EXPLORING THE FACTORS AFFECTING SPATIO-TEMPORAL VARIATION IN GRAPEVINE POWDERY MILDEW

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Abstract:
Context and purpose of the study - The spatial distribution of powdery mildew is often heterogeneous between neighboring plots, with higher disease pressure in certain places that can be considered as disease "hotspots". The position of hotspots can vary over the years, even if some plots consistently present a higher vulnerability over time. This spatio-temporal heterogeneity makes it difficult to obtain accurate prediction by epidemiological models that are fed by meteorological variables coming from weather stations that are not in close proximity to the vineyards or are spatialized over large cell grids. The aim of the project was to explore the role of environmental/agronomic factors involved in powdery mildew pressure variation in time and at the plot and regional scale.
Material and methods - To do so, a series of variables were monitored in 10 different vineyards, in the Beaune region (Bourgogne) of France, over two years. These factors included agronomic descriptors and weather variables. Weather data were acquired at the plot scale. Disease symptoms were observed weekly on leaves and grapes, highlighting inter-plot variation in disease indicators.
Results - The factors that most impacted this variability were relative humidity, rain, leaf wetness, vigor and phenology. A more in-depth study of the interactions between these factors will help to disentangle the complex effects of the environment on powdery mildew inter-plot heterogeneity. Relative humidity and leaf wetness appeared as the most closely correlated variables to powdery mildew onset and pressure. Undoubtedly these results need to be further confirmed and quantified through more extended surveys, but they indicate interesting directions for the improvement of predictive models of powdery mildew

Keywords: Correlation, Heterogeneity, Humidity, Leaf Wetness, local effects

1.Introduction

Powdery mildew (caused by *Erysiphe necator*) is one of the most common and harmful diseases of grapevine. If its optimal conditions are met, a new generation of this disease can be completed in less than a week (Wilcox, 2003). These explosive germinations combined with the fact that symptoms are visible only once the disease is well established, make its control difficult (Pearson &Gadoury, 1987). In addition, the spatial distribution of the disease is often heterogeneous between neighboring plots, with higher disease pressure in certain places that can be considered as disease "hotspots" (Calonnec et al, 2009; Mammeri et al, 2014). This spatio-temporal heterogeneity makes it difficult to obtain accurate prediction by epidemiological models that are fed by meteorological variables coming from weather stations that are not in close proximity to the vineyards or are spatialized over large cell grids. Indeed, local disease pressure might be related to micro-climatic factors but could also be the result of local environmental/agronomic variables that are rarely considered by models (Delp, 1954; Sall, 1980; Caffi et al, 2011), such as the type of soil, agricultural practices and the interaction with the plant: e.g. the growth, the physiology and genetic specificities of the variety.

To date, the effects of local factors on disease pressure have not been analyzed in depth, and the triggers of powdery mildew hotspots have not been clearly identified. However, an exploration of these effects is of the foremost importance to improve the understanding of the disease and to support the development of predictive models of powdery mildew. Therefore, the general aim of this study was to explore the role of the factors involved in powdery mildew pressure variation in time and space at a local scale. To do so, we monitored a series of environmental and agronomic variables, including powdery mildew observations, in 10 different vineyard plots near Beaune (Burgundy), over the growing seasons of 2017 and 2018.

2.Methods

Statistical correlation and multivariate analyses were conducted to explore the relationships between environmental variables and disease pressure. This paper presents the description of the data collected in 2018 (for more details on 2017, see Weens, 2017) and the multivariate and correlation analyses conducted on the joined 2017-2018 datasets.Observations were conducted on 10 plots in the Côte d'Or, all located in the same area near Beaune so that local effects could become evident. The plots were not treated to avoid the confounding effects of pesticides on disease pressure. Each plot was characterized with its soil type, its variety, its training method, its cover crop, whether it was in the plain or on the hills and its orientation. Disease pressure monitoring was carried out in the field through visual notations from April to July. At the same time, meteorological factors and plant-related factors such as vigor and phenological stages were measured. These variables were suspected to contribute to disease heterogeneity, as suggested by previous literature. They can be divided into:

1. Meteorological variables, either measured at reference stations at 2 m above soil on each plot, and also in the canopy (micro-climate) on three specific plots (CRC_20, CRC_21, CRC_28). They included temperature, relative humidity, rain, leaf wetness (only for the three micro-climate stations in the canopy).
2. Agronomic (plant and "situation") variables: phenology, plant vigor (measured as weekly growth in twig length and width), variety, training method, cover crop, plain or hills, orientation year (2017 or 2018).
3. Disease variables: percentage of leaves and grapes affected by powdery mildew.

The data was used to calculate indicators (see below) and organized to compute correlation matrices. The correlation coefficients (Pearson) obtained in this way were used to select a set of "meaningful indicators" highly correlated to disease occurrence that were then used in a principal component analysis (PCA). In order to perform these analyses, static descriptive indicators of the plots (such as grape variety) or synthesis indicators for dynamic variables such as temperature were used.The indicators in the statistical analysis were the following:

1. Meteorological indicators: Average daily temperature, minimum and maximum temperature, relative humidity and leaf wetness. These variables were averaged either over the month of May (typical time of the year for primary contaminations) or weekly with a specific focus on the three weeks before the week of the first symptoms: 15th – 21st of May (week 1), 22nd – 28th of May (week 2) and 29th of May – 4th of June (week 3).
2. Agronomic indicators:

- Plant related: Plant vigor (average weekly growth), date of phenological phases
- Disease related: First date of symptom onset, final percentage of affected leaves or grapes (on the 4th of July)
- Plot related: Variety, training method, cover crop, plain or hills, orientation
- Year

3.Results and discussion

Unlike 2017 that had low powdery mildew pressure, year 2018 was characterized by a moderate powdery mildew pressure. The disease developed relatively late (first symptoms between the end of May and the beginning of June over the region). For the plots, disease pressure ranged between weak and moderate/strong with a maximum of 30% symptoms in July before the beginning of phytosanitary treatments (Figure 1). The date of first observable symptoms was clearly heterogeneous, varying between the 4 and 23 of June (CRC_22 vs CRC_28 on grapes). Dynamics of symptom progression also varied, with some plots showing a faster rate of disease increase than others. Interestingly, whereas final disease pressure was higher in 2018 than 2017, the date of first symptoms (first week of June) was similar for the two years under study.

The correlation analysis highlights a strong year effect, and stronger correlations of powdery mildew with meteorological than with agronomic indicators. Indeed, disease biology in general is known to be strongly affected by weather variables like temperature, humidity and leaf wetness, which also have a large inter-annual variability (Rapilly, 1991). In the case of powdery mildew, temperature hastens germination and promotes spore production, and relative humidity and leaf wetness promotes infections (Delp, 1954; Chellemi&Marois, 1991a; Chellemi&Marois, 1991b).

These effects were confirmed by the correlation coefficients and by the PCAs (Fig 2 and 3) showing positive correlations between temperature and humidity and disease indicators. Almost all indicators of temperature were positively correlated to disease onset on grapes, but not on leaves, implying that warmer temperatures might correspond to later grape infection. This might seem counter-intuitive, given the promoting effect of temperature on spore release (Chellemi&Marois, 1991b). However, this effect might not be directly due to temperature (which over the study period always stayed in a favorable range for powdery mildew) but to relative humidity, which is highly negatively correlated to temperature. The promoting effect of humidity and free water on leaves on disease could be confirmed by the highly significant correlation between leaf wetness and disease onset on leaves. Indeed, whereas some caution must be exerted due to the small size of the leaf wetness dataset (3 data points), this factor seems to explain not just final disease pressure but also the date of onset of leaf symptoms.

The only agronomic factors that appeared to be related to powdery mildew are the year of observation and phenological timing and vigor. These two plant variables are both related to growth. Phenological timing has already been indicated as a factor affecting powdery mildew (Gadoury et al, 2003; Caffarra et al, 2012). On the other hand, vigor is known for favoring diseases in general, as it produces denser canopies, more susceptible tissue, and more humid conditions for the disease to develop (Calonnec et al, 2013). In the study, vigorous plots had later dates of grape infection, contrary to expectations. However, as vigor is positively related to temperature and temperature is negatively related to humidity, it is impossible to say whether the relationship between vigor and disease onset is causal, or whether it is due to the covariance of indicators.

4. Conclusions

In conclusion, the present study highlighted, at least for 2017-2018, a stronger correlation of powdery mildew with climate and plant growth than with static plot descriptors. The high degree of temporal (year effect) and spatial (plot effect) heterogeneity of powdery mildew corresponded to an equally high degree of variability in local weather conditions during the period of primary infections. Such variability and the high correlations with local powdery mildew pressure encourages a more precise weather monitoring on plots and inside the canopy. Relative humidity and leaf wetness appeared as the most closely correlated variables to powdery mildew onset and pressure. Undoubtedly these results need to be further confirmed and quantified through more extended surveys, but they indicate interesting directions for the improvement of predictive models of powdery mildew, that are actually unable to predict disease hotspots. Ultimately the ability to build precise tools to optimize phytosanitary management depends on our understanding of the environmental effects underlying the physiology of this disease.

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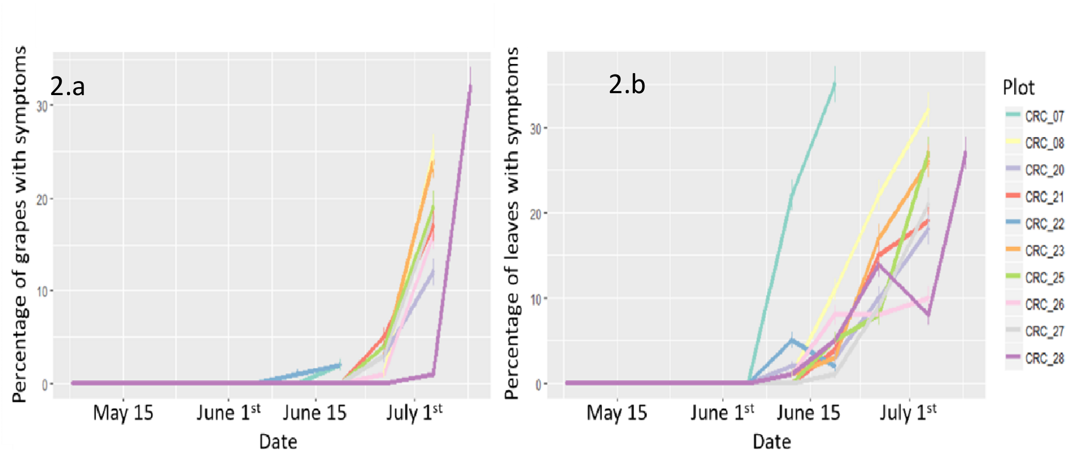

Figure 1. Dynamics of powdery mildew on grapes (2.a) and leaves (2.b) in 2018.

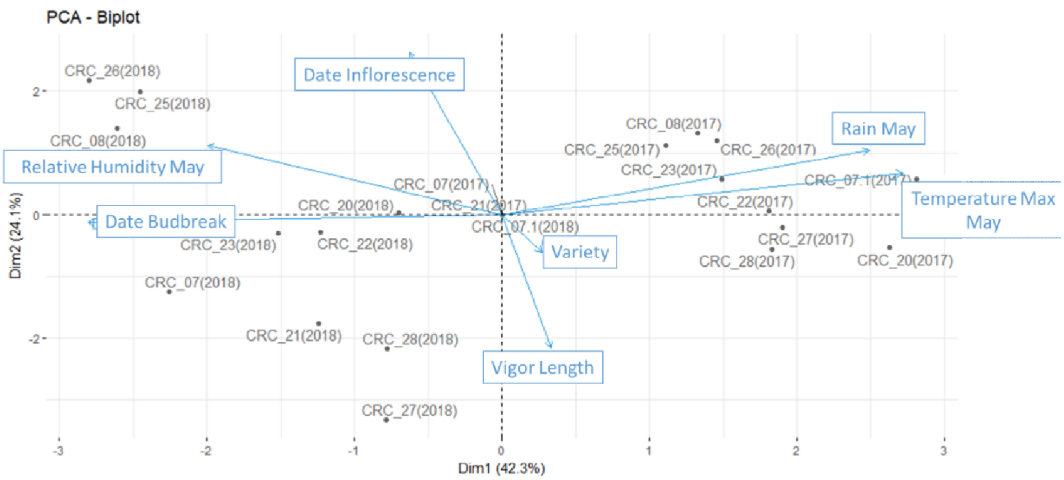

Figure 2. PCA for both years with the variables that were found to be highly correlated to disease pressure.

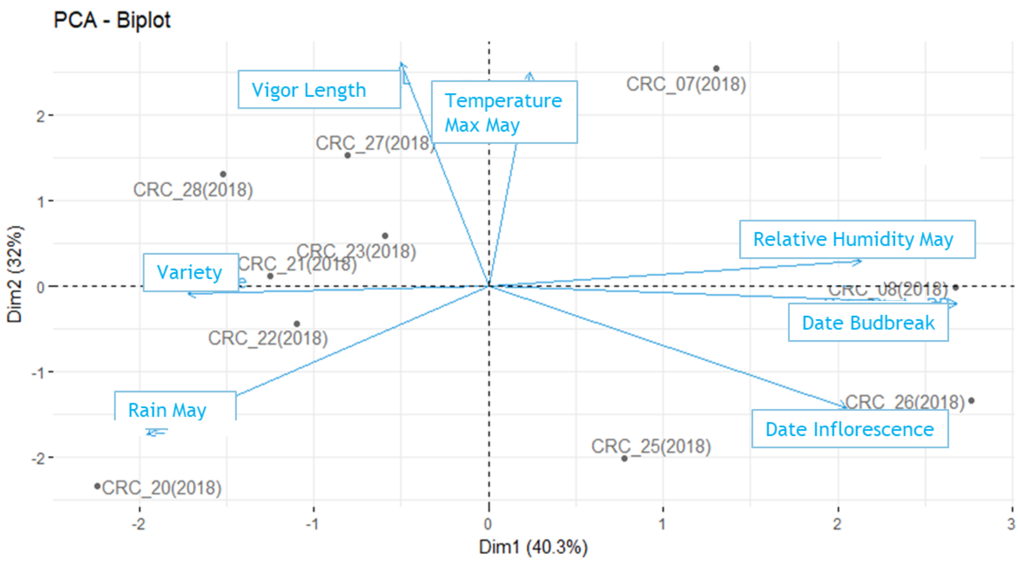

Figure 3. PCA for 2018 with the variables that were found to be highly correlated to disease pressure.