REVISTA BRASILEIRA DE FRUTICULTURA
Published by the Brazilian Society of Fruit Crops
ISSN 0100-2945

Genetics And Plant Breeding - Original Article - Edited by: Willian Krause

Phenology and viticultural performance of different fungus-resistant grapevine advanced selections at three different altitudes in southern Brazil

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Abstract: The objective of this work was to characterize the phenology and the viticultural performance of advanced selections of grapevines resistant to fungal diseases obtained by the Julius Kühn Institute, Institute for Grapevine Breeding Geilweilerhof. The experiment was conducted in three different grape-growing regions of Santa Catarina State, Brazil, in the municipalities of Videira (840 m), São Joaquim (1110 m) and Curitibanos (1000 m) during the seasons of 2018/2019 and 2019/2020. The advanced selections evaluated were the reds Gf.2004-043-0010 (Gf.10), Gf.2004-043-0013 (Gf.13), Gf.2004-043-0021(Gf.21) and the white Gf.2004-043-0004 (Gf.04). We found that pyramided loci *Rpv1+Rpv3.1* and *Run1+Ren3* were present, which confer resistance to downy mildew and powdery mildew, respectively. The phenological stages events evaluated were budbreak, full bloom, *veraison* and maturity. The productive variables evaluated were fertility index, number of clusters, cluster weight and yield. Technological maturity parameters were soluble solids, total acidity and pH. To understand the relationship between the variables and whether these relationships changed depending on the cultivation environment the Multi-Trait Genotype–Ideotype Distance Index was used to rank the genotypes based on the analyzed traits. For most selections, the budbreak occurred in the second half of September; full bloom occurred from late October to mid-November; the *veraison* occurred between the end of December and mid-January; and maturity occurred between the end of January and February. The earliest budbreak occurred in the vineyard located at the highest altitude (1110 m - São Joaquim), while the earliest full bloom, *veraison* and maturity occurred in the lowest altitude vineyard (840 m – Videira). All selections produced grapes with adequate concentrations of pH and total acidity to produce quality wines. Except for Gf.13, all selections produced grapes with levels of soluble solids suitable to produce quality wines. Based on the Multi-Trait Genotype–Ideotype Distance Index (MGIDI) the selections Gf.13 and Gf.10 are the most promising genotypes for the Videira region (840 m) and Gf.10 is the most promising genotype for the regions of higher altitude, 1000 m and 1110 m.

Index Terms: *Vitis vinifera*, climatic conditions, viticultural performance.

Rev. Bras. Frutic., v.45, e-988 DOI: https://dx.doi.org/10.1590/0100-29452023988
Received 25 Aug, 2022 • Accepted 15 Mar, 2023 • Published Jul/Aug, 2023. Jaboticabal - SP - Brazil.

Desempenho vitícola de diferentes seleções avançadas de videiras resistentes a doenças fúngicas em três diferentes altitudes no Sul do Brasil

Resumo: O objetivo deste trabalho foi caracterizar a fenologia e o desempenho vitícola de diferentes seleções avançadas de videiras resistentes a doenças fúngicas obtidas pelo Instituto Julius Kühn, Institute for Grapevine Breeding Geilweilerhof. O experimento foi conduzido em três diferentes regiões vitivinícolas do Estado de Santa Catarina, Brasil, nos municípios de Videira (840 m), São Joaquim (1.110 m) e Curitibanos (1.000 m) durante as safras de 2018/2019 e 2019/ 2020. As seleções avançadas avaliadas foram as tintas Gf.2004-043-0010 (Gf.10), Gf.2004-043-0013 (Gf.13), Gf.2004-043-0021(Gf.21) e a branca Gf. 2004-043-0004 (Gf.04). Elas apresentam os alelos de resistência piramidados *Rpv1*+*Rpv3.1* e *Run1*+Ren3, que conferem resistência ao míldio e ao oídio. Os estádios fenológicos avaliados foram brotação, plena floração, mudança de cor das bagas e maturação. Os componentes de produtividade avaliados foram índice de fertilidade, número de cachos, peso de cachos e produtividade. Os parâmetros de maturação tecnológica foram sólidos solúveis, acidez total e pH. Para entender a relação entre as variáveis e como o ambiente de cultivo se relacionava com elas, foi utilizado o Índice Multi-Trait Genotype–Ideotype Distance para classificar os genótipos com base nas características analisadas. Para a maioria das seleções, a brotação ocorreu na segunda quinzena de setembro; a plena floração ocorreu do final de outubro a meados de novembro; a mudança de cor das bagas ocorreu entre o final de dezembro e meados de janeiro; e a maturidade e a colheita ocorreram entre o final de janeiro e fevereiro. A brotação das plantas ocorreu mais precocemente no vinhedo localizado na maior altitude (1.110 m - São Joaquim), enquanto a plena floração, a mudança de cor das bagas e a maturidade mais precoce ocorreram no vinhedo de menor altitude (840 m - Videira). Todas as seleções produziram uvas com concentrações adequadas de pH e de acidez total para a produção de vinhos de qualidade. Com exceção do Gf.13, todas as seleções produziram uvas com teores de sólidos solúveis adequados à produção de vinhos de qualidade. Com base no Multi-Trait Genotype–Ideotype Distance Index (MGIDI), as seleções Gf.13 e Gf.10 são os genótipos mais promissores para a região de Videira (840 m), e Gf.10 é o genótipo mais promissor para as regiões de maior altitude, 1.000 m e 1.110 m.

Termos para Indexação: *Vitis vinifera*, condições climáticas, desempenho vitícola

Introduction

From the 2000s onwards, viticulture in Santa Catarina State began to grow, based on altitude vineyards installed in regions above 800 m of altitude (VIANNA et al., 2016). Studies report that the altitude regions of Santa Catarina have their own and distinct characteristics from other Brazilian wine producing regions (BRIGHENTI et al., 2014; WÜRZ et al., 2020; MARCON FILHO et al., 2021).

However, in southern Brazil, the combination of susceptible cultivars (*Vitis vinifera*) and favorable environmental conditions (relative humidity above 90%, mild temperatures and leaf wetness for more than two hours) make downy mildew (*Plasmopara viticola*) to be one of the most important diseases. The oomycete**s** infect all the green parts of the vine, leaves and clusters, and throughout the development of the vine, there are numerous cycles of infection, which are responsible for the reduction of production, both quantitatively and qualitatively (DE BEM et al., 2015).

Controlling downy mildew often requires excessive use of fungicides, especially in temperate and rainy regions, to prevent epidemics and obtain grapes of quality for wine. To have economically and environmentally sustainable viticulture, a decrease on the the amount of fungicide used is required. The best alternative is the use of new varieties with resistanceto downy mildew and powdery mildew (DE BEM et al., 2020).Thus, the present study reports the response of new grapevine varieties carrying distinct resistance genes to powdery and downy mildew, which were grownin distinct environments in the south of Brazil.

The development of new varieties with disease resistance is obtained by cross- ing European varieties (*V. vinifera*) with American or Asian germplasm (*Vitis sp.*), that enclose resistant genes, followed by backcrossings with V. vinifera germoplasm to restore wine quality. These new varieties, which combine resistance and wine quality, are known as PIWI, an abbreviation term “Pilswiederstangfähige”, referring to grape varieties resistant to fungal diseases (VEZZULLI et al., 2017). Thus, reduction of fungicide dependency has the potential to contribute substantially to of viticulture sustainability.

Currently, Germany is one of the great centers of grapevine breeding in the world. Breeding programs in Germany commenced at the end of the nineteenth century, the period of dramatic changes regarding novel pests (phylloxera) and diseases (downy and powdery mildew) in Europe. Today, one of the most important breeding programs is conducted by the Institute for Grapevine Breeding of Geilweilerhof, which belongs to the Julius Kühn Institute (JKI), the federal research center for cultivated plants and is focused on wine grape breeding using marker-assisted selection (MAS) (RUEHL et al., 2015).

In Germany, in the second half of 20th century, Professor Gerhardt Alleweldt and his team did pioneer work developing the cultivars Phoenix (Bacchus × Villard blanc) and, in particular, Regent (Diana × Chambourcin). A major breakthrough for grapevine resistance breeding was achieved when these new cultivars became classified for quality wine production. Both cultivars were the first to be accepted by wine growers for their high quality and good resistance. Other cultivars followed in Germany, and today the potential and necessity of grapevine resistance breeding is beyond question (RUEHL et al., 2015).

Current new cultivars show an average reduction of plant protection requirement of approximately two-thirds. They are frequently carrying one major resistance locus. For the next-generation cultivars, pyramiding of some resistance loci should be the prerequisite. It will be a matter of choices if the combination of two or three resistance loci should be the goal. As long as the scientists do not understand the mechanisms of resistance of the loci to be pyramided, the best guess is to combine, for example, up to three loci from diverse origins to achieve durability as good as possible (RUEHL et al., 2015).

Genotypes grown in different environments can show different performances. The environment corresponds to all the factors that affect the development of plants that are not of genetic origin. The difference in the performance of genotypes in different environments is called genotype x environment interaction, which will result in a particular phenotype (EIBACH; TOPFER, 2015). In this sense, to determine the potential of new grapevine varieties in a region, it is important to carry out studies and research on climatic characteristics, phenology and adaptation of the varieties (PARKER et al., 2011).

Therefore, the objective of the present work was to characterize the phenology and the viticultural performance of advanced selections of grapevines resistant to fungal **diseases in** three different altitude ranges in southern Brazil.

Material and methods

The experiment was conducted in three different grape-growing regions of Santa Catarina State, Brazil, in the municipalities of Videira, São Joaquim and Curitibanos during the seasons of 2018/2019 and 2019/2020. The vineyard in Videira is located at Epagri Experimental Station (27°01'S, 51°08'W, altitude 840 m), the vineyard in São Joaquim is located at Suzin Winery (28°13'S, 50°4' W, altitude 1110 m) and the last vineyard in Curitibanos is located at Santa Catarina Federal University Experimental Vineyard (27°16' S, 50°30' W, altitude 1000 m).

The climate in those regions is Cfb - humid mesothermic, according to the Köppen-Geiger climate classification (PEEL et al., 2007). According to the Brazilian Soil Classification System, the soil in São Joaquim is an Inceptisol, characterized as having high levels of clay (485 g kg^{-1}) and organic matter (69 g kg^{-1}); in Curitibanos the soil type is cambisol haplic, which is characterized as having a high level of clay (550 g kg^{-1}); and in Videira the soils were classified as Nitossolo Bruno Distrophic clay texture, moderately plain to slightly undulated landscape, which corresponding to a Typic Hapludox (SANTOS et al., 2013).

Advanced selections obtained by the "Institute for Grapevine Breeding Geilweilerhof", which is part of the Julius Kuhn Institute in Germany, were evaluated in the three locations. These selections present the pyramided loci *Rpv1+Rpv3.1* and *Run1+Ren3*, which confer resistance to downy mildew and powdery mildew, respectively. The advanced selections evaluated were the red Gf.2004-043-0010 (Gf.10), Gf.2004-043-0013 (Gf.13), Gf.2004-043-0021(Gf.21) and the white Gf.2004-043-0004 (Gf.04).

In addition to resistance to downy mildew and powdery mildew, it was reported that the selections Gf. 2004-043-0010, Gf. 2004-043-0013 and Gf. 2004-043-0021, have moderate susceptibility to anthracnose, caused by the causal agent *Elsinoë ampelina*, whereas Gf. 2004-043-0004, has high susceptibility to the pathogen (DIAS et al., 2022).

All the plants were grafted on 'Paulsen 1103'. The vineyard was planted in September 2017 with plants spaced at 3.0×1.2 m. They were trained in vertical shooting position (VSP) trellis, with double spur pruning. We used a randomized block design with five replicates of ten plants of each selection, for a total of 200 plants

The phenological scale and date of occurrence of each phenological stage were recorded between pruning and maturity. The four main phenological events were budbreak, full bloom, *veraison* (change in berry skin color) and maturity (BAILLOD; BAGGIOLLINI, 1993). Dates of occurrence of the main phenological events were compared with other PIWI cultivars grown in the regions.

The productive components evaluated were fertility index, number of clusters, cluster weight (g), productivity per vine (kg) and estimated yield (t ha^{-1}). Technological maturity analyses were performed at the Laboratories of Epagri. Analyses of soluble solids (°Brix), total acidity (meq L^{-1}) and pH, were performed on grape must, according to the methodology proposed by the OIV (2009). Soluble solids (°Brix) were measured using an optical refractometer (model Instrutherm RTD-45) with temperature correction. The pH was measured with a pH meter (model MP 220 Metler-Toledo). Total acidity was measured by a titration method with a 10-mL aliquot of juice with standardized 0.1 M NaOH.

All analyzes were performed in the R software (R CORE TEAM, 2022) using the metan package (OLIVOTO; LÚCIO, 2020). For the analysis of the genotype x environment interaction, each combination of altitude and vintage was considered as a unique environment. Each variable was analyzed using the gamem_met function of the metan package (OLIVOTO; LÚCIO, 2020), using a linear random effect model. A graph showing the variance components was constructed. For the estimates of the genotype x environment interaction, an AMMI2 biplot (GAUCH, 2013) was built with the performs_ammi function of the metan package and shown for the variables yield, pH, soluble solids (SS) and total acidity (TA).

To understand the relationship between the variables and whether these relationships changed depending on the cultivation environment, a network-type graph was built for each cultivation site. In each environment, the Multi-Trait Genotype–Ideotype Distance Index (MGIDI index) (OLIVOTO; NARDINO, 2021) was used to rank the genotypes based on the analyzed characteristics. For this, the average of the BLUPs of the two years in each location was used. Positive desirable gains were used for all variables except TA. The selection gains were computed considering the selection of the genotype with the best ranking in the MGIDI index within each environment.

Results and discussion

The budbreak of most selections occurred in the second half of September, on average, the earliest budbreak occurred in the vineyard located at the highest altitude (1110 m - São Joaquim). Among the evaluated selections, it was found that Gf.13 presented the earliest budbreak. At higher altitude, a smaller variation in the average budbreak date was observed (1 to 7 days), while at the lower altitude the variation in budbreak date was greater, in some cases reaching more than 20 days (Table 1).

Table 1. Average dates of the main phenological stages of PIWI advanced selections in different altitude ranges of Santa Catarina State, Brazil.

Genotype	Altitude	Budbreak	Full Bloom	Veraison	Maturity
Gf.2004-043-0004	840 m	22-sep ± 11	31-oct ± 12	01-jan ± 24	26-jan ± 9
	1000 m	28-sep ± 16	30-nov ± 2	24-jan ± 21	23-feb ± 6
	1110 m	12-sep ± 1	19-nov ± 4	15-jan ± 4	15-feb ± 3
Gf.2004-043-0010	840 m	20-sep ± 11	26-oct ± 12	16-dec ± 17	22-jan ± 8
	1000 m	28-sep ± 14	05-dec ± 4	25-jan ± 19	23-feb ± 6
	1110 m	17-sep ± 4	14-nov ± 1	22-jan ± 16	25-feb ± 12
Gf.2004-043-0013	840 m	11-sep ± 21	26-oct ± 15	20-dec ± 19	24-jan ± 11
	1000 m	25-sep ± 7	28-nov ± 12	03-jan ± 9	15-feb ± 5
	1110 m	05-sep ± 4	13-nov ± 11	06-jan ± 10	20-feb ± 21
Gf.2004-043-0021	840 m	19-sep ± 15	24-oct ± 11	22-dec ± 16	25-jan ± 11
	1000 m	07-oct ± 23	26-nov ± 14	21-jan ± 1	15-feb ± 5
	1110 m	15-sep ± 7	14-nov ± 1	11-jan ± 1	09-feb ± 6

On average, full bloom occurred from late October to mid-November. The earliest full bloom occurred in the lower altitude vineyard. Despite the little difference between the genotypes, it was observed that Gf. 21 showed the earliest flowering (Table 1, Figure 1). In the 2020 vintage at São Joaquim (1110 m) there was a severe reduction in the number of clusters, particularly in Gf.21 selection, due a late frost that hit the experiment site in September 2019.

The *veraison* period occurred between the end of December and mid-January, once again the vineyard located in the lower altitude region exhibited the earliest color change and the smallest fluctuations in the color change dates were verified in the vineyard located at higher altitude (Table 1**,** Figure 1).

Maturity occurred between the end of January and February. The earliest harvest was carried out in the lower altitude region, and the smallest variation in the average harvest date was observed in the Gf.04 selection (Table 1, Figure 1).

In a previous study that evaluated the performance of PIWI varieties in Videira (840 m), it was observed that the average budbreak date of Calardis Blanc occurred on September 6, Bronner on September 11 and Felicia on August 29 (BRIGHENTI et al., 2019). In São Joaquim (1110 m) the average budbreak date of Calardis Blanc occurred on September 4, Aromera on September 12 and Felicia on August 30 (SOUZA et al., 2019). The budbreak date was similar to Merlot and Sangiovese (September 15) and similar to Sauvignon Blanc (September 22) (BRIGHENTI et al., 2013; BRIGHENTI et al., 2014). The late budbreak is favorable to prevent damage by late frosts that are common in higher altitude regions (MASSIGNAM and DITTRICH, 1998).

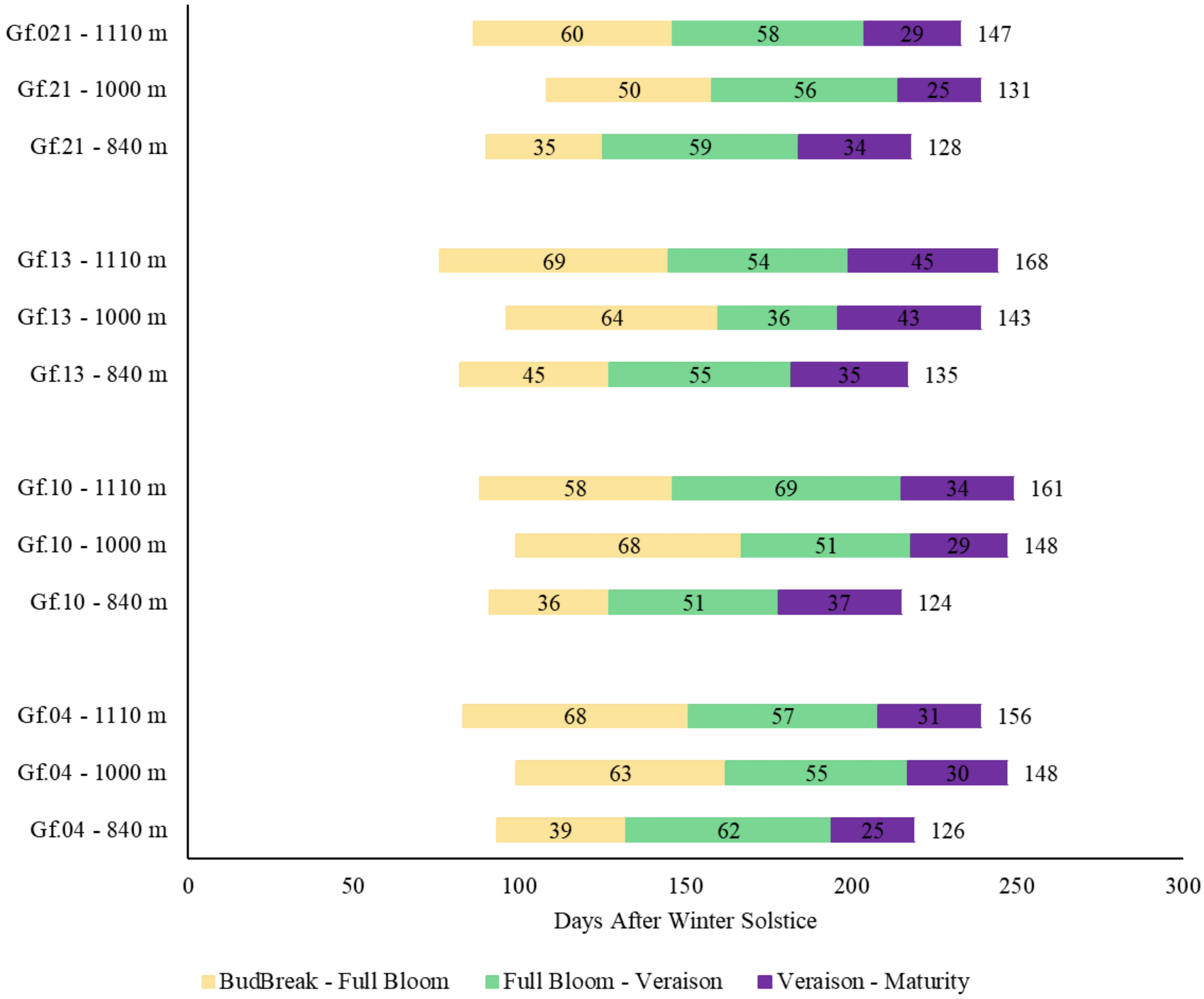

Figure 1. Chronological lenght (days) of each phenological stage of PIWI advanced selections in different altitude ranges of Santa Catarina State, Brazil.

Phenology is considered an evident manifestation of the genotype-environment interaction. A strong relationship between climatic aspects and the extension of phenological stages has been shown (CAFFARA; ECCEL, 2011). In the present study, phenology can be explained by the low temperatures observed in the region of highest altitude (Table 1), resulting in a prolongation of early development stages of the vine. In this case, differences in the extent of the cycles can be explained by the temperature that occurred in distinct places. When a region has higher average temperatures than others, the vine growth cycle is accelerated due to higher heat accumulation and starting ripening in advance (MUNIZ et al., 2015).

Besides the actual date of each phenological event, the interval between events, which gives an indication of the overall climate during those periods, was also evaluated in the present work. The selection Gf.13 presented the longest cycle cultivated at 1110 m (168 days) and at 840 m (135 days); at the intermediate altitude site (1000 m) Gf.04 and Gf.10 had the longest cycle (148 days). There is an average difference of approximately 30 days in cycle length when comparing the higher altitude vineyard with the lower altitude vineyard.

According to these criteria it can be stated that all selections presented good climatic adaptation (Figure 1). The knowledge of plants phenological characteristics is extremely important, since the development of grape quality destined for winemaking .is directly related to the occurrence and duration of the phenological sub-periods (JONES; DAVIS, 2000). Short intervals between phenological events are associated with optimum conditions that facilitate rapid physiological growth and differentiation (McINTYRE et al., 1982). Long intervals between events indicate suboptimal climate conditions and a delay in growth and maturation (CALÒ et al., 1996).

In addition, another criterium used to evaluate cultivar adaptation in new growing regions is the length of the subperiod *veraison* to maturity (FREGONI, 2006). The selection Gf.21 showed a short period between *veraison* and maturation (25 to 29 days), while the longest periods were found in Gf.13 (45 and 43 days) at higher altitude sites.

Short-cycle selections like Gf.21 could be chosen to avoid the rainy periods of the Brazilian summer and still ensure excellent yields and high-quality grapes. Long maturation periods increase the likelihood of damage due to grape bunch rot. Very early ripening is a factor that can be highly advantageous under tropical and subtropical conditions (SCHAEFER, 2016).

To better understand the performance of the different genotypes cultivated in different altitude ranges, a graph was constructed with the variance components; in this case, the phenotypic variance was decomposed into the environment, genotype, interaction and residue components (Figure 2). It is possible to observe that components such as SS and TA are more significantly related to the genotypes than to the environment. However, the other traits, yield, fertility index, number of clusters and pH, are more significantly related to the environment, which in this case was considered the altitude range and the vintages. It was also possible to observe a significant effect of the genotype x environment interaction.

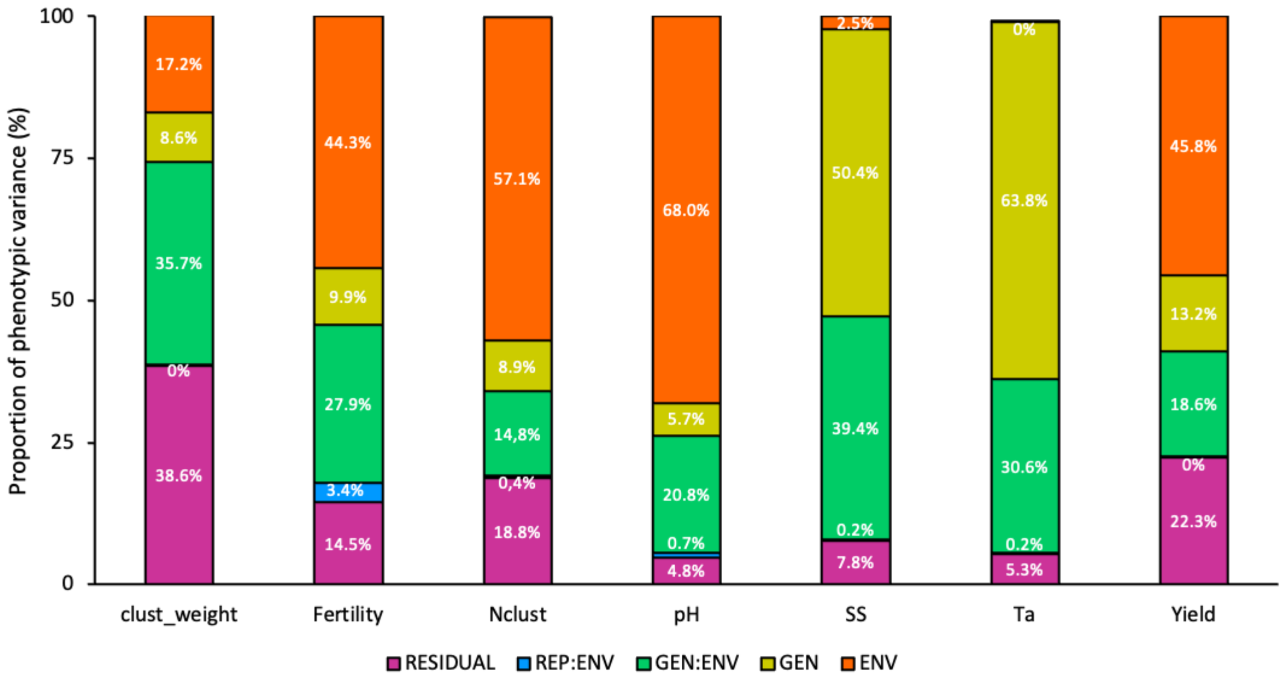

Figure 2. The proportion of phenotypic variance and qualitative and productive traits evaluated for PIWI genotypes, environments and their interactions. Clust_weight: cluster weight (g). Fertility: fertility index (clusters per shoot). Nclust: number of clusters. pH: must pH. SS: must soluble solids (°Brix). Ta: must total acidity (meq L-1). Yield (kg plant-1).

Figure 3 depicts the effect of the genotype x environment interaction for yield (a), pH (b), soluble solids (c) and total acidity (d). Regardless of the evaluated vintage, the lowest yields were found in the vineyard located at 1000 m (Figure 3a). The highest yields were found in the vineyard located at 840 m and in the vineyard located at 1110 m in the vintage 2019. The late frost that hit the vineyard located at 1110 m in the vintage 2020 reduced the yield of all genotypes evaluated at that location. Among the evaluated genotypes, Gf.13 and Gf.10 can be considered the most productive, with an average productivity of 6.2 and 5.6 tons per hectare in the most productive vineyard located at 840 m. The genotype Gf.04 presented, on average, the lowest yields, which ranged from 0.5 to 2.3 tons per hectare.

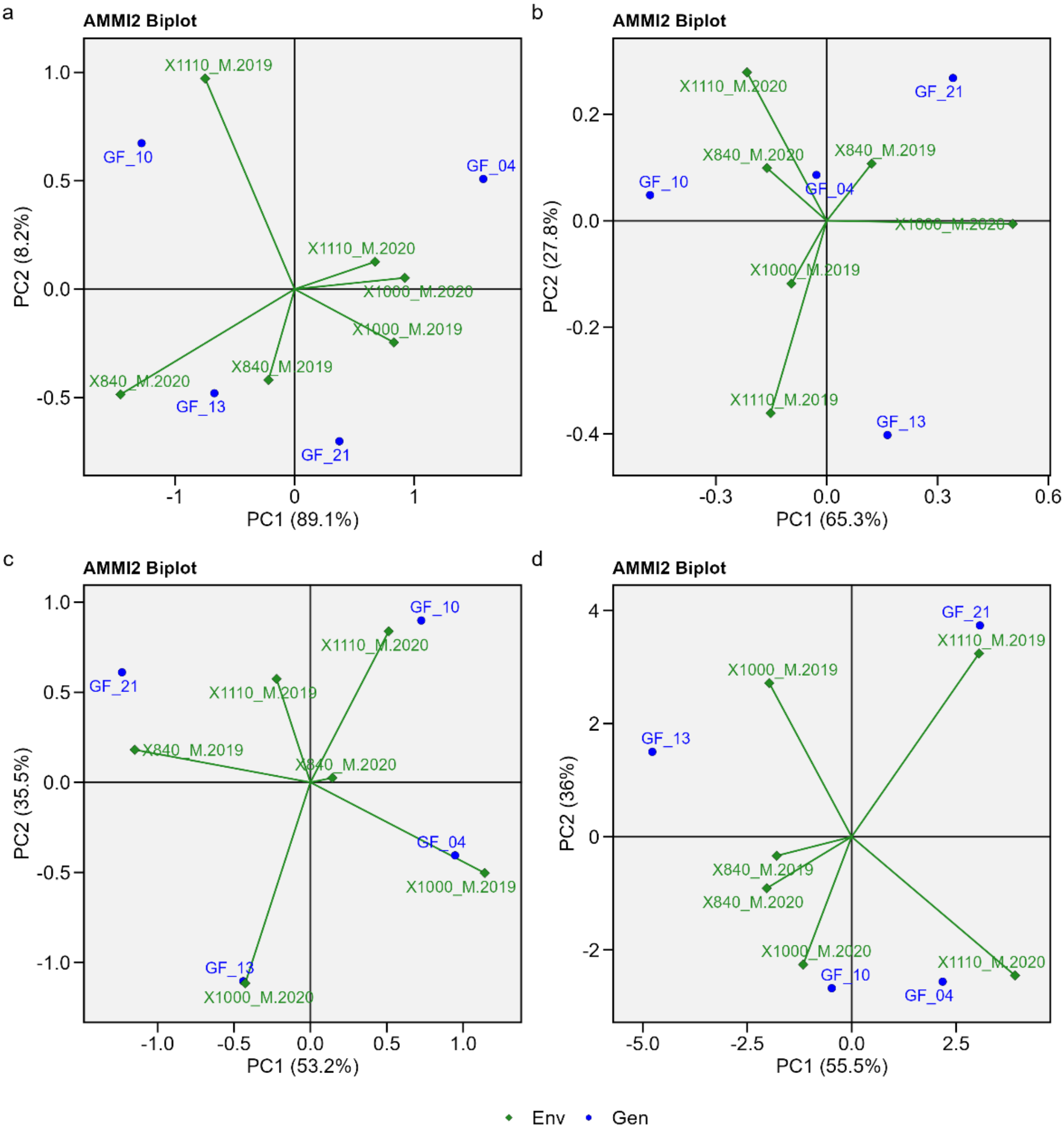

Figure 3. Genotype x environment interaction for the variables yield (a), pH (b), soluble solids (c) and total acidity (d). X840 (altitude 840 m – Videira), X1000 (altitude 1000 m – Curitibanos), X1110 (altitude 1110 m – São Joaquim). M.2019 (season 2018/2019). M.2020 (season 2019/2020).

In Figure 3b there is the genotype x environment relationship for pH, in general the pH values obtained by the different genotypes are within the ideal range. However, the Gf.21 genotype grown at 1000 m and 1110 m in the vintage 2019 and Gf.10 grown at 1000 m in the vintage 2020 showed pH values below those recommended to produce quality wines. The ideal pH range for producing quality wines is between 3.10 and 3.50; values outside this range negatively affect the wine final quality (JACKSON, 2014).

On average, the genotype Gf. 13 showed the lowest SS values in practically all evaluated environments, but it is interesting to note that this same genotype also showed high yields, which suggests that Gf.13 may be more sensitive to quality loss caused by overcropping. In Figure 3c there is the genotype x environment relationship for SS. The highest concentrations of SS for the genotype Gf. 10 were associated with its cultivation at an altitude of 1110 m. The vineyard located at 1000 m in the vintage 2019 was associated with the lowest concentration of SS for Gf.10 and high concentrations of SS for Gf.04. In general, to produce quality red wines, a concentration of SS above 19 °Brix is recommended for the must (JACKSON, 2014).

However, the effect of crop load on berry composition depends on how a difference in crop load is achieved. Thus, the so-called overcropping effects are often actually shade effects caused by poor pruning practices or other vineyard management errors. Overcropping ordinarily delays fruit maturation and therefore decreases grape sugar and color if harvest cannot be delayed (BRAVDO et al., 1984; WILLIAMS, 1996).

In Figure 3d there is the genotype x environment interaction for the variable TA. It is possible to observe the vintage effect for the genotype Gf.10, where at 1000 m in 2019 low TA values were observed, but in 2020 this selection was associated with high TA values. The selection Gf.13 was associated with lower concentrations of TA when grown at 1110 m; and Gf. 21 was associated with high levels of TA at 1110 m in the vintage 2019.

In general, the acidity values obtained in this work are in line with expectations to produce quality wines. Total acidity is expected to decrease with the course of maturation and is expected to reach a value below 110 meq L^{-1} for white varieties and 100 meq L^{-1} for red varieties (JACKSON, 2014). In other PIWI varieties also evaluated in São Joaquim, acidity values ranged between 65.5 $meqL^{-1}$ and 217.6 $meqL^{-1}$ for the white varieties Solaris and Muscaris respectively, while for red varieties acidity values were found in the range between 57.6 $meqL^{-1}$ for Regent and 110 $meqL^{-1}$ for Cabernet Cortis (DE BEM, 2019).

To understand the relationship between the variables and whether these relationships changed depending on the cultivation environment, a network-type graph was built for each cultivation site (Figure 4). This graph shows the correlations between the different variables, blue lines show positive correlations, while red lines show negative correlations between the variables. Highly correlated variables tend to be closer together and linked by thicker, opaque lines.

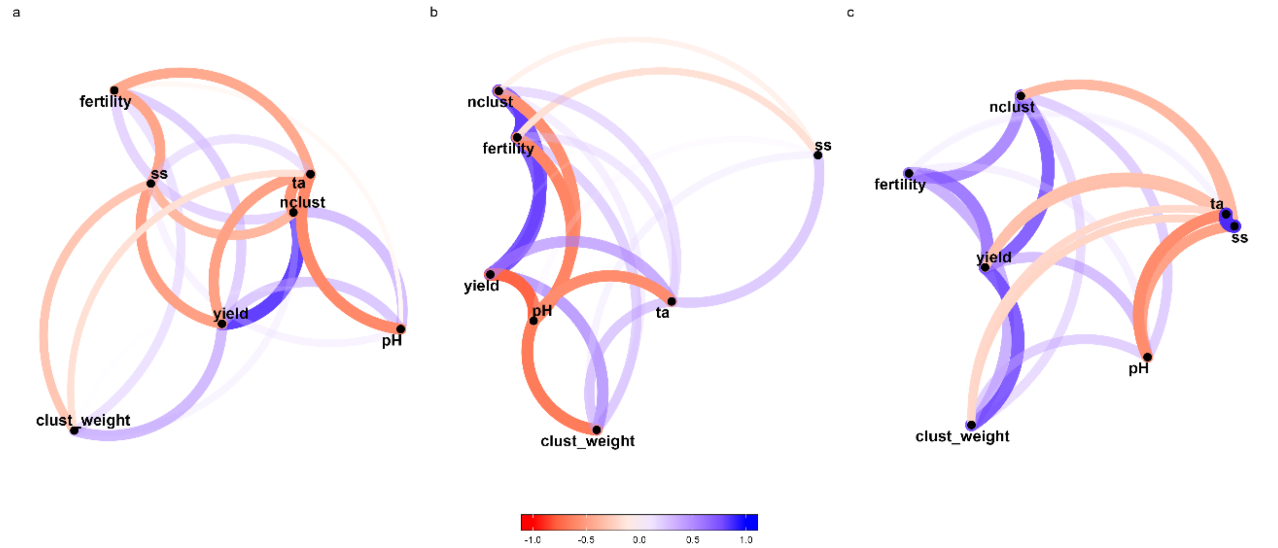

Figure 4. Network-type graph for cultivation environments, 840 m (a), 1000 m (b) and 1110 m (c). Clust_weight: cluster weight (g). Fertility: fertility index (clusters per shoot). Nclust: number of clusters. pH: must pH. SS: must soluble solids (°Brix). Ta: must total acidity (meq L-1). Yield (kg plant-1).

In the vineyard located at 840 m (Figure 4a) there is a positive correlation between the number of clusters and the cluster weight with yield. But it shows a negative correlation between yield and SS and TA. As well as a negative correlation between the number of clusters and pH.

In the vineyard located at 1000 m (Figure 4b) there is a positive correlation between the number of clusters, the fertility index and the cluster weight with yield. And a negative correlation between yield, cluster weight and TA with pH.

In the vineyard located at 1110 m (Figure 4c) there is a positive correlation between the variables related to yield indexes, number of clusters, fertility index, cluster weight and yield. There is a negative correlation between the number of clusters, yield, cluster weight and pH with TA and SS.

Viticultural yields are determined by the amount of carbohydrate (sugar) partitioned to the fruit rather than to other organs. Yield formation is often referred to as cropping, with the crop being the amount of fruit borne on a vine or produced by a vineyard (KELLER, 2020). Grapevine yield is made up of several different components, such as buds per vine, shoots per bud, clusters per shoot, berries per cluster and berry weight (COOMBE; DRY, 2001). Yield components are those factors in grapevine reproduction that, multiplied together, total the yield obtained from a single vine or an entire vineyard.

The classical view of the relationship between grape yield and quality is that of a linear decrease in quality with increasing yield per vine (CURRLE et al., 1983). However, this is an oversimplification, and there are many instances in which the quantity and the quality of the crop are not related (HOFÄCKER et al. 1976; KELLER et al., 2005) or are increased simultaneously (CHAPMAN et al., 2004). A meta-analysis of Riesling clonal trials conducted at 16 locations over 37 years found that yield and SS both increased over time, whereas titratable acidity decreased (LAIDIG et al., 2009).

Much of the variation in yield was attributed to site effects, whereas the change in fruit composition was clearly linked to the rise in average temperature during the same period. Although yields and mean temperatures continued to vary considerably from year to year, the variation in fruit composition declined over time, indicating that composition was not greatly affected by yield and that improved vineyard management contributed to the change in fruit composition (KELLER, 2020).

To help the selection of which genotype was the most adapted to each evaluated environment, multi-trait genotype–ideotype distance index (MGIDI) was used to rank the genotypes based on information of multiple traits (Figure 5 and Table 2).

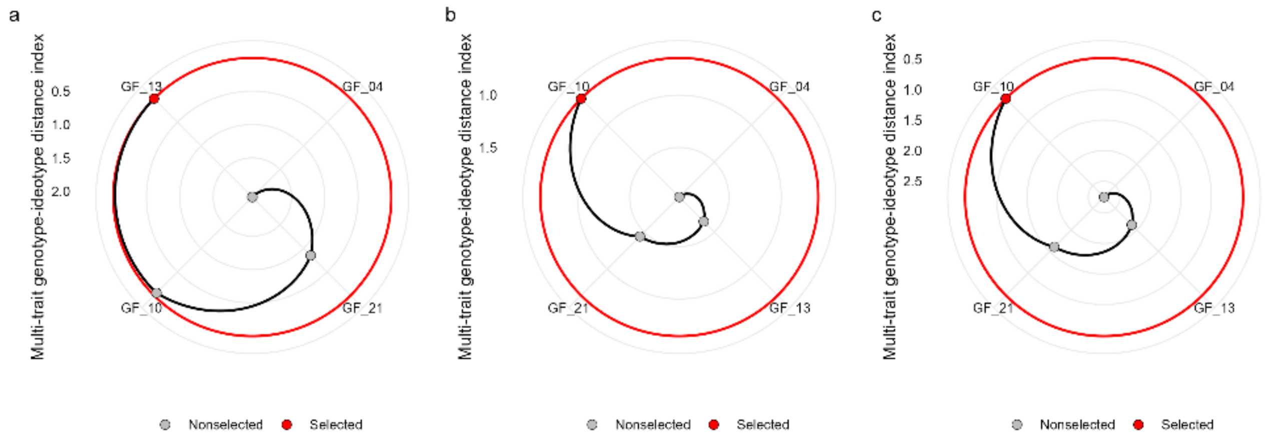

Figure 5.1 Genotype ranking in ascending order for the MGIDI index for vineyards located at 840 m (a), 1000 m (b) and 1110 m (c). The strengths and weaknesses view of the selected genotypes is shown as the proportion of each factor on the computed multi-trait genotype–ideotype distance index (MGIDI) for vineyards located at 840 m (d), 1000 m (e) and 1110 m (f).

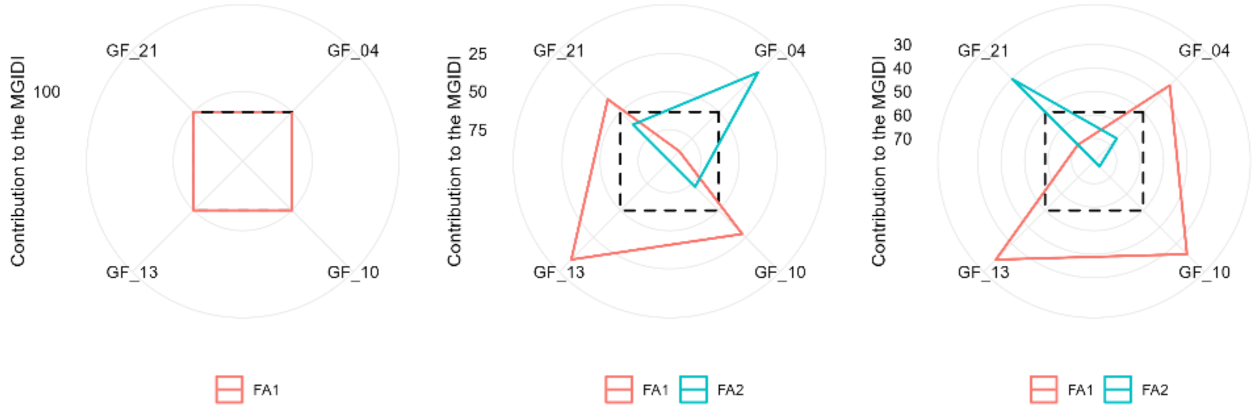

Figure 5.2 Genotype ranking in ascending order for the MGIDI index for vineyards located at 840 m (a), 1000 m (b) and 1110 m (c). The strengths and weaknesses view of the selected genotypes is shown as the proportion of each factor on the computed multi-trait genotype–ideotype distance index (MGIDI) for vineyards located at 840 m (d), 1000 m (e) and 1110 m (f).

Table 2. Selection differentials for the variables studied considering the ranking of genotypes by the MGIDI index.

Altitude	Variable	Factor	Xo	Xs	SD	SDperc	Goal
840 m	Cluster Number	FA1	14.37	17.44	3.07	21.34	increase
	Fertility Index	FA1	2.08	2.51	0.43	20.65	increase
	Yield	FA1	4.18	5.42	1.24	29.63	increase
	Cluster Weight	FA1	100.98	105.31	4.33	4.28	increase
	pH	FA1	3.51	3.57	0.06	1.68	increase
	Soluble Solids	FA1	18.01	16.70	-1.32	-7.31	increase
	Total Acidity	FA1	82.52	69.68	-12.84	-15.56	decrease
1000 m	Cluster Number	FA1	2.075	2.74	0.66	31.96	increase
	Soluble Solids	FA1	17.99	16.90	-1.09	-6.06	increase
	Total Acidity	FA1	88.01	81.20	-6.81	-7.74	decrease
	Fertility Index	FA2	0.64	0.87	0.23	35.84	increase
	Yield	FA2	0.48	0.85	0.37	76.88	increase
	Cluster Weight	FA2	77.29	99.80	22.50	29.12	increase
	pH	FA2	3.20	3.08	-0.12	-3.75	increase
1110 m	Yield	FA1	3.46	4.83	1.37	39.52	increase
	Cluster Weight	FA1	105.47	116.97	11.51	10.91	increase
	pH	FA1	3.038	3.13	0.096	3.175	increase
	Soluble Solids	FA1	19.36	19.22	-0.14	-0.72	increase
	Total Acidity	FA1	88.35	75.57	-12.78	-14.47	decrease
	Cluster Number	FA2	11.27	14.15	2.87	25.51	increase
	Fertility Index	FA2	1.656	1.77	0.13	7.63	increase

Xo general average of genotypes; Xs average of the selected genotype; SD selection differential; SDperc percentage selection differential of the variable; Goal selection objective for the variable

In the vineyard located at 840 m, all evaluated variables were grouped in Factor 1 and among the evaluated genotypes, Gf.13 was the most promising (Figure 5a). When selecting the genotype Gf.13, desirable selection differentials were observed for all variables, except for SS; Gf.13 also showed a gain in productivity 29.6% greater than the other genotypes (Table 2). Gf.10 was very close to the cut point (red line that indicates the number of genotypes selected according to the selection pressure), which suggests that this genotype can present interesting features (Figure 5a).

In the vineyard located at 1000 m, the variables cluster number, SS and TA were grouped in Factor 1, while the others were grouped in Factor 2 (Figure 5b). Based on the analysis, in this environment, the most promising genotype was Gf. 10. When selecting the Gf.10 genotype, desirable selection differentials were observed for all variables, except for SS and pH; Gf.10 showed a gain in productivity 76.8% greater than the other genotypes, as well as gains in the number of clusters produced (31.9%), fertility index (35.8%) and cluster weight (29.1%). The Gf.10 genotype also presented TA around 7.7% lower than the others (Table 2).

In the vineyard located at 1110 m, the variables cluster number and fertility index were grouped in Factor 2 and the other variables in Factor 1 (Figure 5c). Based on the analyses, Gf.10 was the most promising genotype in this environment. When selecting the Gf.10 genotype, desirable selection differentials were observed for all variables, except for SS, Gf.10 showed a gain in productivity 39.5% greater than the other genotypes, as well as gains in the number of clusters (25.5%), cluster weight (10.9%), fertility index (7.6%) and pH (3.14%). The Gf.10 genotype also presented TA around 14.4% lower than the others (Table 2).

In all environments evaluated, the genotype Gf.04 was the least adapted (Figure 5a, 5b and 5c), mainly due to its low productive potential.

Presented in Figure 5 (d, e and f) are the strengths and weaknesses of genotypes, which are accounted for by the proportion of each factor to the MGIDI index of the genotypes. The smallest the proportion explained by a factor (closer to the external edge), the closer the traits within that factor are to the ideotype. The dashed line shows the theoretical value if all the factors had contributed equally. The multi-trait genotype-ideotype distance index (MGIDI) is a selection index for selecting genotypes and/or recommending treatments based on information of multiple traits. It allows a more efficient and accurate treatment recommendation based on desired or undesired characteristics of the crop studied (OLIVOTO; NARDINO, 2021).

At the altitude of 840 m, only one factor was found containing all variables (Figure 5d). At the altitude of 1000 m the genotype Gf.13 and Gf.10 have strengths related to FA1 (cluster number, SS and TA), while the genotype Gf.04 has strengths related to FA2 (fertility index, yield, cluster weight and pH) (Figure 5e). At the altitude of 1110 m the genotypes Gf.13 and Gf.10 have strengths related to FA1 (yield, cluster weight, pH, SS and TA), while the genotype Gf.21 has strengths related to FA2 (cluster number and fertility index).

When considering the adaptation of varieties intended for wine production, it is important to consider that in addition to the agronomic performance of the plants, it is necessary to evaluate the enological quality of the final product. in preliminary evaluations and blind tastings, it was observed that the wines of the Gf.10 genotype were better evaluated in relation to the other selections.

Conclusions

For the most selections, the budbreak occurred in the second half of September; full bloom occurred from late October to mid-November; the *veraison* occurred between the end of December and mid-January; and Maturity occurred between the end of January and February.

The earliest budbreak occurred in the vineyard located at the highest altitude (1110 m - São Joaquim), while the earliest full bloom, *veraison* and maturity occurred in the lowest altitude vineyard (840 m – Videira).

All selections produced grapes with adequate concentrations of pH and total acidity to produce quality wines. Except for Gf.13, all selections produced grapes with levels of soluble solids suitable for the production of quality wines.

Based on the Multi-Trait Genotype–Ideotype Distance Index (MGIDI) the selections Gf.13 and Gf.10 are the most promising genotypes for the Videira region (840 m) and Gf.10 is the most promising genotype for the regions of higher altitude, 1000 m and 1110 m.

References

BAILLOD, M.; BAGGIOLLINI, M. Les stades repères de la vigne. **Revue Suisse de Viticulture, Arboriculture, Horticulture**, Lausanne, v.25, p.7-9, 1993.

BRAVDO, B.; HEPNER, Y.; LOINGER, C.; COHEN, S.; TABACMAN, H. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. **American Journal of Enology and Viticulture**, Davis, v.35, p.247–52, 1984.

BRIGHENTI, A.F.; BRIGHENTI, E.; BONIN, V.; RUFATO, L. Caracterização fenológica e exigência térmica de diferentes variedades de uvas viníferas em São Joaquim, Santa Catarina -Brasil. **Ciência Rural**, Santa Maria, v.43, p.1162-7, 2013.

BRIGHENTI, A.F.; SILVA, A.L.; BRIGHENTI, E.; PORRO, D.; STEFANNINI, M. Desempenho vitícola de variedades autóctones em condições de elevada altitude no Sul do Brasil. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.49, n.6, p.465-74, 2014.

BRIGHENTI, E.; SOUZA, A.L.K.; BRIGHENTI, A.F.; STEFANINI, M.; TRAPP, O.; GARDIN, J.P.P.; CALIARI, V.; DALBÓ, M.A.; WELTER, L.J. Field performance of five white Pilzwiderstandsfahige (PIWI) cultivars in the south of Brazil. **Acta Horticulturae**, The Hague, v.1, p.115-22, 2019.

CAFFARRA, A.; ECCEL, E. Projecting the impacts of climate change on the phenology of grapevine in a mountain área. **Australian Journal of Grape and Wine Research**, Victoria, v.17, n.1, 2011.

CALÒ, A.; TOMASI, D.; CRESPAN, M.; COSTACURTA, A. Relationship between environmental factors and the dynamics of growth and composition of the grapevine. **Acta Horticulturae**, The Hague, v.427, p.217-32, 1996.

CHAPMAN, D.M.; THORNGATE, J.H.; MATTHEWS, M.A.; GUINARD, J.X.; EBELER, S.E. Yield effects on 2-methoxy-3-isobutylpyrazine concentration in Cabernet Sauvignon using a solid phase microextraction gas chromatography/mass spectrometry method. **Journal of Agricultural and Food Chemistry**, Easton, v.52, p.5431-5. 2004.

COOMBE, B.G.; DRY, P.R. **Viticulture**. 7th ed. Adelaide: Winetitles, 2001.

CURRLE, O.; BAUER, O.; HOFÄCKER, W.; SCHUMANN, F.; FRISCH, W. **Biologie der rebe**. Meininger: Neustadt an der Weinstrasse, 1983.

DE BEM, B.P. **Resistência de variedades de videira do grupo PIWI ao míldio (Plasmopara viticola) e seus efeitos sobre as características agronômicas e potencial enológico nas regiões de altitude de Santa Catarina**. 2019. Tese (Doutorado em Produção Vegetal) - Universidade do Estado de Santa Catarina. 2019. Disponível em: *https://www.udesc.br/arquivos/cav/id_cpmenu/1322/De_Bem__BP__tese__2019__corrigida__15819713710191_1322.pdf*. Acesso em: 11 ago. 2022.

DE BEM, B.P.; BOGO, A.; EVERHART, S.; CASA, R.T.; GONÇALVES, M.J.; MARCON FILHO, J.L.; CUNHA, I.C. Effect of Y-trellis and vertical shoot positioning training systems on downy mildew and botrytis bunch rot of grape in highlands of southern Brazil. **Scientia Horticulturae**, Wageningen, v.185, p.162- 66, 2015.

DE BEM, B.P.; BOGO, A.; BRIGHENTI, A.F.; WRUZ, D.A.; ALLEBRANDT, R.; STEFANINI, M.; RUFATO, L. Dinâmica temporal do míldio da videira em variedades Piwi na região de San Michele all Adige, Trentino - Itália. **Summa Phytopathologica**, São Paulo, v. 46, p. 212- 20, 2020.

DIAS, A.H.; MODESTO, L.R.; STEINER, D.M.; SOUZA, A.L.K.; DAL VESCO, L.L.; WELTER, L.J.; NODARI, R.O. Anthracnose suscptibility for grapevines with resistance loci to downy and powdery mildew in Southern Brazil. **Vitis**, Davis, v.61, p.93–100, 2022.

EIBACH, R.; TÖPFER, R. Traditional Grapevine Breeding Techniques. *In*: REYNOLDS, A. (ed.). **Grapevine breeding programs for the wine industry**. Cambridge: Woodhead Publishing. 2015. p.3-21.

FREGONI, M. **Viticoltura di qualitá**. Verona: Edizione l'Informatore Agrário, 2006. p.826.

GAUCH, H.G. A simple protocol for AMMI analysis of yield trials. **Crop Science**, Madison, v.53, p.1860-9, 2013.

HOFÄCKER, W.; ALLEWELDT, G.; KHADER, S. Einfluss der umweltfaktoren auf beerenwachstum und mostqualit€at bei der Rebe. **Vitis**, Davis, v.15, p.96–112, 1976.

JACKSON, R. S. **Wine science**: principles and applications. 4th ed. Amsterdam: Elsevier, 2014. 751 p

JONES, G.V.; DAVIS, R. E. Climate influences on grapevine phenology, grape compostion, and wine production and quality for Bordeaux, France. **American Journal of Enology and Viticulture**, Davis, v.51, p.249-61, 2000. Disponível em: *https://www.researchgate.net/publication/275832371*. Acesso em: 11 aug. 2022.

KELLER, M. Deficit irrigation and vine mineral nutrition. **American Journal of Enology and Viticulture**, Davis, v.56, p.267-83, 2005. Disponível em: *https://www.ajevonline.org/content/ajev/56/3/267.full.pdf*. Acesso em: 09 aug. 2022.

KELLER, M. **The science of grapevines**. 3rd ed. Amsterdam: Elsevier, 2020. 543 p.

LAIDIG, F.; PIEPHO, H.P.; HOF€ACKER, W. Statistical analysis of ‘White Riesling’ (Vitis vinifera ssp. sativa L.) clonal performance at 16 locations in the Rheinland-Pfalz region of Germany between 1971 and 2007. **Vitis**, Davis, v.48, p.77–85, 2009.

MARCON FILHO, J.L.; WURZ, D.A.; BRIGHENTI, A.F.; KRETZSCHMAR, A.A.; RUFATO, L.; CALIARI, V. Physicochemical and aromatic composition of ‘Sauvignon Blanc’ wines obtained from the Y-trellis and VSP training systems. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v. 56, p. 1, 2021.

MASSIGNAM, A.M.; DITTRICH, R.C. Estimativa do número médio e da probabilidade mensal de ocorrência de geadas para o estado de Santa Catarina. **Revista Brasileira de Agrometeorologia**, Santa Maria, v.6, p.213–220, 1998. Disponível em: *https://www.academia.edu/7918901/ESTIMATIVA_DO_NÚMERO_MÉDIO_E_DA_PROBABILIDADE_MENSAL_DE_OCORRÊNCIA_THE_ESTIMATION_OF_MEAN_NUMBER_AND_THE_MONTHLY_PROBABILITY_OF_OCCURRENCE_OF_FROST_FOR_SANTA_CATARINA_STATE_BRAZIL*. Acesso em: 11 aug. 2022.

McINTYRE, G.N.; LIDER, L.A.; FERRARI, N.L. The chronological classification of grapevine phenology. **American Journal of Enology and Viticulture**, Davis, v.33, p.80-5, 1982. Disponível em: *https://www.ajevonline.org/content/33/2/80*. Acesso em: 11 aug. 2022.

MUNIZ, J.N.; SIMON, S.; BRIGHENTI, A.F.; MALINOVSKI, L.I.; PANCERI, C.P.; VANDERLINDE, G.; WELTER, J.F.; ZOTTO, D.D.; SILVA, A.L. Viticultural performance of merlot and cabernet sauvignon (Vitisvinifera L.) cultivated in high altitude regions of Southern Brazil. **Journal of Life Sciences**, Libertyville, v.9, p.399-410, 2015.

OIV - Office International de la Vigne et du Vin. **Recueil des méthodes internationales d’analyse des vins et des moûts**. Paris, 2009. 368p. Disponível em: *https://www.oiv.int/public/medias/7786/oiv-recueil-des-methodes-internationales-danalyses-vol2-fr.pdf*. Acesso em: 11 aug. 2022.

OLIVOTO, T.; LÚCIO, A.D. Metan: An R package for multi-environment trial analysis. **Methods in Ecology and Evolution**, Hoboken, v.11, p.783-9, 2020.

OLIVOTO, T.; NARDINO, M. MGIDI: toward an effective multivariate selection in biological experiments. **Bioinformatics**, Oxford, v.37, p.1383-9, 2021.

PARKER, A. K.,DE CORTÁZAR-ATAURI, I. G., VAN LEEUWEN, C. E THUINE, I.General phenological model to charactere the timing of flowering and veraition of Vitis vinifera L. Australian Journal of grape and Wine Research, 17:206-216. 2011.

PEEL, M.C.; FINLAYSON, B.L.; MCMAHON, T.A. Updated world map of the Köppen- Geiger climate classification. **Hydrology and Earth System Sciences**, Katlenburg-Lindau, v.4, p.439-73, 2007.

R CORE TEAM. **R**: a language and environment for statistical computing. Vienna, 2022. Disponível em: *https://www.r-project.org/*. Acesso em: 11 ago. 2022.

RUEHL, E.; SCHMID, J.; EIBACH, R.; TÖPFER, R. Grapevine breeding programmes in Germany. *In*: REYNOLDS, A. (ed.). **Grapevine breeding programs for the wine industry**. Cambridge: Woodhead Publishing, 2015. p.77-101.

SANTOS, H.G.; JACOMINE, P.K.T.; ANJOS, L.H.C.; OLIVEIRA, V.A.; OLIVEIRA, J.B.; COELHO, M.R.; LUMBRERAS, J.F.; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 3. ed. rev. ampl. Rio de Janeiro: Embrapa Solos, 2013.

SCHAEFER, W.W. New developments in tropical viticulture under monsoon climate. **Acta Horticulturae**, The Hague, v.1115, p.195-202, 2016.

SOUZA, A.L.K.; BRIGHENTI, A.F. ; BRIGHENTI, E. ; CALIARI, V. ; STEFANINI, M.; TRAPP, O.; GARDIN, J.P.P. ; DALBÓ, M.A.; WELTER, L.J.; CAMARGO, S.S. Performance of resistant varieties (PIWI) at two different altitudes in Southern Brazil. **Bio Web of Conferences**, Lês Ulis, v.12, p.01021, 2019.

VEZZULLI, S.; VECCHIONE, A.; TEFANINI, M.; ZULINI, L. Downy mildew resistance evaluation in 28 grapevine hybrids promising for breeding programs in Trentino region (Italy). **European Journal of Plant Pathology**, Dordrecht, v.150, p.485-95, 2017.

VIANNA, L.F.; MASSIGNAN, A. M.; PANDOLFO, C.; DORTZBACH, D.; VIEIRA, V. F. Caracterização agronômica e edafoclimáticas dos vinhedos de elevada altitude. **Revista de Ciências Agroveterinárias**, Lages, v.15, p.215- 26, 2016.

WILLIAMS, L.E. GRAPE. IN: ZAMSKI, E., SCHAFFER, A. (ed.). **Photoassimilate distribution in plants and crops: source-sink relationships**. New York: Dekker, 1996. p.851-81.

WURZ, D.A.; MARCON FILHO, J.L.; BRIGHENTI, A.F.; ALLEBRANDT, R.; BEM, B.P. de; RUFATO, L. Phenolic composition of wine from 'Cabernet Sauvignon' grapes subjected to leaf removal at different timing in Southern Brazil. **Pesquisa Agropecuária Brasileira,** Brasília, DF, v.55, p.1-7, 2020.