

Innovative approaches in the evaluation of the spatial and temporal variability of grape varieties from the Portuguese Bairrada Appellation using innovative statistical tools: a study across five harvests

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Sustainable viticulture and winemaking continue to represent huge challenges, requiring deeper knowledge about the functional role of biodiversity in the vineyard ecosystems and the grape varieties' plasticity. Taking advantages of chemometric tools, this research aims to advances the analysis of interactions between climatic conditions, vineyard ecosystem and composition of grape varieties cultivated in Bairrada Appellation (Portugal).

Grapes from five varieties (Arinto, Cercial, Bical, Maria Gomes, and Baga *Vitis vinifera* L.) sampled during 5 years were selected as case study. A combination of linear mixed models with Principal Component Analysis (LiMM-PCA) was applied to analyze effects of three factors, harvest, grape variety and vineyard on the physical-chemical parameters and both free and glycosidically bound potential aroma compounds of the grapes. LiMM-PCA allowed to analyze data set with underlying design, which included both fixed (harvest and variety) and random (vineyard) factors. The selected vineyards were representative of the Bairrada Appellation and treating the vineyard as a random factor permitted to draw conclusions about Bairrada region. All three factors and their interactions were found to be statistically significant. Moreover, this approach enabled to assess varietal adaptability to varying climatic conditions, revealing Arinto as the most resilient variety, while Bical and Baga were the most susceptible. Joint information in chemical parameters, aroma compounds and meteorological data was assessed using multi-block method – Common Dimensions (ComDim). This analysis identified the meteorological factors with the greatest impact on grape composition, emphasizing the critical role of maximum temperature and precipitation in August, as well as the number of cold hours per month throughout the year (Figure 1).

The proposed methodological framework offers a valuable tool for supporting vineyard and wine production management, amid current climate challenges.

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FIGURE 1

ComDim model for Arinto white grape variety showing common information in four datasets: sample scores (A); variable loadings (B) related to meteorological data (Meteo), technological ripening parameters (FQ), free volatile fraction (VOCs) and glycosylated (Glyc-linked) of the grapes under study; saliences (C), i.e. contribution of each dataset to the common components, and number of cold hours per day (D), where * indicates statistically significant differences were observed ($p < 0.05$) and ** indicates statistically significant differences ($p < 0.001$).

