne	0.47a	0.98a	0.03ab	0.23a
Sangiovese	0a	6.05abc	0a	0.8a
Sauvignon Blanc	4.72bc	16.88d	0.19cd	3.85b
Sauvignon Gris	1.28a	37.7e	0.048ab	9.80c
Syrah	0a	0.25a	0a	0.03a
Tempranillo	0a	2.53ab	0a	0.10a

*When there is a value for the incidence but the severity is 0, it is because the severity value is less than 0.001.

Table 7. Comparison of the susceptibility to *B. cinerea* of 13 grapevine cultivars according sources and our results

Cultivar	Mean lit.	Sd lit.	Our res.	Sd res.
Grenache Noir	4	0.5	0	1.0
Cabernet Franc	3	1.5	0	1.6
Petit Verdot	1	0.3	0	1.6
Cabernet Sauvignon	1	0.7	0	1.2
Mourvèdre	1	-	0	0.5
Merlot	3	0	1	1.5
Syrah	2	0.8	1	1.2
Cot	3	0	1	1.5
Roussanne	4	0	2	1.2
Chardonnay	3	0.8	3	1.2
Pinot Noir	3	0.8	3	1.3
Gewürztraminer	3	1.7	4	0
Sauvignon Blanc	3	1.2	4	0.5

0 = highly resistant, 1 = resistant, 2 = intermediate, 3 = susceptible, 4 = highly susceptible; Mean lit = Mean of literature source, Our res = Results of our study; Sdlit = standard deviation of literature sources, Sd res = standard deviation of our results.

Figure legends

Figure 1. Monthly mean rainfall (mm) in France (a) and Chile (b) and mean air temperature (°C) in France (c) and Chile (d) during all seasons. The horizontal dotted lines in (c) and (d) represent the mean air temperature (°C) in each season. Bud = Budbreak; Flo = Flowering; Ver = Veraison; Har = Harvest.

Figure 2. Cluster classification of cultivars in France in the sites "Tour Blanche" (a) and both "Grande Ferrade and "Tour Blanche" (b) according to their severity values.

Figure 3. Cluster classification of cultivars in Chile according to their severity values.

Figure 4. Box plot of cultivars according to the susceptibility index. HR = Highly Resistant; R = Resistant; I = Intermediate; S = Susceptible; HS = Highly Susceptible. The vertical line in each box and the cross represent the median and mean value of the SI, respectively.

Figure 5. Relationship between the maturity of cultivars (F Mat) and susceptibility to BBR (SI), assessed at different dates, in France and Chile.

Figure 6. Relationship between the maturity of cultivars (F Mat_adj) and susceptibility to BBR (SI) at both sites, France (a) and Chile (b), during all study seasons.

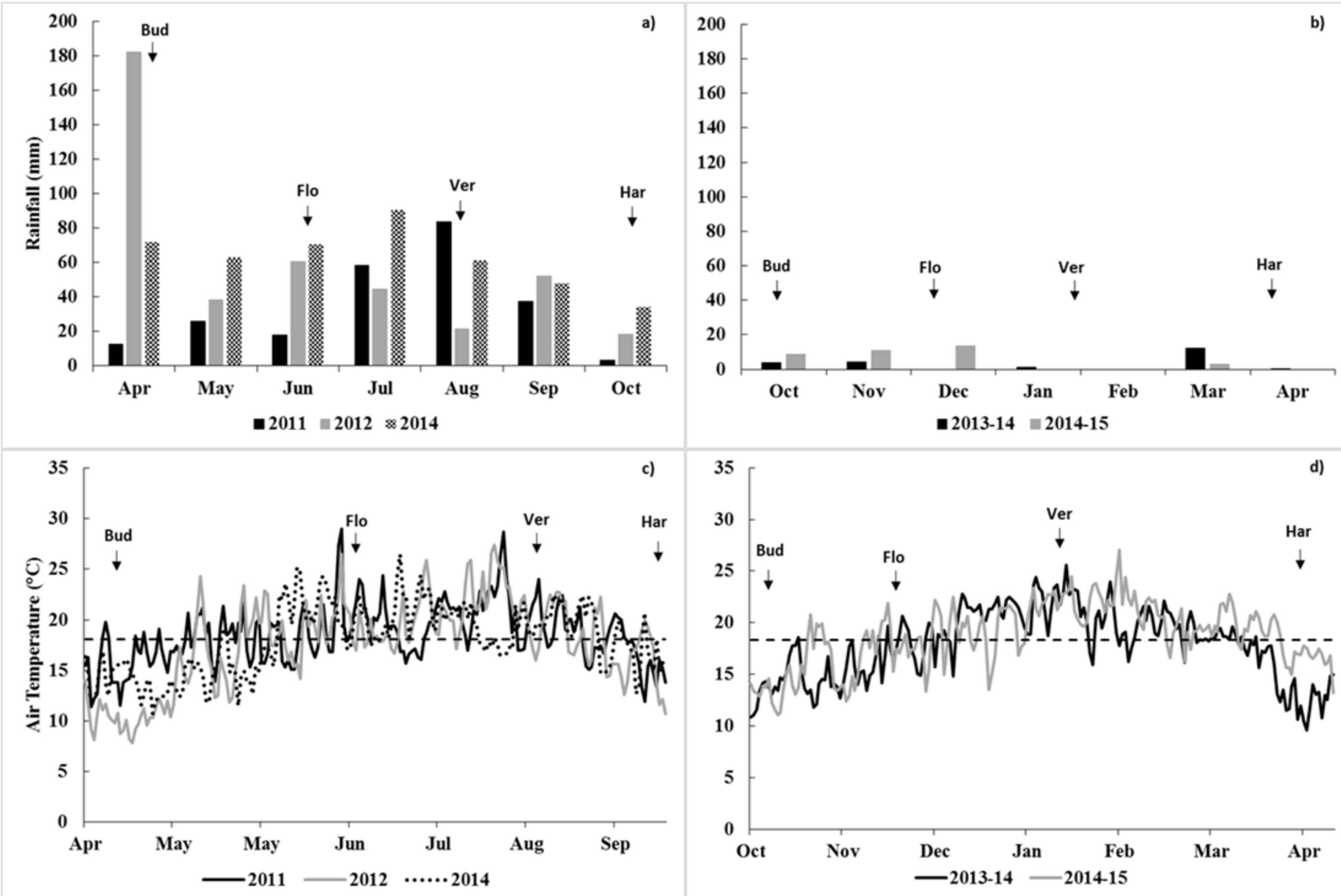

Figure 1. Monthly mean rainfall (mm) in France (a) and Chile (b) and mean air temperature (°C) in France (c) and Chile (d) during all seasons. The horizontal dotted lines in (c) and (d) represent the mean air temperature (°C) in each season. Bud = Budbreak; Flo = Flowering; Ver = Veraison; Har = Harvest.

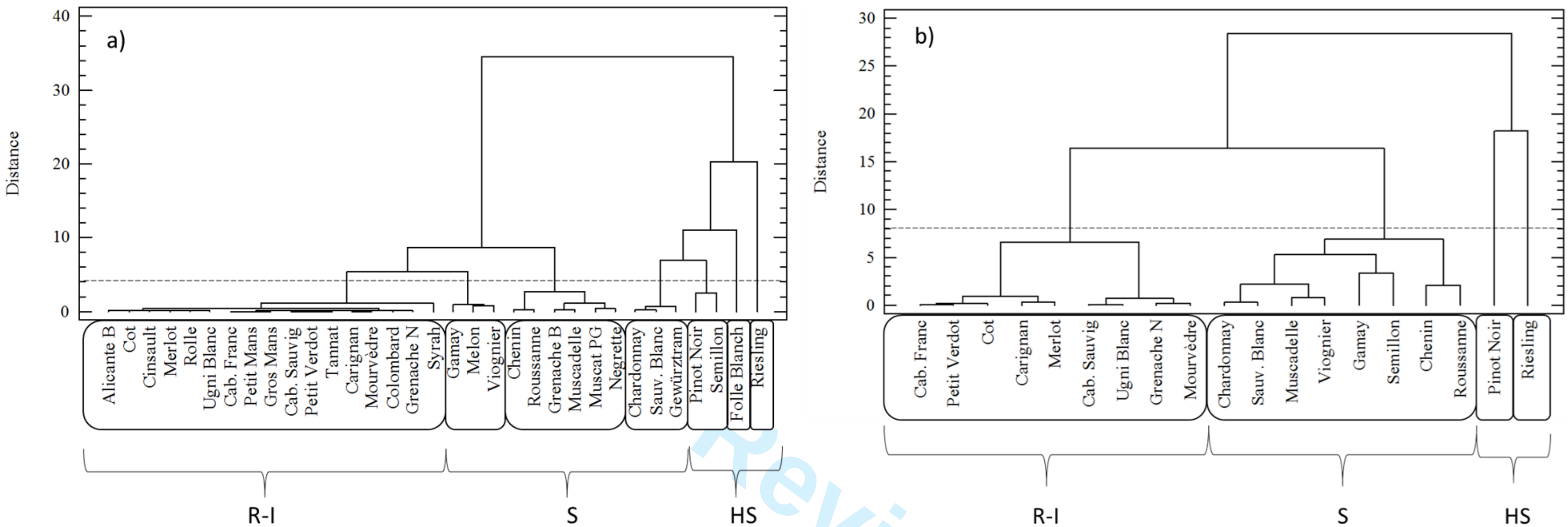

Figure 2. Cluster classification of cultivars in France in the sites "Tour Blanche" (a) and both "Grande Ferrade and "Tour Blanche" (b) according to their severity values.

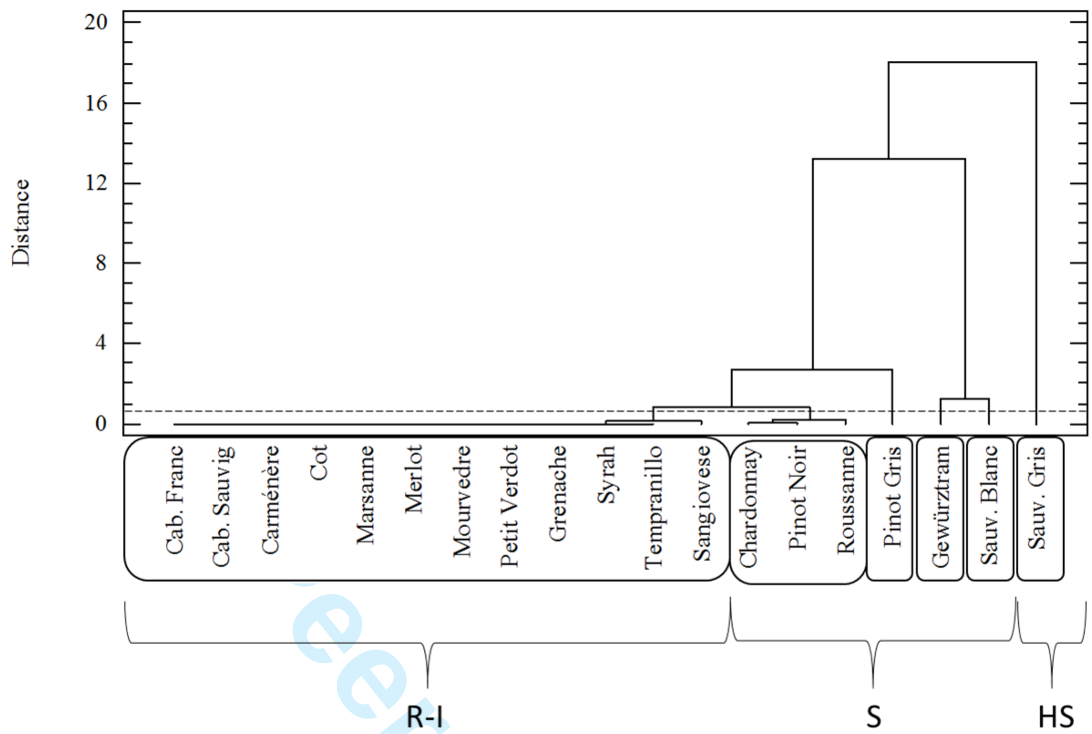

Figure 3. Cluster classification of cultivars in Chile according to their severity values.

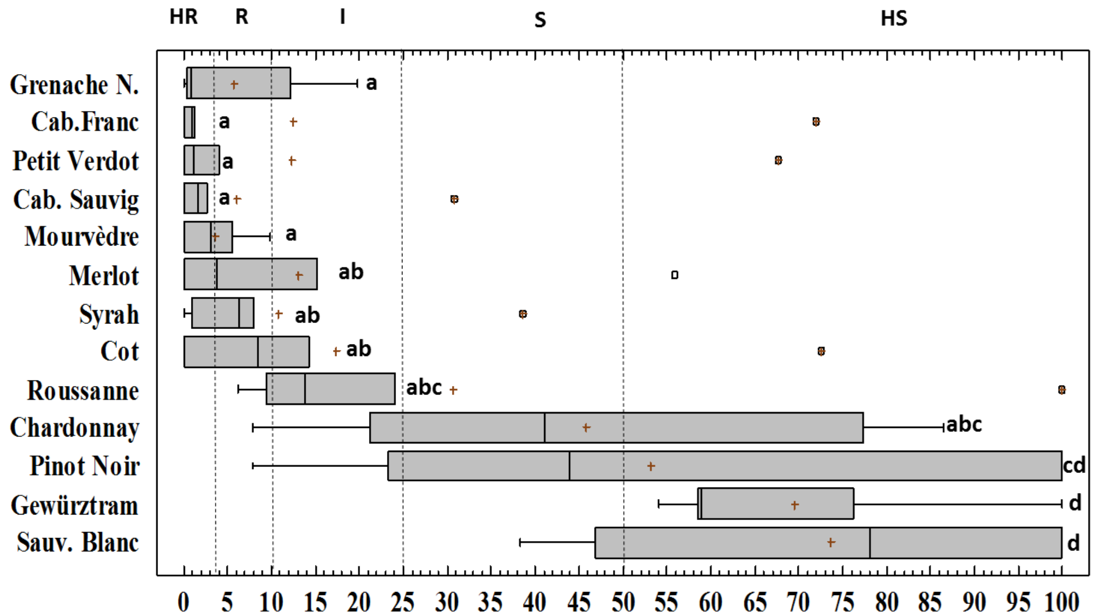

Figure 4. Box plot of cultivars according to the susceptibility index. HR = Highly Resistant; R = Resistant; I = Intermediate; S = Susceptible; HS = Highly Susceptible. The vertical line in each box and the cross represent the median and mean value of the SI, respectively.

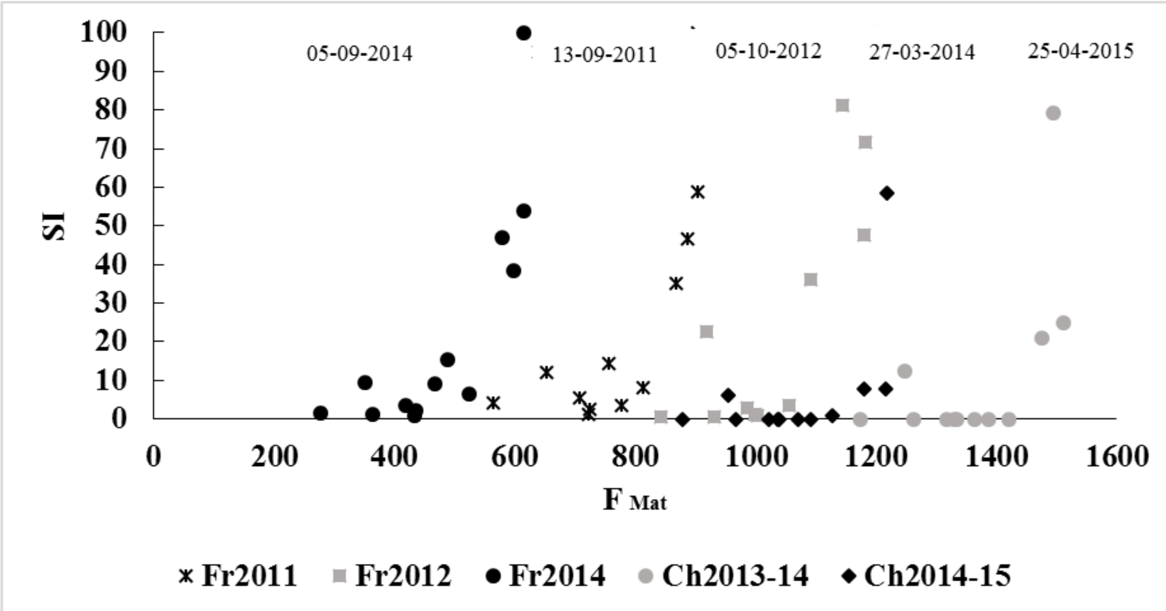

Figure 5. Relationship between the maturity of cultivars (F Mat) and susceptibility to BBR (SI), assessed at different dates, in France and Chile.

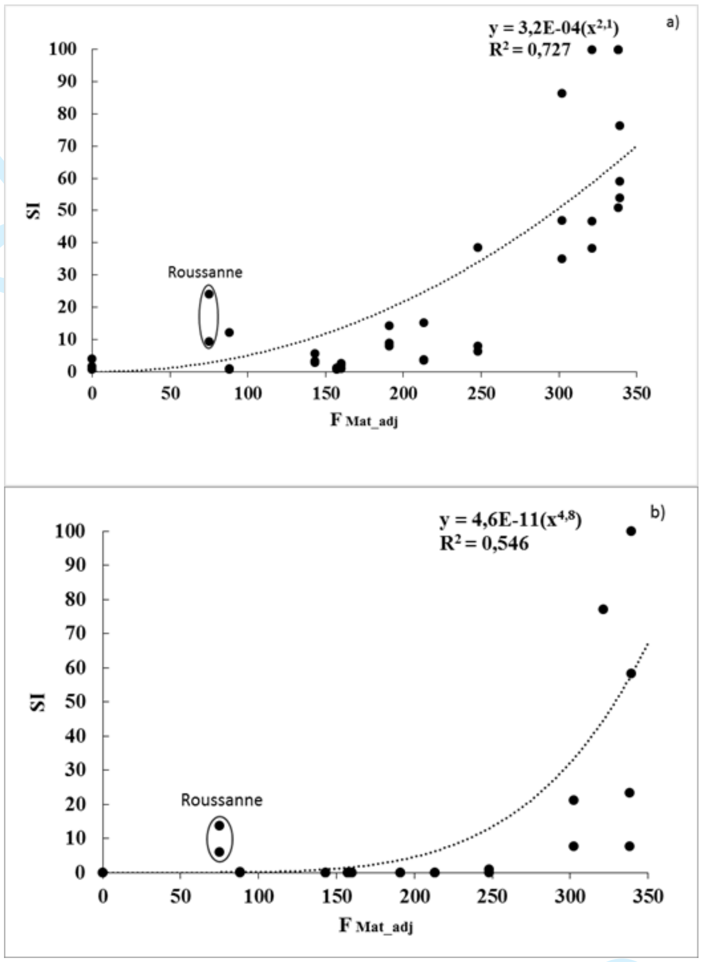

Figure 6. Relationship between the maturity of cultivars (F Mat_adj) and susceptibility to BBR (SI) at both sites, France (a) and Chile (b), during all study seasons.