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Climate vs grapevine pests and diseases worldwide: the first results of a global survey

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Abstract

Aim: This paper aimed to address the relationship between grapevine disease, pest occurrences and climate. The extremely large extension of viticulture worldwide offers the possibility to evaluate the impacts of climate variability on many aspects of the grape growing system. For this, we initiated a global survey to retrieve the most important diseases and pests in many grape growing regions worldwide and to identify the risk of exposure to pests and diseases of viticulture as a function of climate.

Methods and results: Based on the answer of respondent about the main reported diseases/pests in their region, a severity index was calculated. Each region was geolocalised and data were compared to the WorldClim gridded climate database to document the range of climate conditions (growing season temperature and rainfall) associated to the main diseases/pests. The potential climatic-induced changes of grapevine disease and pest geography by 2050 are assessed using agro-climate projections from the ARPEGE CNRM model, using the RCP 4.5 scenario. The preliminary results allow to determine the distribution of diseases as function of agroclimatic indicators.

Conclusion: While the distribution of diseases differs according to the region of the world, the current analysis suggests that mildews remain the major phytosanitary threat in most of the regions. Powdery mildew, trunk diseases and viruses were reported in extremely diverse climatic conditions, including intermediate and wet regions.

Significance and impact of the study: This paper present an original methodology to address the relationship between grapevine disease and pest occurrences and climate. Such documentation is scarce in the current literature. Further analysis is currently being performed, including additional survey answers, climate indices and supplementary data collected (spatial extension, frequency of treatments…) to better depict the challenges of grapevine phytosanitary management in a changing climate.

Keywords: diseases, pests, viticulture, climate change, grapevine

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Introduction

Viticulture sustainability in response to climate change has been addressed mostly considering agronomical impacts such as grape phenology (Xu *et al.*, 2012), grape ripening (Barnuud *et al.*, 2014; Stock *et al.*, 2005), and water management (Hofmann *et al.*, 2014), either separately or together (Moriondo *et al.*, 2013; Webb *et al.*, 2012). All indicate considerable changes, either recent or projected during the 21st century. The environmental impacts of climate change on viticulture have been explored by Hannah *et al.* (2013). While their conclusion was partially biased (van Leeuwen *et al.*, 2013), their study brought insights into the potential impacts of climate change in the next decades on water use, ecosystems and land use shifts by vineyards. Disease and pest control is another important issue of the environmental footprint of viticulture, potentially leading to pollution (Komárek *et al.*, 2010), human health issues (Ntzani *et al.*, 2013) and economic consequences (Pimentel, 2005). Climate change is likely to affect parasite biology and populations and, therefore, plant protection is expected to evolve in response to the increase and/or decrease of pest or disease development in the vineyard (Caffarra *et al.*, 2012; Salinari *et al.*, 2006). Phytopathology responses to climate change have to be addressed by considering (1) changes in plant sensitivity to the pathogen, (2) the response of the parasite, and sometimes its vector, to climate and (3) changes in the parasite ecosystem, taking into account global changes from cultivation, climate and pathogen/pests interactions.

While the biology of grapevine sensitivity to many parasites and pest or disease agents is well documented (Chuche and Thiéry, 2014; Esmenjaud *et al.*, 2008; Gadoury *et al.*, 2012; Gessler *et al.*, 2011; Reineke and Thiéry, 2016), the evolution of populations and potential breaking of life cycles in response to climate change is difficult to predict (Gregory *et al.*, 2009).

Rather than trying to examine the potential response to each element of the complex grapevine pathosystem, the present paper proposes a global approach to describe climate vs viticulture pests and diseases relationships. The approach is based on the opportunity offered by the cultivation of grapevine worldwide under a wide diversity of climate conditions. Grapevine pest and disease geography is being documented by a global survey initiated in late 2015. The current paper reports an early analysis of the survey results and presents a method to evaluate the possible evolution of pest and disease management in response to climate change.

Material and methods

1. Viticulture pests/diseases survey

In December 2015, an online survey was sent to researchers, consultants and production professionals (winemakers, vinegrowers, etc.) worldwide. The survey consisted in 4 sections. In sections one to three, the questions focused on the report of 3 diseases or pests considered as the most "important" in the opinion of the interviewees. Additional information concerning spatial extension, frequency of occurrence, management and treatments was collected. Section IV addressed general information concerning the documented area, such as its location, grape products (wine, table grapes, etc.) and vineyard characteristics (training system, irrigation, soil, etc.).

In this study, only the frequencies of answers concerning the #1 to #3 diseases and pests were analyzed. To quantify the pests or diseases according to the concern of the interviewees, a so-called "severity index" (SI) was calculated, globally or for each part of the world, as follows:

$$SI_d = \frac{3N_{1,d}+2N_{2,d}+N_{3,d}}{N_{tot,d}} \quad (1)$$

where $N_{i,d}$ is the number of answers citing the disease/pest d as the number i in the reported area (i=1 indicating that the respondent considered the disease/pest d as the #1 is the reported area), and N_{tot} is the total number of answers collected in the region. Consequently, a SI_d value of 3 indicates that all respondents considered the disease/pest d as the number 1.

2. Climate data

Regions documented by the respondents were geolocated using the Vineyard Geodatabase (VGDB). This database was launched in 2012 (Bois *et al.*, 2012) and has recently been updated using wine atlases and maps to locate the major wine growing regions worldwide. The delineation of wine regions was adjusted by analyzing aerial photographs as displayed in Google Earth©. In Europe, the CORINE Land Cover 2006 version (European Environment Agency, 2007) was used to restrict wine regions to areas actually planted with vines. The VGDB, in its current version 1.1.2, references 626 wine growing regions worldwide as a polygon layer.

Amongst the 214 answers collected early 2016 in response to the pest and disease survey, 205 corresponded to regions documented in the VGDB. The remaining 9 were located in regions with small and scattered vineyards. The 205 responses covered 87 VGDB wine growing regions in 26 countries.

Within each polygon of these 87 wine regions, climate data were extracted from the WorldClim 30 sec arc (about 1 km) resolution rasters, version 1 (Hijmans *et al.*, 2005).

WorldClim data provides monthly precipitation (Prec) and minimum (Tmin) and maximum temperature (Tmax) averaged over the 1950-2000 period (hereafter referred to as HIST). To match current climate conditions, WorldClim data was updated to the 2000-2014 period (CURRENT). As the CURRENT period is not available in the WorldClim database, we performed this update using the CRU3.2 gridded monthly database (Harris *et al.*, 2014) providing monthly precipitation and temperature data from 1901 to now. CRU CURRENT minus HIST average was calculated for each month and each climate variable (Prec, Tmin and Tmax). As CRU spatial resolution (0.5 degree) is much coarser than WorldClim's, the resulting delta (CURRENT – HIST difference) was then downscaled by bilinear interpolation to match WorldClim higher resolution.

The downscaled delta was then added to HIST (1950-2000) WorldClim high resolution data.

Climate projections for the mid-21st century (2046-2065 hereafter referred to as FUTURE) by the CNRM (Météo-France ARPEGE) model run under the RCP 4.5 scenario were collected from the WorldClim database at 30 sec arc resolution (see www.worldclim.com for further information on the downscaling methods).

Both CURRENT and FUTURE climate data were used to calculate growing season temperature average (GST ; Jones, 2006) and rainfall (GSR), which correspond to mean (sum) monthly temperatures (rainfall) from April to October in the northern hemisphere and from October to April in the southern hemisphere.

We analyzed GST and GSR distributions in CURRENT and FUTURE climate conditions in the regions where diseases/pests were reported. In this paper the analysis is limited to the 5 diseases/pests exhibiting the highest severity index at a global level (i. e. the most "important" diseases and pests worldwide, according to this survey).

Results and discussion

1. Countries of origin of respondents

Most of the 214 responses analyzed concerned Europe (165), with a large majority of answers (79) from France, provided by wine growers or consultants. 17 answers concerned the United States, 14 South America, 13 Spain, 12 South Africa, 10 Greece, 6 Portugal, 7 Italy, 6 Australia and 5 Israel (Figure 1).

2. Geography of major pests and diseases

At a global level (all 214 responses considered), downy mildew exhibited the first severity index (*SI*=1.74) due to its dominance in Europe (*SI*=2.01). It is closely followed by powdery mildew (*SI*=1.64), which is considered as the most damaging everywhere else (Figure 2). According to *SI*, this disease was the most reported for North America (*SI*=2.11), Australia (2.14) and South Africa (1.92). Grey mold (caused by *Botrytis cinerea*) and Trunk diseases are the third and fourth most reported diseases worldwide (*SI*=0.72 and 0.70, respectively). Grey mold ranks third in Europe (0.99), North America (0.41) and Australia (1) and even first in South America (2.11) where the vine is irrigated. Virus-induced diseases (mostly GFLV fanleaf and GRLaV leafroll-associated viruses) were mostly reported for South Africa (2.08) but also consistently reported for North America (0.29), South America (0.21) and Europe/Mediterranean (0.22).

Amongst other pests and diseases (Figure 2), Flavesence dorée (for Europe/Mediterranean – 0.10 and North America – 0.17), European Grape moth (Europe/Mediterranean – 0.22 and South America – 0.28) and black rot (North America – 0.23) were the most frequently cited.

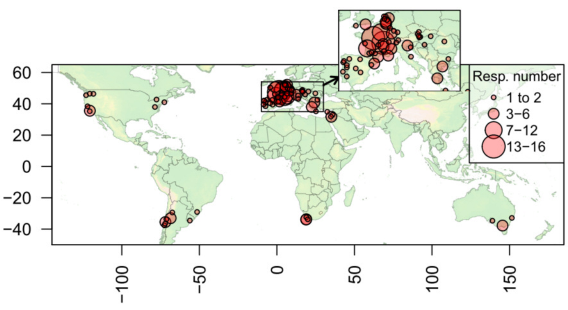

Figure 1 - Spatial distribution of the wine producing regions which interviewees reported diseases from.
The size of the red circles indicates the number of answers collected in each region.

Table 1 - Terms used to describe the climate conditions as function of growing season temperature (GST) and rainfall (GSR). Ranges and classes for GST are taken from Jones (2006). GSR ranges and class names are given based upon a comparison of GSR and the dryness index classes given by Tonietto and Carbonneau (2004).

GST [°C]		GSR [mm]	
Range	Class	Range	Class
< 15	Cool	< 250	Dry
15-17	Intermediate	250-500	Sub-humid
17-19	Warm	> 500	Humid
> 19	Hot		

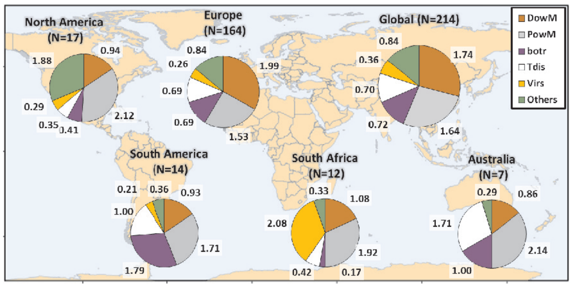

Figure 2 - Severity indices of the main grapevine diseases for each region of the world. DowM: Downy mildew, PowM: Powdery mildew, TDis: Trunk diseases, Botr: Grey mold (*Botrytis cinerea*), Virs: Virus-related diseases.

3. Climate profiles of the most reported diseases

Major diseases (reported as the #1 to #3 diseases by the respondents) exhibited various climate features (Figure 3).

GST and GSR are used to describe the climate conditions with the terms proposed in Table 1. The ranges presented hereafter correspond to the 0.05 to the 0.95 quantiles (thus embracing 90 % of the sample data).

Mildews and grey mold were reported as #1 to #3 diseases in almost all climate conditions met in the regions covered by the survey. Note, however, that grey mold was less frequently reported in dryer conditions. Trunk diseases and viruses were reported in sub-humid to dry regions, within a large range of thermal conditions (Figure 3).

Downy mildew was reported as the #1 disease mostly in intermediate to hot climate with sub-humid to humid conditions: GST from 14.9 °C (0.05 quantile) to 20.3 °C (0.95 quantile) and GSR from 184 mm to 727 mm. This disease was not reported in intermediate and dry climate regions, such as Walla Walla or Yakima Valley (WA, USA; bottom-left of the downy mildew plot in Figure 3). Powdery mildew was reported #1 pest in a larger range of temperature conditions (15.1 to 21.8 °C) with globally lower rainfall during the grape growing season (59 to 675 mm). As for powdery mildew, wide ranges of temperature conditions were associated with areas where grey mold was considered as the number 1 disease: growing season temperature 0.05 and 0.95 quantiles ranging from 14.2 to 21.6 °C. Rainfall in those regions displayed a narrower span (181 to 561 mm). Where trunk diseases were reported as major diseases, climate was either intermediate to hot (15.8 to 20.8 °C) and sub-humid (350 to 500 mm approx.) or hot (19 to 22 °C) and dry to sub-humid (200 to 260 mm). Viruses were also reported in two different types of climates: either intermediate to warm and sub-humid (15 to 18 °C and 350 to 500 mm approx.) or hot (22 to 23.5 °C) and dry (below 250 mm).

For all 5 diseases reported here, the CNRM global circulation model RCP 4.5 scenario projections for 2050 exhibit little expected change in growing season temperature and rainfall conditions from 2000-2014, in comparison to the span of climate condition in which these diseases are currently met. Consequently, no conclusion concerning possible changes in the occurrence of these diseases in the future was proposed on the basis of this preliminary analysis.

Discussion and conclusions

In our survey, pests were seldom reported as major phytosanitary concern in grape growing regions. Cryptogamic diseases were, in contrast, most reported.

While the distribution of diseases differs according to the region of the world, the current analysis suggests that mildews remain the major phytosanitary threat in most of the regions. As the development rate of the powdery mildew agent (*Erysiphe necator*) is mostly temperature driven and rainfall-induced (free water is detrimental to conidia germination; Gadoury *et al.*, 2012), one could have expected little occurrence of this disease in wet and cool climate conditions. In this survey, powdery mildew was reported in extremely diverse climatic conditions, including intermediate and wet regions, probably because of a large tolerance of *Erysiphe necator* to thermal conditions. In contrast, downy mildew is a disease typical of

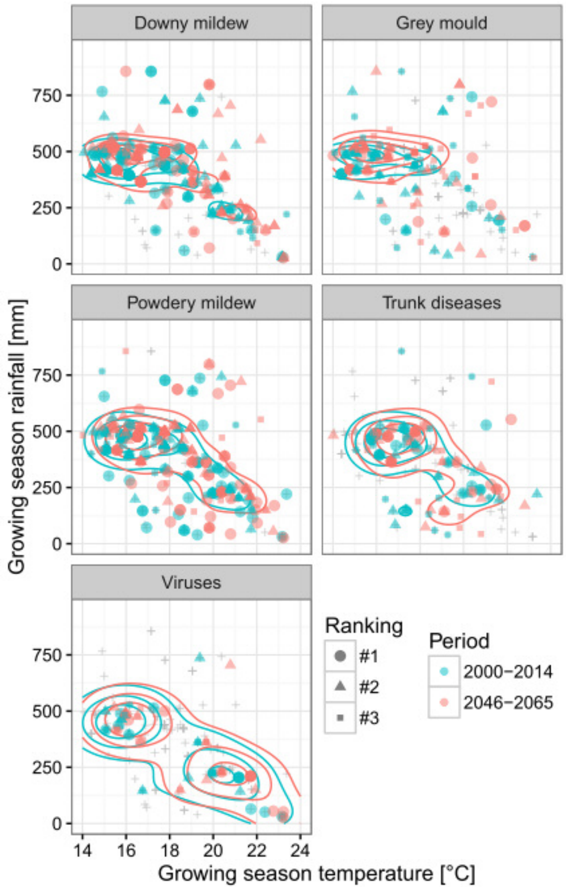

Figure 3 - Distribution of mildews, grey mold, trunk diseases and viruses in each region as function of growing season average temperature and cumulated rainfall of CURRENT (2000-2014, blue color) and FUTURE projected (2046-2065, red color) climate conditions of regions where these diseases were reported as #1 (circles), #2 (triangles) and #3 (squares). The grey "+" locates climate of the regions where the disease was not reported. The contour lines correspond to values that are the most represented (as depicted by a 2D kernel density function).

regions with frequent rainfall (Gessler *et al.*, 2011; Wilcox *et al.*, 2015). However, even in regions with less than 250 mm rainfall during the growing season, downy mildew was reported as the #1 disease by the respondents. Such occurrence might be related to irrigation practices, but also to the fact that downy mildew can be highly damaging and requires a quick response due to its very short cycle. Including such practices (our survey collected information concerning irrigation techniques, quantities and frequency of treatments) together with climate indices calculated on shorter pertinent periods in relation to each pathogen cycle and on its development on bunches may improve our analysis of the risk.

The same observation can be made for grey mold, which was reported as a major disease even in regions where little rainfall is met during the growing season. While rainfall is a key factor for the onset of grey mold (Molitor *et al.*, 2016), other factors such as relative humidity and wind speed may favor *Botrytis cinerea* development on berries (Thomas *et al.*, 1988). In dry climate vineyards, low temperatures are common (high thermal amplitude), possibly favoring dew development on berries. In vineyards where training systems lead to humid grape cluster microclimate, grey mold occurrence could be expected.

Trunk diseases are a growing concern of the grape growers worldwide (De La Fuente *et al.*, 2016), as, contrarily to mildews, the pathogens are not controllable by means of phytochemical products. Many wine production regions around the world reported these diseases as major in our survey. Their link to climate conditions is still unclear and the limited response number in some parts of the world, such as in Australia (N=7), where trunk diseases were reported, is not sufficient to provide any hypothesis concerning the climatic ranges associated with these diseases. The same caution should be observed concerning virus-related diseases, as the role of climate in their occurrence and propagation is certainly minor in comparison to the key role played by plant material selection, breeding, transportation and sanitary control. Moreover, vectors change according to each major virus disease, making it difficult to evaluate the contribution of climate in the extension of such a "group". Note also that some virus-related diseases are difficult (sometimes virtually impossible) to identify through field observations. Consequently, their severity is probably under-estimated in this survey.

The results presented here are preliminary, as some world regions have not been sufficiently documented due to the small number of responses collected. This paper aimed at sharing an original methodology to address the relationship between grapevine disease and pest occurrences and climate. Such documentation is scarce in the current literature. Further analysis is currently being performed, including additional survey answers, climate indices and data (spatial extension, frequency of treatments, etc.) to better depict the challenges of grapevine phytosanitary management in a changing climate.

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