



# Reducing possibly synthetic fungicide input by using vigor thresholded NDVI as early risk indicator of *Botrytis* bunch rot in vineyards

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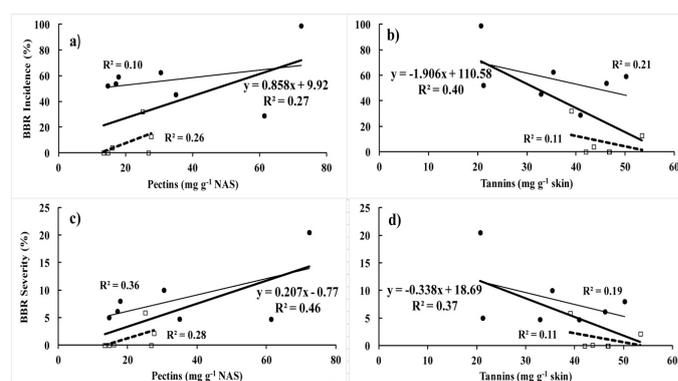
*Botrytis* bunch rot (BBR) is a major disease occurring in vineyards worldwide. Its control, still largely based on synthetic fungicide sprayings at pre-determined intervals, often leads to residues in grapes and wines that may negatively affect the environment and/or human health. To rationalise BBR management, early disease risk indicators were developed and evaluated in field experiments carried out between 2010 and 2019 in both France and Chile.

When developing decision-making tools for growers, early and predictive indicators of epidemic risk are key to optimising prophylactic, phytosanitary and/or biocontrol applications. In the vineyard, BBR caused by *Botrytis cinerea* is a very serious disease with a complex cycle that is extremely multi-factorial. Of the various influencing factors, this study allowed us to target two main indicators of great interest, which are early and predictive of epidemic risk. Their significance is also justified by our convergent and consistent results in two major wine-producing countries (France and Chile) corresponding to most contrasting pedo-climatic conditions worldwide. The study presents not only the choice of these early indicators, but also a practical way to measure them in the vineyard, with a very important focus on the precise stage at which to implement such precision-agriculture measurements<sup>1</sup>. Three early risk indicators were assessed: i) one related to the pectin and tannin composition of the berry skin, ii) another related to early vine vigor estimated by NDVI, and iii) A combination of the latter two along with meteorological data.

The experiments<sup>2</sup> were carried out in two vineyards using the Merlot cultivar. One was in the Nouvelle Aquitaine Region (France) at the 'Grande Ferrade' site (Villenave d'Ornon), and the other, which also included a trial with Sauvignon Blanc cultivar, was in the Maule Region of Chile (Panguilemo). Sauvignon Blanc, a cultivar highly susceptible to *B. cinerea*, was included in order to express BBR symptoms under the Chilean climatic conditions, which are not very favourable to BBR development<sup>2</sup>. The normalised difference vegetation index (NDVI) was measured using a hand-held GreenSeeker® RT-100 (Trimble Agriculture division, Sunnyvale, California, USA) as described in Drissi *et al.* (2009)<sup>1</sup>.

## Relationships between berry skin components and BBR intensity at harvest

Significant correlations between grapevine susceptibility to BBR and phenolic contents in berry skin had already been established, but only in the laboratory<sup>3,4,5</sup>. During this study<sup>2</sup>, positive relationships were observed between the pectin content in the berry skin and the BBR incidence and severity at harvest (Figure 1 a,c). Moreover, negative relationships were established between the tannin content and disease incidence and severity at harvest (Figure 1 b, d). All correlations including pooled data from France and Chile, were significant at  $p = 0.05$ , except for the relationship between the pectin and BBR incidence.

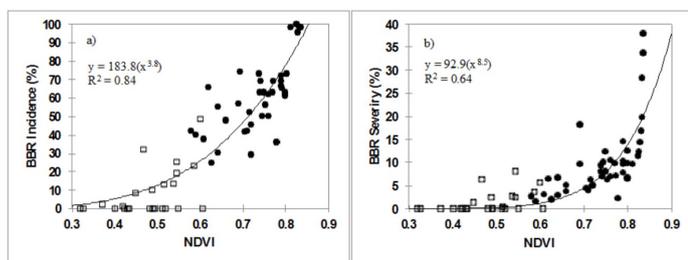


**FIGURE 1.** Relationships between BBR incidence (%) with the concentration in the young berry skin of (a) pectins and (b) tannins. Relationships between BBR severity (%) with the concentration in the young berry skin of (c) pectins and (d) tannins. In France (●) using cv. Merlot noir and in Chile (□) using cv. Merlot noir or Sauvignon Blanc. Each dot corresponds to a study season. The main black bold line in the middle indicates the relationship for all data (France and Chile).

## Relationships between vegetative growth and BBR intensity at harvest

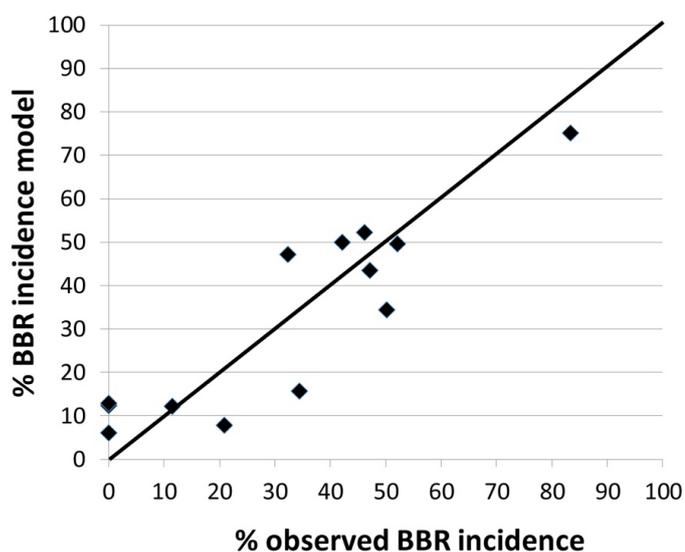
Grapevine vegetative vigor was assessed early in the season, when the berry was at around the pea size stage. Under our trial conditions, this corresponded to approximately 40 days before veraison. From a practical point of view, such an early indicator is a very important condition that allows growers to use low-cost NDVI measurements as a vineyard management strategy for BBR control. The NDVI also has the advantage of depending on precise and reproducible evaluation timing during each season. The best time point to measure it, based on the thermal phenological model facilitating the measurement scheduling, is 300 growing degree days (GDD) (Base temperature = 10 °C, accumulated from precise mid-flowering; that is, 50% caps off, code 23, according to Eichhorn-Lorenz Phenological Stages). The early NDVI measurements during the season allowed us to avoid the negative effects of NDVI saturation due to the vineyard canopy closure. The NDVI saturated threshold ranges between 0.8 and 0.86 according to different studies<sup>6,7</sup>. In this study<sup>2</sup>, the data showed NDVI values no higher than 0.85.

For the first time, we established exponential relationships between NDVI values measured at 300 GDD after mid-flowering and BBR incidence and severity at harvest (Figure 2). The relationship between BBR (incidence and severity) and vegetative growth (NDVI) was plotted



**FIGURE 2.** Relationships in France (●) and Chile (□) between (a) BBR incidence (%) with early NDVI evaluation and (b) BBR severity (%) with early NDVI evaluation.

and modelled using a nonlinear model with the equation  $BBR\ inc/ sev = a \cdot (NDVI)^b$ , which was the best model according to the  $R^2$  value. The relationships between these variables were positive, showing that vines with higher vegetative growth in an early phenological stage were more likely to be infected by *B. cinerea* during the season. The pattern was similar for both disease variables, but with a steeper curve between NDVI and disease severity (Figure 2b). A trend was noticeable, showing a change in BBR incidence and severity when NDVI values reached approximately 0.5 and 0.6 respectively.



**FIGURE 3.** Relationship between observed and modelled BBR incidences (Table 4, first incidence model in Pañitru-De la Fuente *et al.*, 2020)<sup>2</sup>. The  $Y = X$  equation is also indicated.

### BBR at harvest related to explanatory variables: vegetative growth and climate

First, the best model explaining BBR incidence included the variables: i) pluviometry cumulated 35 days before harvest (PL35) as the predominant explanatory variable, and ii) NDVI early in the season. Figure 3 shows the good relationship (close to  $Y = X$ ) between the observed BBR incidence and the modelled BBR incidence from the long-term experiments in both France and Chile (2010–2017). Second, for estimating BBR severity, the best regression model was also based on two variables: i) vegetative growth (NDVI), which was the predominant explanatory variable, and ii) pluviometry cumulated 15 days before harvest (PL15).

## Conclusions

The new management and risk indicators developed in this study were significantly related to BBR development at harvest. Thus, we propose that such new tools be used to develop specific decision support systems (DSS) to limit botrycide treatments in vineyards in the near future. The regression models included the cumulated rainfall a few weeks before harvest, corroborating the importance of the climatic factor in BBR development. Importantly from a practical point of view, the early grapevine vegetative growth (NDVI as measured in this study) has been demonstrated to be a major factor also governing *B. cinerea* infection. Regarding the tannin content in berry skin evaluated approximately at berry pea size stage, this BBR risk indicator can also be used in integrated pest management (IPM) strategies. Further investigations should consider the cluster compactness and pathogen inoculum throughout the season to better understand their relationships with BBR at harvest, as well as to optimise management and control methods in IPM strategies against the highly damaging fungal pathogen in grapevine; i.e., *Botrytis cinerea*<sup>8</sup>. ■

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