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Identifying the pedoclimatic conditions most critical in the susceptibility of cultivar Gamaret to Esca disease

Vinciane Monod[1,2], Vivian Zufferey[3], Matthieu Wilhelm[2], Olivier Viret[4], Katia Gindro[2], Daniel Croll[1], Valérie Hofstetter[✉2]

[1] Laboratory of Evolutionary Genetics, Institute of Biology, University of Neuchâtel, CH-2000 Neuchâtel, Switzerland
[2] Agroscope, Plant Protection, Mycology, 1260 Nyon, Switzerland
[3] Agroscope, Viticulture, Avenue de Rochettaz 21, 1009 Pully, Switzerland
[4] General Direction of Agriculture, Viticulture and Veterinary Affairs (DGAV), Department of Finances and Agriculture (DDFA), CH-1110 Morges, Switzerland

To understand the highly variable susceptibility of the Gamaret cultivar to Esca disease, we carried out a four-year study to identify the environmental factors (climate, plant physiology, and soil) that most strongly influence disease expression. Soil water-holding capacity was found to have the strongest impact on Esca incidence, with higher rainfall in early summer also responsible for an increase in foliar symptoms. This research provides a valuable model for identifying environmental drivers of Esca symptom expression in other grapevine cultivars.

Materials and Methods

The study was carried out across 19 vineyards in four regions of western Switzerland (Figure 1A). To minimise confounding factors related to cultivar variability, vine age, and pruning method, all vineyard plots were uniformly planted in 2003 with *Vitis vinifera* L. cv Gamaret (a cross between Gamay x Reichensteiner) grafted on 3309C rootstock. All plants were grafted in the same nursery using homogeneous material and trained using the simple Guyot pruning system.
Cumulated plant mortality data gathered before the experiment (2003-2017) appeared highly variable (Figure 1B), ranging from 0 % to 48 % depending on the vineyard plots. Based on this variability, the Gamaret cultivar was selected as an ideal model for investigating the influence of biotic and abiotic factors on Esca incidence. Over four consecutive years (2018-2021), when Esca symptoms were most visible (late August to early September), about 300 vines per vineyard plot were examined for the presence of Esca symptoms, totalling 5,700 plants across the entire vineyard network. Symptom severity was classified into five categories: 1) asymptomatic plants (no discernible symptoms), 2) weak foliar symptoms (a single symptomatic shoot), 3) medium foliar symptoms (> one symptomatic shoot), 4) severe foliar symptoms (shoots all displaying symptoms), and 5) apoplexy. The proportion of affected plants per plot was determined annually, based on the number of vines originally planted in 2003 and still present during the year of observation.
Climatic data (rainfall and temperature) were obtained for sites representative of each of the four wine-growing regions under study from https://www.meteoswiss.admin.ch/. Data from previous years (1990-2017) were also collected to establish a climate norm for comparative analysis.
To estimate the soil water holding capacity (SWHC) of each plot, a hole was dug between vine rows. In most plots (n=15), the hole measured 1.5 m deep x 1 m wide, while in plots where vine roots extended more deeply (n=4), holes were excavated to 2 m depth without reaching bedrock. SWHC was calculated for each plot following the method described by Letessier and Fermond[1].
Additional physiological and agronomical data were collected, including vine water status, carbon isotope composition in berries at harvest, foliar nutrient content (nitrogen, potassium, phosphorous, calcium and magnesium), berry weight, and cover cropping practices.

Results

This publication is an abridged version of an article published in OENO One[2]; see figures and tables not presented here in that publication). Measured biotic (plant physiology and cover cropping) and abiotic (climate and SWHC [Table1]) variables, and incidence of Esca were summarised using a principal component analysis (PCA).
Our PCA results (not shown here; see Monod *et al.*, 2025[2]) suggested that soil water holding capacity (SWHC) was an important factor for the expression of plant symptoms. Consequently, the relationship between total mortality rate since the vines were planted (2003) and SWHC was tested for the 19 studied vineyard plots. Linear regression inferred a positive association between plant mortality and SWHC (Figure 2).
Additionally, we computed the Pearson and ξ-correlation (package available in R; 3) coefficients of 70 variables with Esca incidence and selected those with the highest association (Figure 3). The sum of symptoms and the rainfall in June (Figure 3A) displayed the highest Pearson correlation coefficient (R= 0.58). Both correlation coefficients also underscored a positive association between the precipitation regime observed in June. Specifically, the total rainfall and the deviation from the 1991-2017 climatic norm for rainfall in June are relatively highly associated with the Esca incidence indices according to both correlation coefficients for the former and the ξ-correlation coefficient for the latter (Figure 3). Other relatively highly correlated variables included cover cropping and chlorophyll content.

Discussion

Our main objective was to investigate associations between a range of pedoclimatic factors and the prevalence of Esca disease across different viticultural regions, to identify those that might explain Gamaret's highly variable susceptibility to Esca disease. To achieve this, we carried out Esca annual epidemiological measurements, closely monitored various physiological indicators across all vineyard plots, and gathered soil characteristics and climatic conditions.
Over four years of monitoring, we observed annual variations in Esca incidence between and within bio-climatic regions. This variability in disease expression within a single grapevine cultivar suggests that specific abiotic factors may influence disease incidence, as has previously been proposed[3]. We therefore set out to identify which factors could influence the incidence and severity of Esca symptoms expressed by Gamaret.
Our principal component analysis (2) showed an association between Esca incidence and SWHC. To further investigate this relationship, we performed a linear regression analysis across the entire vineyard network, using mortality data collected for each plot over an 18-year period (Figure 2). This analysis showed

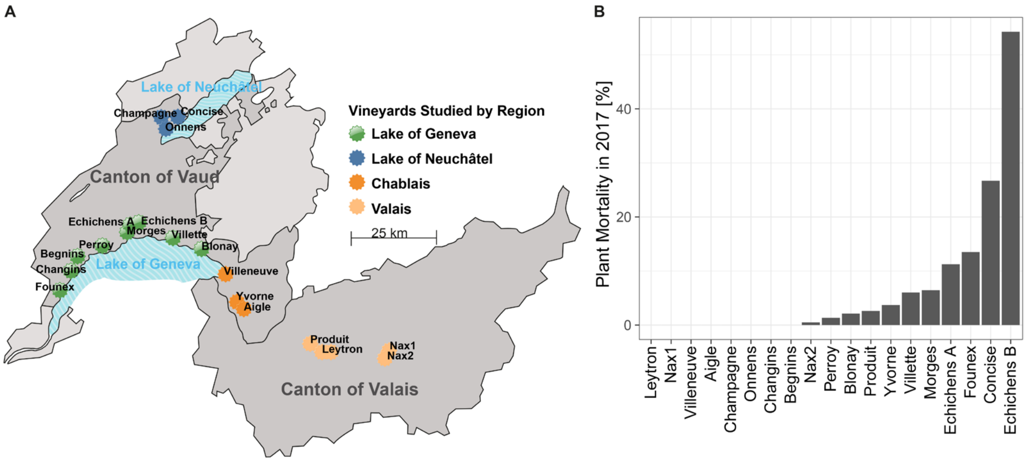

FIGURE 1. A Map of the Gamaret vineyards monitored across western Switzerland. B Cumulative replacement rate [% of plants] from vineyard plantation in 2003 through 2017 across the study plot network.

TABLE 1. Experimental sites in four wine-growing regions (Switzerland), and their respective soil type management (% soil cover cropping) and soil water holding capacity (SWHC).

Sites	Region	Soil types	% Cover cropping	SWHC (mm)	SWHC category
Founex	Lake of Geneva	Gravelly moraines	70	155	Medium
Changins	Lake of Geneva	Bottom moraines	70	110	Medium
Begnins	Lake of Geneva	Bottom moraines	70	130	Medium
Perroy	Lake of Geneva	Bottom moraines	70	155	High
Morges	Lake of Geneva	Bottom moraines	70	240	High
Echichens A	Lake of Geneva	Bottom moraines	70	230	High
Echichens B	Lake of Geneva	Bottom moraines	70	230	High
Villette	Lake of Geneva	Marly sandstones	70	250	High
Blonay	Lake of Geneva	Marly sandstones	70	200	High
Onnens	Lake of Neuchâtel	Jurassic sandy stones	70	120	Medium
Champagne	Lake of Neuchâtel	Jurassic sandy stones	60	95	Low
Concise	Lake of Neuchâtel	Jurassic sandy stones	70	180	High
Villeneuve	Chablais	Gravelly moraines	70	90	Low
Yvorne	Chablais	Gravelly moraines	50	100	Low
Aigle	Chablais	Gravelly moraines	50	80	Low
Produit	Valais	Clay schists	0	160	High
Leytron	Valais	Stony moraines	0	100	Low
Nax1	Valais	Stony moraines	0	90	Low
Nax2	Valais	Colluvial/stony moraines	0	140	Medium

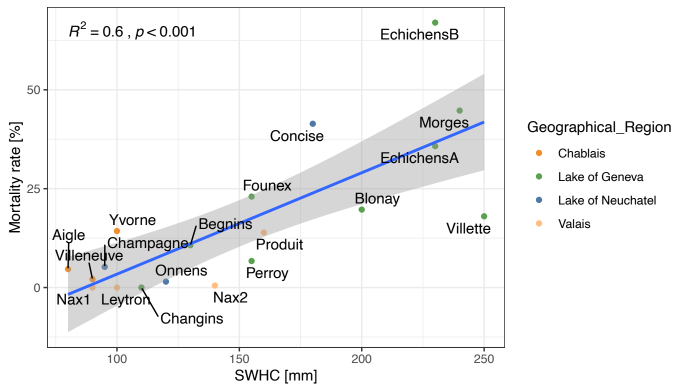

FIGURE 2. Linear regression between total mortality rate by vineyard plot (from 2003-2021) and soil water holding capacity (SWHC) index for each plot.

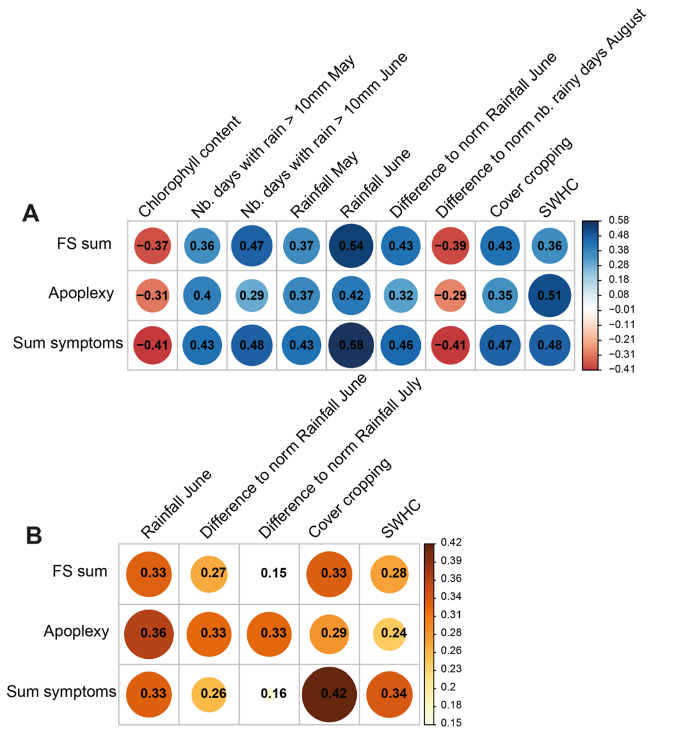

FIGURE 3. Correlation coefficient matrix with variables most correlated with the Esca incidence indices: number of plants with foliar symptoms (FS_sum), number of plants with apoplectic symptoms (apoplexy), number of plants affected by Esca (FS_sum + apoplexy). The size of the dot reflects the strength of the correlation. A. Variables with the highest correlation rate with the Esca incidence indices according to Pearson correlation coefficient. B. Variables most correlated with the Esca incidence indices according to ξ-correlation coefficient.

that Chablais, in which the studied vineyard plots all had low SWHC, also had the lowest plant mortality rate (Table 1; Figures 1 and 2), while in the Lake Geneva region, where vineyard plots were planted in soils with medium to high SWHC, the mortality rate was highest. Furthermore, in the Valais and Lake Neuchâtel regions, where vineyard plots were planted in soils with heterogeneous SWHC, the highest mortality rates were observed for plots planted in soils with the highest SWHC. Our results confirm an association between SWHC and plant mortality, both between and within regions, which is in line with recent studies[4] [5]. Furthermore, our correlation analyses (Figure 3) suggest that disease incidence is associated with rainfall, particularly in June. Rainy summers appear to favour the expression of Esca symptoms, especially the rainfall patterns from May to July, as has previously been suggested by other authors[5]. The year 2021, the wettest of the study period, recorded the highest number of foliar symptoms and apoplectic events in three of the four monitored viticultural regions. Both 2019 and 2021 were characterized by a particularly rainy and cold May, followed by a hot summer in 2019 and a hot and rainy summer in 2021 (data not shown; see Monod *et al.*, 2025[2]). Our results contrast with the prevailing notion that the combination of high temperatures and drought intensifies plant damage[3]. However, they concur with findings suggesting that prolonged exposure to drought (as observed in Valais) does not seem to alter the susceptibility of a particular grape cultivar to Esca[6]. This may indicate that the Gamaret cultivar is sensitive to Esca symptoms when located on soil with a high SWHC and is less affected under hot and dry climates. Our findings provide some guidelines to wine growers regarding the optimal plot selection for planting the Gamaret cultivar, ensuring better management of Esca incidence. We stress that our conclusions are based on a four-year study, with plants grafted on a single rootstock, and are thus limited. ■

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