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Uncertain changes to spring frost risks in vineyards in the 21st century

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With milder winters, earlier budburst could lead to increased frost damage in the 21st century, despite global warming. However, the projection of future frost risk is currently subject to uncertainty. We look here at the data to be considered when assessing the risk of spring frost damage and the limitations of spring frost simulation, based on simulation work carried out in the Chablis wine region (Burgundy, France).

Frost risk factors

For spring frosts to cause damage to the vine, a combination of two factors is required: negative temperatures and a frost-sensitive plant. This second factor is referred to as vulnerability. The vulnerability of grapevine is dynamic. It changes after cold weather in the preceding days, to which the vine acclimatizes during dormancy, in particular due to an increase in the soluble sugar concentration in the dormant buds and vascular tissues[1]. In early fall, latent buds can withstand temperatures down to about -10 °C, and the cold hardiness threshold can reach -25 °C in the middle of winter (Figure 1a). The threshold gradually rises to around 5 °C as budburst approaches (Figure 1b) and reaches a maximum of around 2 °C on young vine shoots[6].
Wetness of the buds (rain, melted snow or saturation humidity) increases bud sensitivity to frost by 3 to 4 °C in winter and until budburst[2] (Figure 1b). Hence, at the green tip stage, temperatures of 3 °C will cause severe damage to wet buds but will be of no consequence in dry weather.

Models highly sensitive to climate, producing contradictory results

To reproduce these variations in vulnerability over time, according to phenological stage and as a function of bud wetness, we adapted a dynamic model of winter and spring frost susceptibility (referred to here as FergSec) developed by Washington State University (WSU[2]), by incorporating a higher frost sensitivity (+3.5 °C) during wet weather (FergHum). We also simulated the frost risk through a more simplistic "binary" approach, used in previous work[3]. In this approach, it is considered that the vine is only vulnerable to frost after budburst. We compared the frost risk simulated using this binary approach by varying the budburst date simulated by different phenological models[4]: GDD5, BRIN, Fenovitis and SU, more or less complex, and both with and without incorporation of the chilling accumulation needed to release the buds from dormancy.
Each of the 6 methods (dynamic: FergSec and FergHum and binary: GDD5, BRIN, Fenovitis and SU) used to assess the vulnerability of the vine adequately simulated frost damage in Chablis over the period 1964-2020 (in 81 % to 90 % of cases, compared with observations reported by winegrowers, consultants and historians).
The changes to frost risk in 2050 and 2100 simulated by these 6 methods were compared using climate data from 14 climate models (RCP8.5/CMIP5 scenario) spatially refined ("disaggregated") to a resolution of 8 km[5]. The 6 frost risk simulation methods provide different, even contradictory, results. An increase or decrease in the frequency of frost-sensitive years was simulated depending on the modeling approach used (Figure 2).

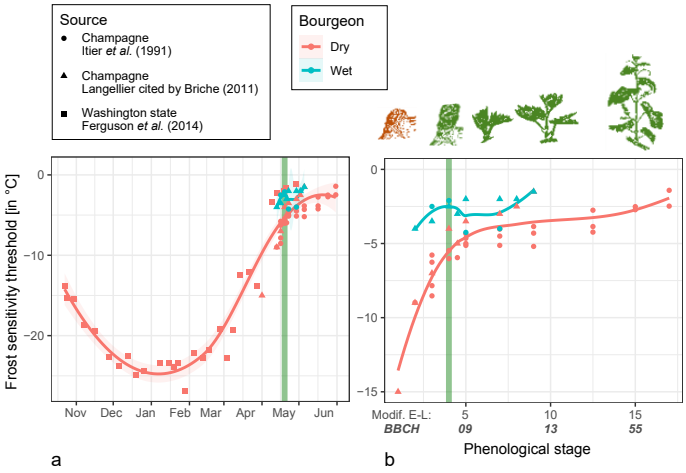


FIGURE 1. Change in the frost sensitivity of the Chardonnay grape variety during vine dormancy up to the end of spring (a) with a focus on the period from the dormant bud at the end of winter up to the "single flowers separated" stage (b). The phenological stages are shown according to the modified Eichhorn-Lorenz (Modif. E-L) and BBCH scales. Budburst (stage 4 on the Modif. E-L scale / 07 on the BBCH scale) is shown by the vertical green line. The curves have been fitted to match data from the literature for Champagne[7,8] on dry and wet buds and from Washington State, USA[2]. The observations in Champagne have been synchronized with those in the USA by aligning the reported budburst in both studies (graph (a)). As the other phenological stages were not specified for Washington State, the corresponding data is not shown in graph (b).

A cascade of uncertainties

Why should there be such deviations in frost risk projections? The binary approach is very sensitive to the budburst date predicted by the phenological models. However, the date prediction error is in the order of +/- 5 to 12 days depending on the model and the grape variety considered. The dynamic models (FergSec, FergHum), which aim to reproduce the changing level of bud frost sensitivity more

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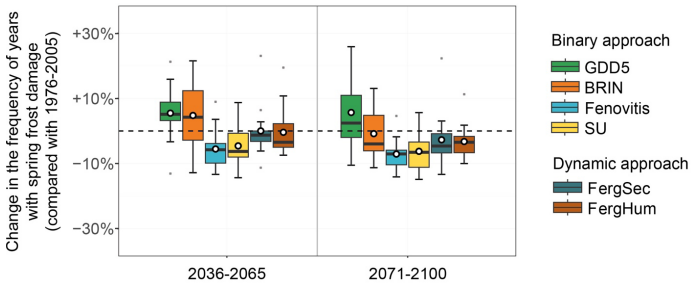


FIGURE 2. Distribution of the deviation (compared with the period 1976-2006) of the frequency of years with frost damage for the Chablis region (Burgundy, France) in 2050 and 2100. The box plots show the distribution of the calculated deviations for 14 climate models. The white dot in the center of each box shows the mean difference in the frequency of frost-sensitive years for the different climate models (RCP8.5/CMIP5 scenario) and the horizontal black bar shows the median. Each box corresponds to a comparison of the 6 frost-sensitivity models.

accurately, suffer from a lack of robustness due to the sampling of calibration buds from a single wine region. To improve their accuracy, large-scale campaigns of bud cold hardiness measurements should be conducted in other wine regions (using cooling chambers, for example, ideally taken into the vineyard[6]).

In addition to these limitations specific to biological models, there are also uncertainties related to the climate data: non-standard climate measurement sites (over- or under-estimation of frost intensity) or not representative of vineyard conditions, bias in climate models, uncertainties in future projections, etc.

Conclusion

Assessing the impact of future climate change is fundamental for the wine sector, particularly because of the long timeframes associated with grape and wine production (first harvest 3 or 4 years after planting, optimum yield after 10 to 15 years, etc.). But when it comes to simulating phenomena that are highly sensitive to small variations, such as frost risks, or risks involving complex systems (such as climate-plant-pathogen relationships to estimate the change in risk from disease or pests), a cascade of uncertainties leads to projections that are sometimes very unreliable. Studying the change in the risk of spring frost illustrates these limits and underlines the importance of improving vulnerability models for the vine, which still lack accuracy, through more field or laboratory observations.

Nevertheless, it would be foolhardy to ignore the results of such simulations simply because they are subject to high variance and uncertainty. Knowing the degree of uncertainty is an essential part of strategic thinking for risk management. ■

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