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Relationship between the El Niño-Southern Oscillation and yield and sugar content of wine grapes grown in Santana do Livramento, RS, Brazil

Relações entre El Niño-Oscilação Sul, e produtividade e acúmulo de açúcares em uvas cultivadas em Santana do Livramento, RS, Brasil

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Highlights

Simple calculations for detecting annual oscillations in yield and sugar content.
The El Niño-Southern Oscillation has a significant impact on yield and sugar content.
El Niño events tend to lower yield and sugar content.
La Niña events tend to increase yield and sugar content.
Neutral events affect growing seasons more similarly to El Niño events.

Abstract

The El Niño-Southern Oscillation (ENSO) is a well-known source of interannual variability in the climate of Santana do Livramento, Campanha Gaúcha, Brazil. It affects the agronomic responses of several crops grown in the region. Analysis of a dataset comprising observations of grape yield and sugar content in 11 white and 17 red grape cultivars over the last 3 decades revealed some patterns. In the long term (several years or decades), yield and sugar content showed a negative relationship, that is, larger crop loads resulted in lower sugar content at harvest. However, a number of calculations and principal component analyses showed that annual yield and sugar content fluctuations in the short term can be better explained by considering as reference points only the results obtained for each crop one and two years before. Based on these simple calculations, there was a clear separation between El Niño and La Niña events. In the vineyards of this region, La Niña events typically tend to result in higher grape yields and sugar content at harvest, while the opposite is true for El Niño, which tend to produce lower grape yields and sugar content at harvest. The results of

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neutral events are typically closer to those of El Niño events.
Key words: Campanha Gaúcha. La Niña. *Vitis vinifera.* ENSO.

Resumo

O El Niño-Oscilação Sul (ENSO) é uma fonte conhecida de variabilidade interanual no clima de Santana do Livramento, Campanha Gaúcha, Brasil, que afeta as respostas agronômicas de diversas culturas agrícolas cultivadas na região. A análise de um conjunto de dados que compreende observações de produtividade e teores de açúcar em uvas de videiras de 11 cultivares brancas e 17 cultivares tintas ao longo de quase 3 décadas revelou alguns padrões. No longo prazo (vários anos ou décadas), a produtividade e o teor de açúcar mostraram correlação negativa - maiores cargas de fruto resultaram em menores teores de açúcar na colheita. No entanto, alguns cálculos e análises de componentes principais permitiram definir que as oscilações da produtividade anual e do teor anual de açúcar no curto prazo podem ser melhor explicadas se for considerando apenas os resultados de um e dois anos anteriores de cada safra como pontos de referência. Seguindo esses cálculos, pôde-se notar uma clara separação entre eventos de El Niño e eventos de La Niña. Nos vinhedos desta região, os eventos de La Niña tipicamente tendem a resultar tanto em maior produtividade quanto em maior teor de açúcar na colheita. Em contraste, eventos de El Niño tipicamente tendem a causar menor produtividade e menor teor de açúcar na colheita. Anos neutros tipicamente apresentam resultados mais próximos aos eventos de El Niño.
Palavras-chave: Campanha Gaúcha. La Niña. *Vitis vinifera.* ENOS.

Introduction

The El Niño-Southern Oscillation (ENSO) is correlated with crop production anomalies in South America (Anderson et al., 2017). In Rio Grande do Sul, the southernmost state of Brazil, El Niño events cause higher rainfall throughout the year (Matzenauer et al., 2018).

The overcast conditions and rainy weather during spring and early summer tend to limit the availability of photoassimilates and increase the incidence of fungal diseases. Both are negative factors for flowering and fruit set and tend to compromise yields (Vasconcelos et al., 2009). During ripening, these weather conditions also have a negative effect on grape sugar accumulation (Keller, 2020).

Crop load influences ripening. Lower vine yields tend to accelerate maturation (sugar accumulation rate) and consequently increase grape sugar content at harvest (Nuzzo & Matthews, 2006; Parker et al., 2015; Previtali et al., 2021). In addition to crop load, seasonal effects also have a considerable impact on yields and sugar accumulation (Keller, 2020).

Campanha Gaúcha is the second largest grape producing region in Brazil, account for 31% of Brazilian wine (produced from *Vitis vinifera* grape varieties) (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2020).

The aim of this study was to understand the correlations between grape yield and sugar contents and the influence of ENSO events on these variables over the last three decades in a vineyard in Santana do Livramento, Campanha Gaúcha, Brazil

Material and Methods

Data on grape yield and sugar content in Santana do Livramento were obtained for the 28 growing seasons between 1992-1993 and 2020-2021 (coded with 'y' followed by 1 or 2 numerals specifying the vintage, e.g. '99' for 1998-1999, '0' for 1999-2000, and '1' for 2000-2001, or simply the numerals). The dataset was recorded and maintained by the Almadén company as part of their internal control protocols and comprised 11 white (Chardonnay, Chenin blanc, Flora, French colombard, Gewurztraminer, Riesling [Johannisberg], Moscato, Riesling italico, Sauvignon blanc, Semillon, Saint-Émilion) and 17 red grape cultivars (Alicante, Ancelota, Arinarnoa, Cabernet Franc, Cabernet Sauvignon, Ekigaina, Gamay, Marselan, Merlot, Black Muscat, Napa Gamay, Pinot Saint George, Petit Syrah, Pinot noir, Pinotage, Tannat), all *Vitis vinifera,* growing on a total area of 374 to 575 ha, with yields calculated in metric tons per hectare for each cultivar.

Temperature oscillation data in the Niño 3.4 region and the definition of ENSO (El Niño-Southern Oscillation) events (El Niño, La Niña and Neutral periods) were obtained from the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration [NOAA], 2021).

Several types of graphs (dispersions, barplots, histograms, etc.) were applied to visualize the data, trends and correlations. When applicable, trend lines (using linear, exponential, and polynomial regression equations) were drawn and tested, based on the coefficient of determination (R^2). Some additional variables were calculated based on the yield and sugar content, as shown in Equations 1-4. These yield and sugar content calculations were applied in order to partially isolate the effects of annual fluctuations (largely due to diverse weather conditions) from their long-term counterparts (resulting from technological trends). It is important to note that the calculation of these variables means that the first or first two growing seasons of observations in the time series cannot be used for further analysis.

(Equation 1):

[1 year yield shift, 'yield1'] = [yield] - [Previous year's yield]

(Equation 2):

[2-year yield shift, 'yield2'] = [yield] - [Average of the two previous years' yields]

(Equation 3):

[1 year sugar content shift, 'sugar1'] = [sugar content] - [Previous year's sugar content]

(Equation 4):

[2-year sugar content shift, 'sugar2'] = [sugar content] - [Average of the two previous years' sugar contents]

Principal component analysis (PCA) was applied to the dataset or parts of it. Different arrangements of active or supplementary quantitative variables were used, including yield (t ha^{-1}), sugar content (Babo) and the other variables shown in Equations 1-4. The quantitative variables were always standardized to variance unit value. The supplementary qualitative variables were ENSO (El Niño, La Niña, or Neutral). The analyses were run using R software (R Core Team [R], 2020), the RStudio interface (R Studio Team [R], 2020), and the FactoMiner (Lê et al., 2008) and FactoShiny packages (Vaissie et al., 2020). A Wilks test was conducted to determine which variables are better correlated with the PCA dimensions and better explain the distance between the individuals. Confidence ellipses were drawn around the barycenters of the individuals belonging to the three ENSO categories (El Niño, La Niña and Neutral), by applying a v-test at a 95% confidence level.

Results and Discussion

Red and white grape cultivars exhibited, respectively, mean yields of 9.38 and 11.93 t ha^{-1}; median yields of 9.33 and 12.57 t ha^{-1}; mean sugar content of 17.49 and 16.13 Babo; and median sugar content of 17.68 and 16.21 Babo. These results characterize red and white grape cultivars as diverging data populations, which were therefore analyzed separately.

The trend lines fitted to the yield and sugar content data of the 28 growing seasons (Figures 1 and 2) follow the same pattern in red and white grape cultivars. The entire time series of 28 growing seasons demonstrated that yield and sugar content tend to be inversely proportional. This is expected since each plant has a limited photosynthetic capacity and as yields increase, the photoassimilates have to be further partitioned between the fruits, which tend to accumulate sugars more slowly (Parker et al., 2015; Previtali et al., 2021). Nevertheless, pairwise comparison demonstrated that annual yield and sugar content (separately for red and white grape cultivars) vary above and below their trend lines without always exhibiting the same inverse relationship. These observations indicate that, in addition to the long-term trend of an inverse relationship between yield and sugar content, other factors are causing specific annual variations in the two variables.

When average annual yields and sugar contents in red and white grape varieties are plotted against each other, only minor trends (according to ENSO) are observed (Figure 3). The same is true for PCAs run with the same datasets (Figure 4). In the second dimension, each PCA captured the inverse relationship between the two variables, which was observed across the time series in Figures 1 and 2. Nevertheless, in the first dimension, each PCA displays a positive correlation between these two variables.

The PCAs (Figure 5) constructed using yield, sugar content and the other variables calculated in Equations 1-4 explained more than 80% of the variance in both cases (only 20% of the information cannot be seen in the first two dimensions). These PCAs provided further insights on the correlations between yield and sugar content in these datasets, as well as the influence of ENSO. In regard to the scoreplots (Figures 5a and c), the growing seasons are divided according to their ENSO group (El Niño and La Niña).

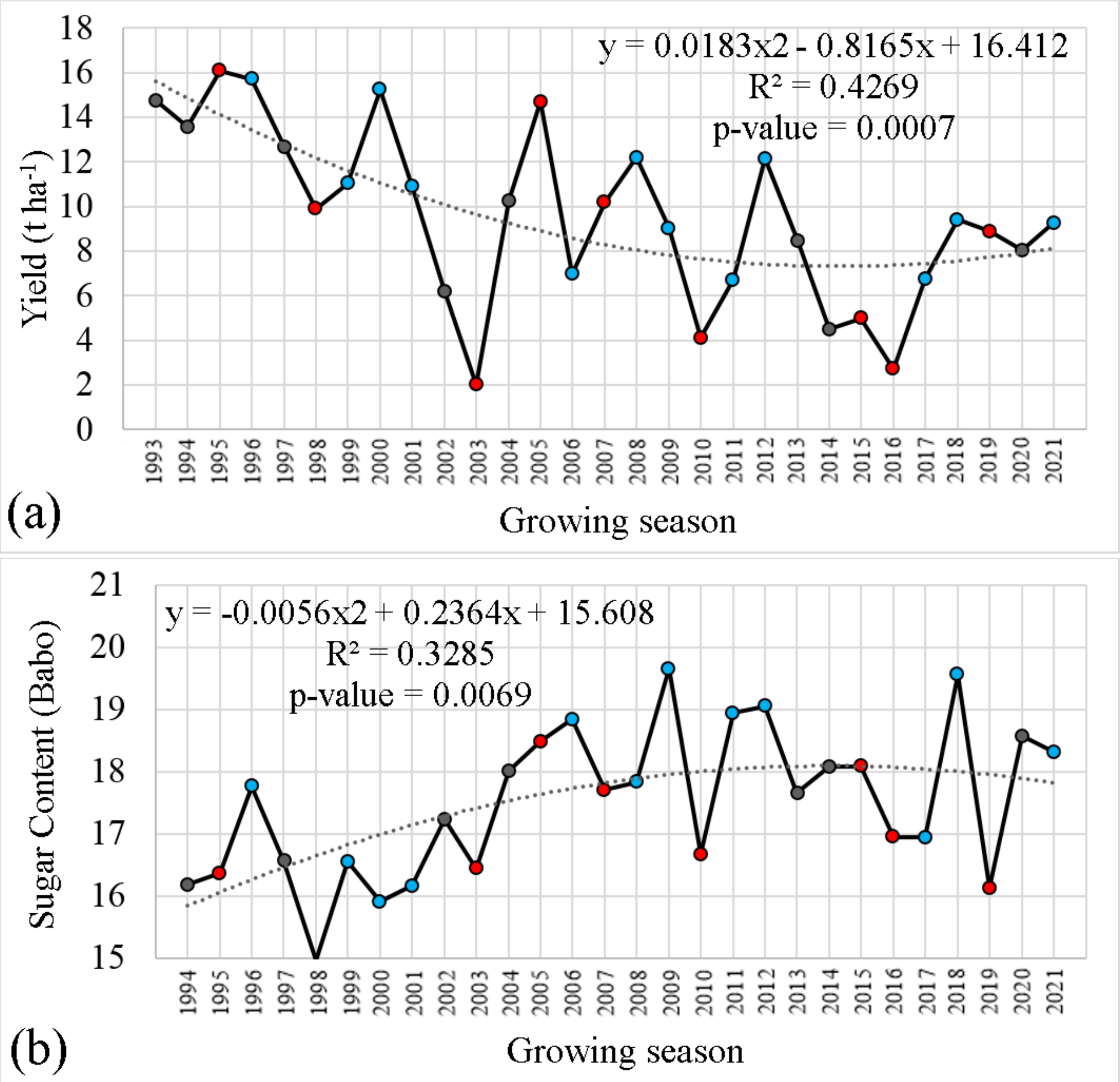

Figure 1. Average annual yield (a) and sugar content (b) of red grape varieties. Red dots - El Niño; blue dots - La Niña; and black dots - neutral.

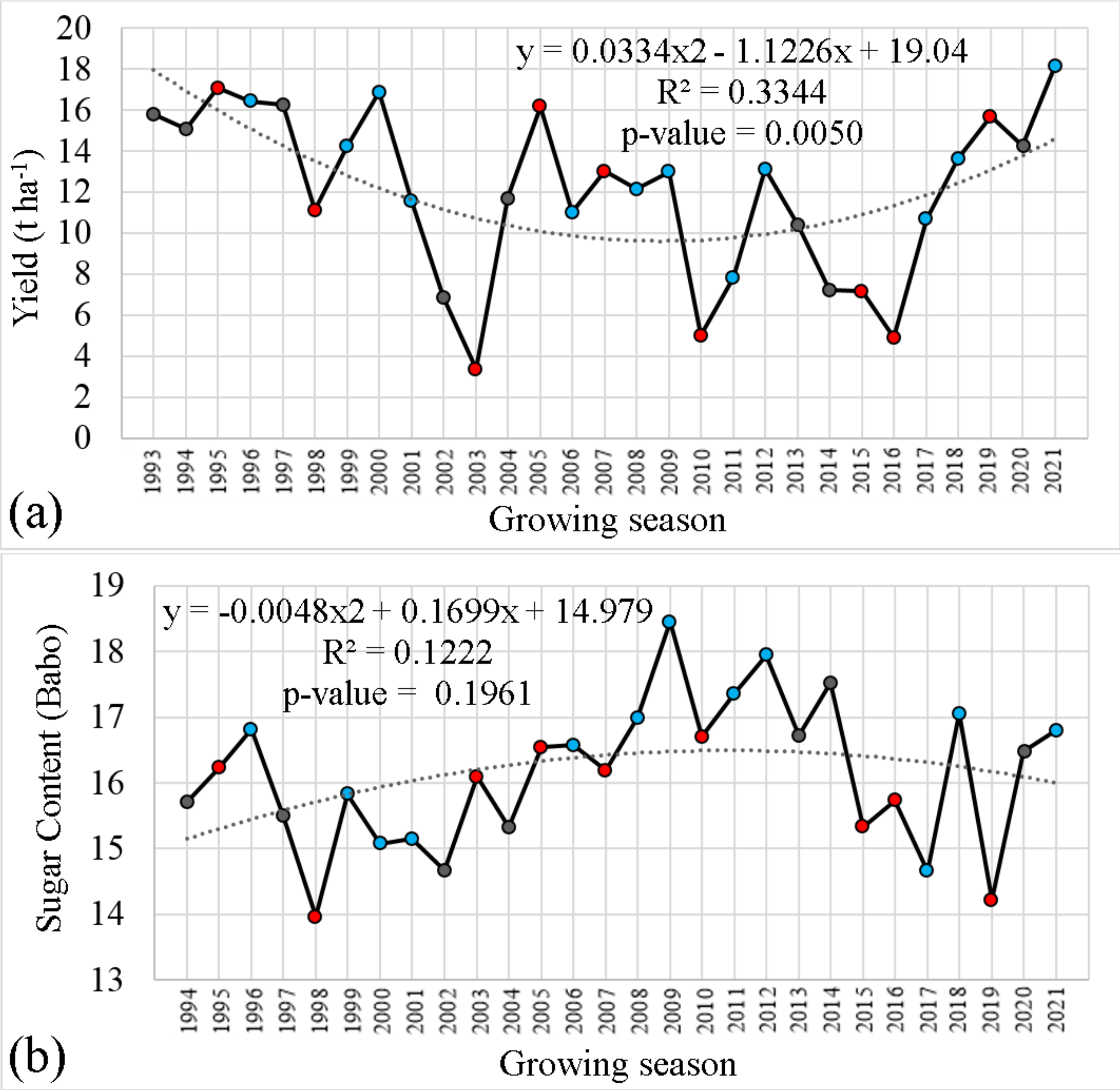

Figure 2. Average annual yield (a) and sugar content (b) of white grape varieties. Red dots - El Niño; blue dots - La Niña; and black dots - neutral.

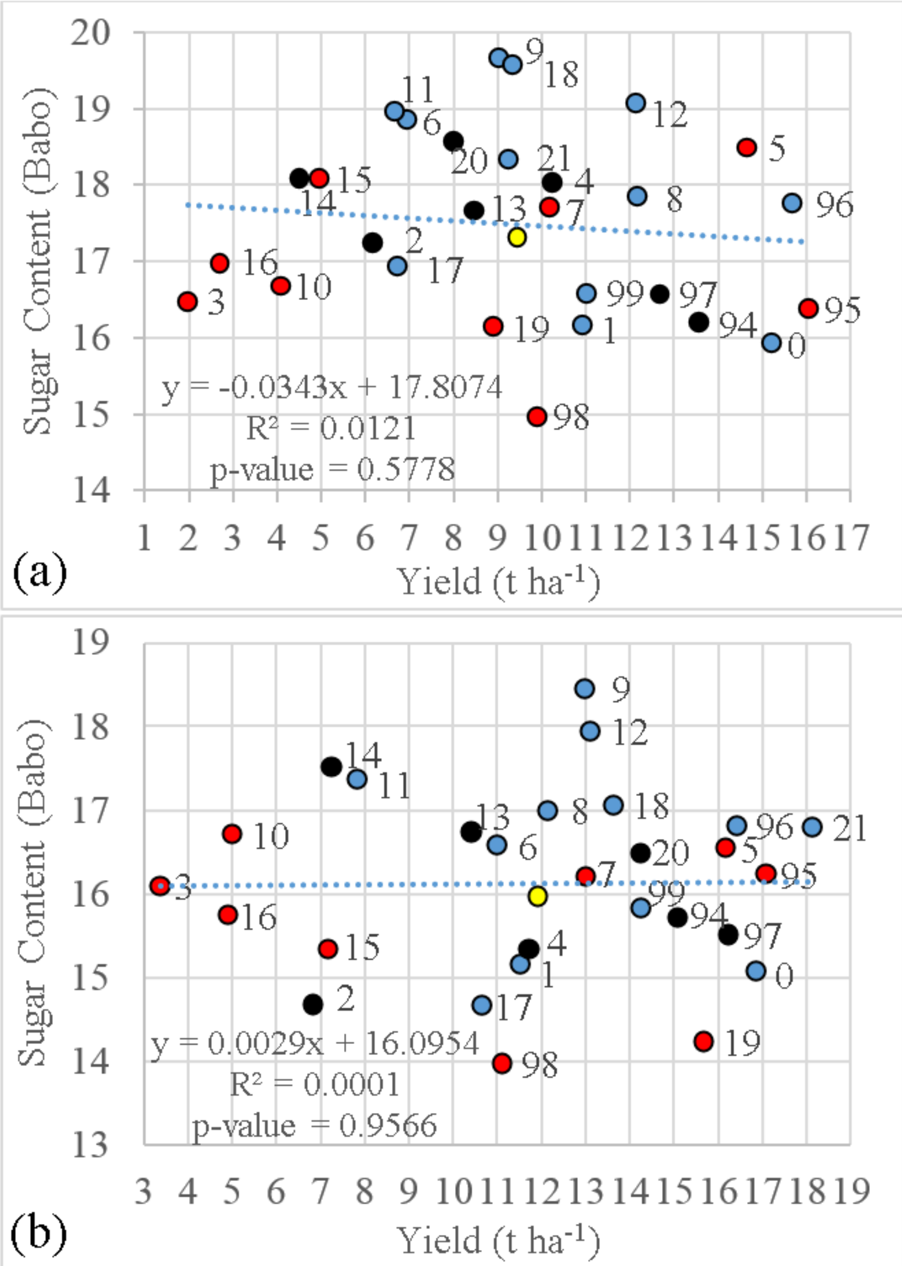

Figure 3. Dispersion of average annual yield x average annual sugar content in red (a) and white (b) grape varieties. Red dots - El Niño; blue dots - La Niña; black dots - neutral; and yellow dot - centroid.

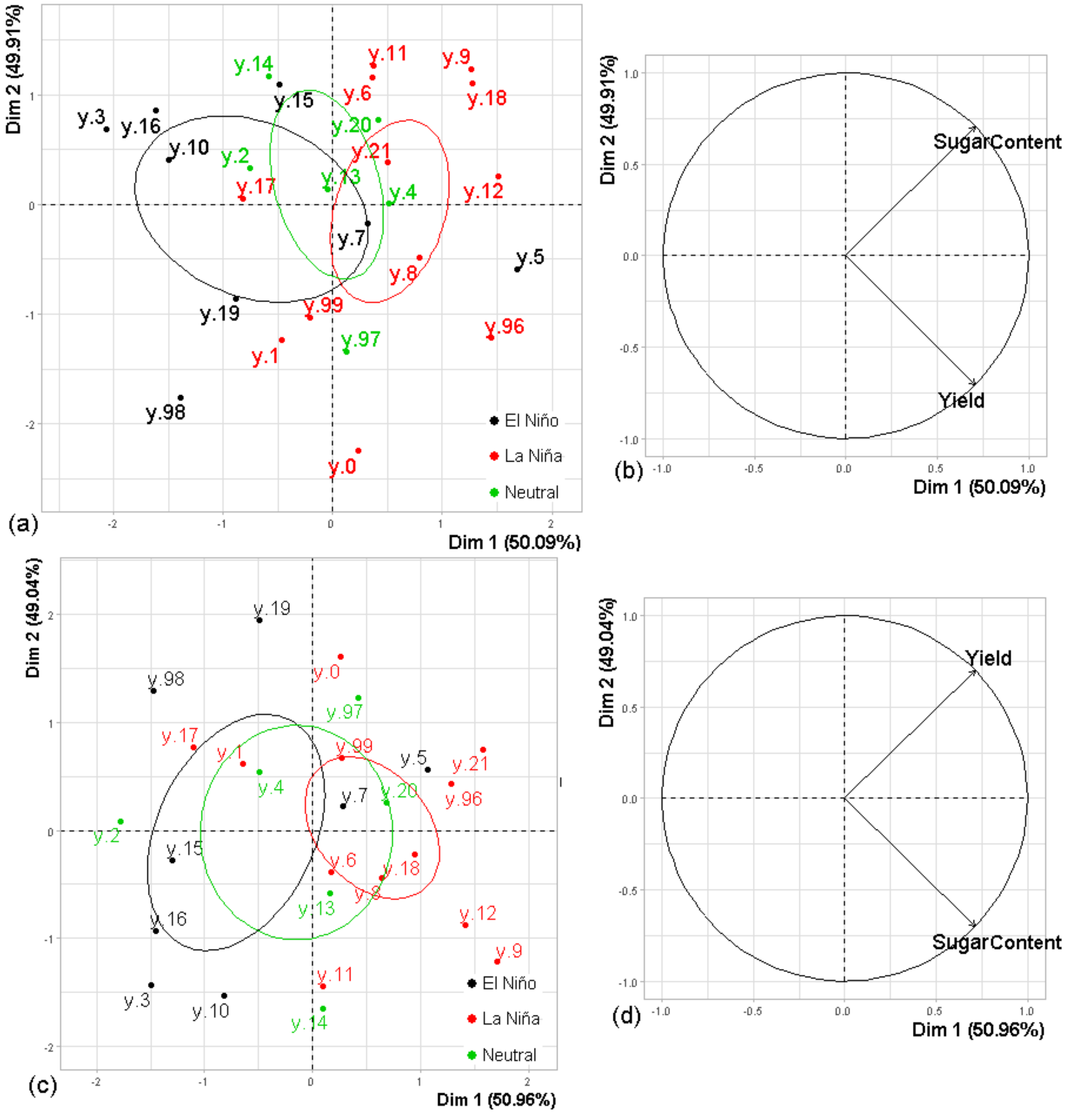

Figure 4. PCAs run solely with average annual yield and average annual sugar content of red and white grape varieties. Score plot (a) and loading plot (b) for red grape varieties, and score plot (c) and loading plot (d) for white grape varieties.

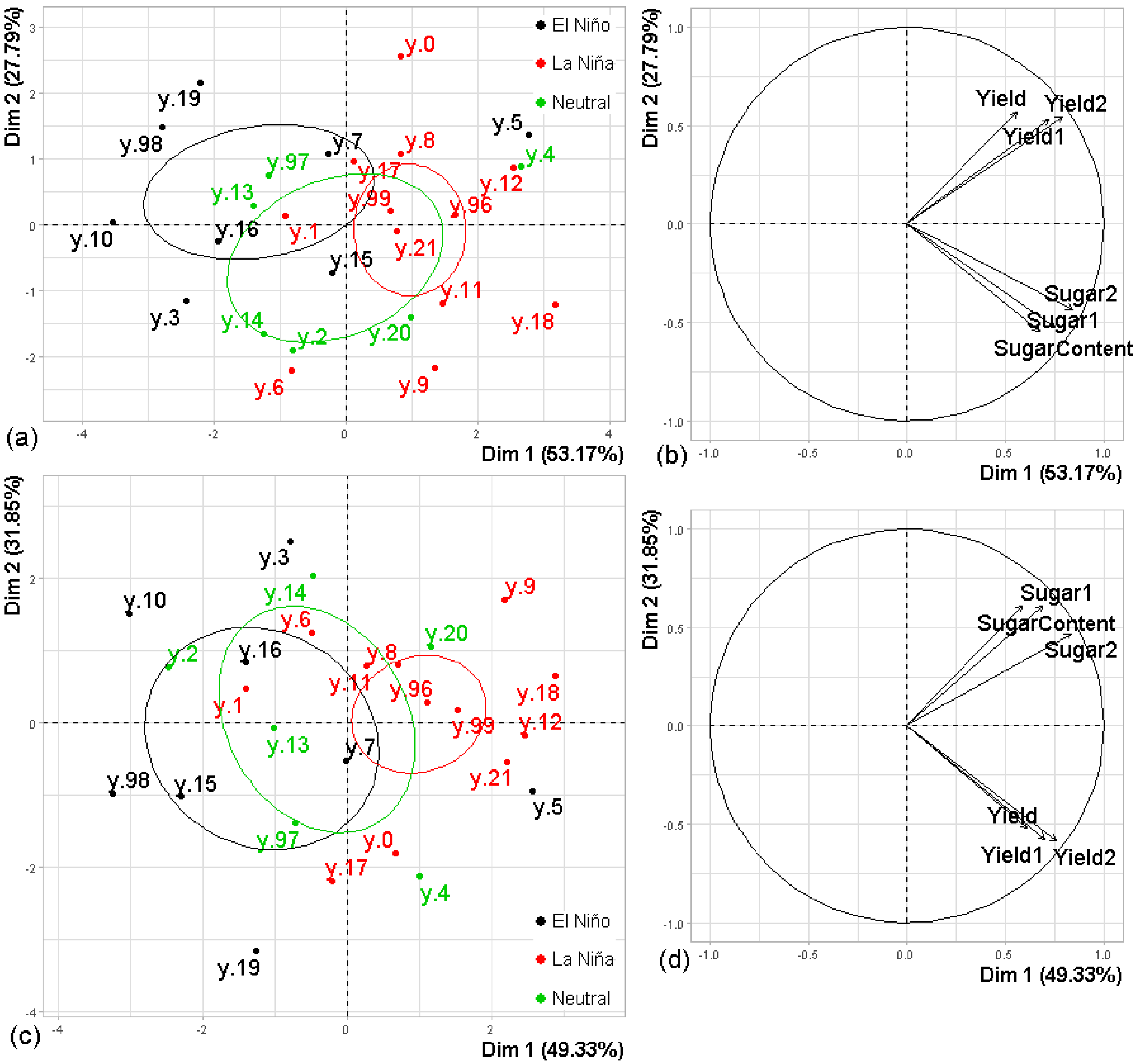

Figure 5. PCAs run with yield, sugar content and the other variables shown in Equations 1-4. Score plot (a) and loading plot (b) for red grape varieties, and score plot (c) and loading plot (d) for white grape varieties.

In the loading plots (Figures 5a and c), the yield and sugar content projections in the first dimension of each PCA are the lowest. By contrast, multivariate analysis showed that the 4 other variables that express short term fluctuations are better than yield and sugar content at characterizing the dataset, since they are better projected in the first dimension. Thus, these 4 variables were successful in generating a more accurate estimate of annual fluctuations caused by current growing season weather.

The variables with the best projection in the first dimension (Figures 5b and d) were sugar2, followed by sugar1 (in those involving sugar content) and yield2, followed by yield1 (in those involving yield). The variables yield2 and yield1, and sugar2 and sugar1 were all well projected in the first dimension, showing a direct relationship between them, while yield and sugar content were less projected than the other variables in the first dimension and better projected in the second dimension, showing an inverse relationship.

PCAs (Figure 6) run with the variables yield2 and sugar2, which showed the best projections (the highest correlations and smallest p-values) in the first dimension in Figure 5, further confirm these patterns and can be compared with the PCAs in Figure 4, run solely with yield and sugar content. In this data set, analysis of the projections of the variables in the first two dimensions of each PCA clearly demonstrate a considerable inverse relationship between yield and sugar content across the entire time series (inversely proportional in the second dimensions, which comprise approximately 50% of the variability in the datasets). By contrast, the new variables calculated considering the average of the previous years - accounting for the short-term status of the vineyard and annual fluctuations - are mostly positively correlated (directly proportional in the first dimension of each PCA, accounting for most of the variability in the datasets, Figure 6). Moreover, only these new variables were able to separate the years according to ENSO.

Finally, simple dispersions (Figure 7) of yield2 against sugar2 isolated the effects of ENSO far more accurately than in Figure 3 (yield and sugar content dispersions). When considering short-term/annual fluctuations, the general trends are clear. Most El Niño events are characterized by lower yields and sugar contents. Most neutral events are closer to El Niño events, but form almost an interface between El Niño and La Niña events. La Niña events display predominantly above average sugar contents and close to or above average yields. Thus, seasonal effects are strong and highly impacting. Another study on crop load management over a five-year period showed that variations in vine growth, yield and fruit composition were more influenced by the intrinsic conditions of each growing season than the pruning strategies themselves (Keller et al., 2004).

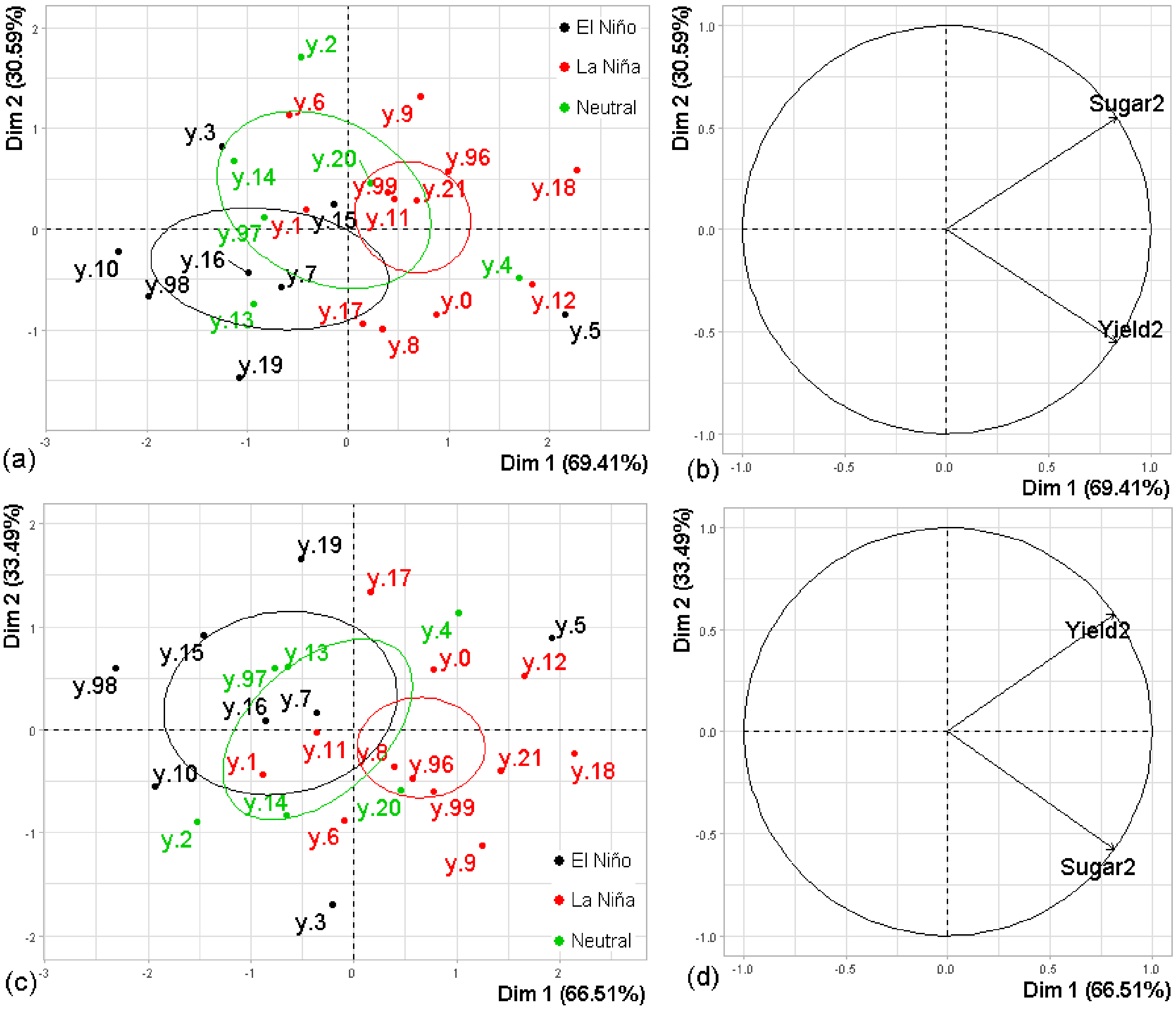

Figure 6. PCAs run with the variables yield2 and sugar2. Score plot (a) and loading plot (b) for red grape varieties, and score plot (c) and loading plot (d) for white grape varieties.

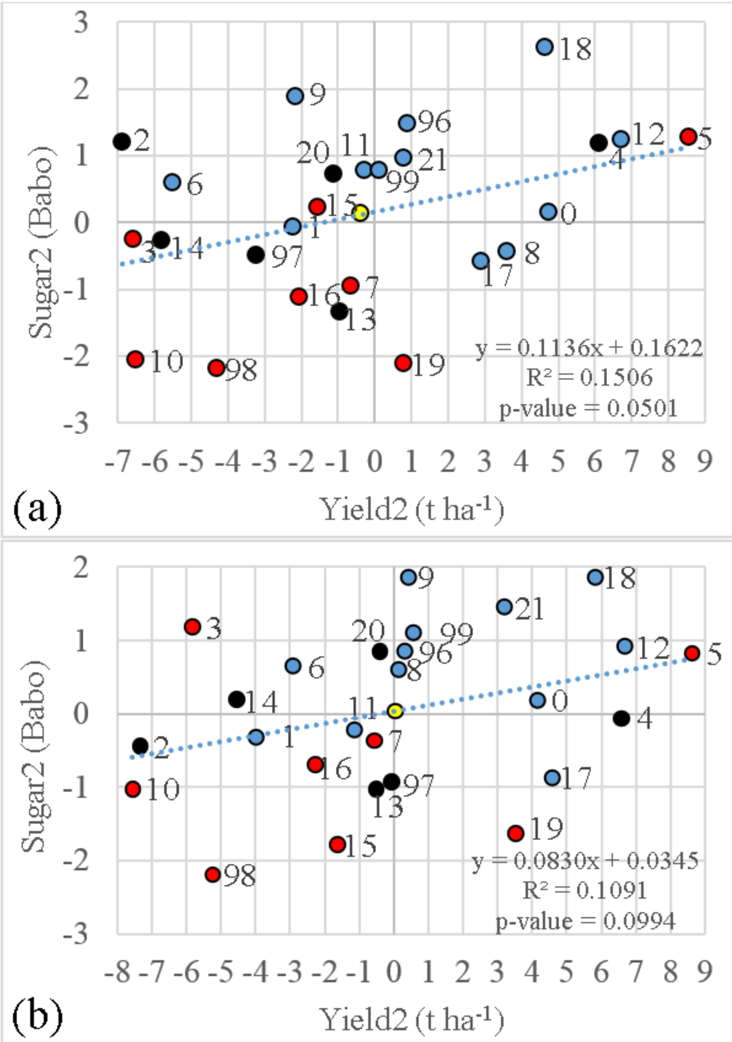

Figure 7. Dispersions of yield2 x sugar2 for red (a) and white (b) grape varieties. Red dots - El Niño; blue dots - La Niña; black dots - neutral; and yellow dot - centroid.

Conclusion

Across the entire time series, there was a negative correlation between sugar content and yield. Thus, hypothetically, if the growing seasons had identical weather conditions, yield and sugar content would tend to exhibit an inverse relationship. The definition of simple calculations involving the results of the two previous years of each growing season demonstrated the short-term patterns of yields and sugar contents and their correlation with ENSO. Since weather conditions in this region vary markedly from year to year (primarily due to ENSO), growing seasons with more favorable weather conditions (typically La Niña) tend to obtain both higher grape yield and sugar content at harvest, while those with less favorable conditions (typically El Niño) tend to have lower yield and sugar content at harvest. Neutral events typically exhibit results closer to those of El Niño events.

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