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Performance of resistant grape varieties (PIWI), 'Felicia', 'Calardis Blanc' and 'Helios' in two locations of Santa Catarina State (BR)

Rodrigo Nogueira Giovanni[1]*; André Luiz Kulkamp de Souza[2], Vinicius Caliari[2]; Alberto Fontanella Brighenti[3], Angelica Bender[4]; Marcelo Barbosa Malgarim[1]

[1] Pelotas Federal University, UFPEL – FAEM, Pelotas, RS, Brazil.
[2] Agricultural and Rural Extension Company of Santa Catarina, EPAGRI, Videira, SC, Brazil.
[3] Santa Catarina Federal University, UFSC - CCA, Florianópolis, SC, Brazil.
[4] Minas Gerais Agricultural Research Company, EPAMIG, Caldas, MG, Brazil.
*Corresponding author. E-mail address: rodrigo.giovanni@ifc.edu.br

ABSTRACT - Downy mildew (*Plamopora* viticola) is one of the major problems to produce wine grapes in Brazil, a main cause of yield losses in the Southern region of the country. An alternative to the use of pesticides is the use of resistant varieties (PIWI): wine grapes combining high oenological potential and resistance to diseases. The goal of this work was to assess the vegetative and productive performance and maturation of three PIWI varieties ('Felicia', 'Calardis Blanc' and 'Helios') produced at altitudes of 840m and 1250m in the 2020, 2021 and 2022 vintages. The study is focused on four phenological stages: budbreak (BBCH 7), full bloom (BBCH 65), *veraison* (BBCH 81) and maturity/harvest (BBCH 89). The criteria for measuring the productive performance were, the number of clusters, average cluster weight, production per plant, yield and Ravaz index. As parameters for technological and phenolic maturation, pH, soluble solids, total acidity and total polyphenols were evaluated. The budbreak occurred at the end of August until the second fortnight of September, the flowering occurred in the second week of October, the *veraison* occurred during the month of December, and the maturity/harvest occurred from the second fortnight of January until the beginning of February. The earliest budbreak occurred with 'Felicia' in the vineyard at 1250m and the latest occurred with 'Calardis Blanc'. Regardless of the vineyard altitude, there was practically no difference in the flowering date between varieties and the vineyards altitude, the *veraison* and the maturity/harvest occurred earlier in the vineyard at 840m. The varieties produced at 840 m had a shorter cycle and proved to be more productive when compared to those produced at 1250 m. The studied varieties showed good phenological adaptation, high yield and maturation indices suitable for the production of quality still and sparkling white wines at both altitudes. From the results obtained, 'Felicia' and 'Calardis Blanc' seem to be the most promising varieties for cultivation in both altitude ranges.

Index Terms: phenology, productive indices, technological maturation.

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Desempenho de variedades das uvas resistentes (PIWI), 'Felicia', 'Calardis Blanc' e 'Helios' produzidas em dois locais do estado de Santa Catarina (BR)

RESUMO - O Míldio (*Plasmopora viticola*) é um dos grandes problemas para a produção de uvas viníferas (*Vitis vinifera*) no Brasil, principalmente na região Sul, podendo causar perdas de até 100% da produção. Além do uso de defensivos para o tratamento dessa doença, uma alternativa é a utilização de variedade resistentes (PIWI), que são consideradas uvas viníferas por apresentar alto potencial enológico aliado a resistência a doenças. O objetivo deste trabalho foi avaliar o desempenho vegetativo, produtivo e a maturação de três variedades PIWI ('Felicia', 'Calardis Blanc' e 'Helios') produzidas em Videira (840m) e Água Doce (1250m) nas safras 2020, 2021 e 2022. Os estádios fenológicos avaliados foram brotação (BBCH 7), plena floração (BBCH 65), mudança de cor das bagas (BBCH 81) e maturidade/colheita (BBCH 89). Para o desempenho produtivo foram avaliados o número de cachos, massa média de cachos, produção por planta, produtividade e índice de Ravaz. Para os parâmetros de maturação tecnológica e fenólica avaliou-se pH, teor de sólidos solúveis, acidez total e polifenóis totais. A brotação ocorreu no final de agosto até a segunda semana de setembro, a floração ocorreu na segunda quinzena de outubro, a mudança de cor ocorreu ao longo do mês de dezembro, e a maturidade/colheita ocorreu a partir da segunda quinzena de janeiro até o início de fevereiro. A brotação mais precoce aconteceu com a 'Felicia' no vinhedo a 1250m e a mais tardia para a 'Calardis Blanc', independente da altitude do vinhedo, praticamente não houve diferença na data de floração entre as variedades e a altitude dos vinhedos, a mudança de cor e a maturidade/colheita foram mais precoces no vinhedo a 840m. As variedades produzidas em 840 m tiveram um ciclo mais curto e demonstraram ser mais produtivas quando comparadas às produzidas em 1250m. As variedades estudadas apresentaram boa adaptação fenológica, elevada produtividade e índices de maturação adequados para a produção de vinhos brancos tranquilos e espumantes em ambas as altitudes. A partir dos resultados obtidos 'Felicia' e 'Calardis Blanc' demonstraram ser as variedades mais promissoras para o cultivo em ambas as faixas de altitude.

Palavras-chave: fenologia, índices produtivos, maturação tecnológica.

Introduction

Brazil has recently stood out in grape production. The South region is the largest producer in the country, where most of grapes are used for processing (juices and wines) and the largest volume consists in 'common' grapes (*V. labrusca* and hybrids). Nonetheless nowadays, Santa Catarina State also stands out in processing wine grapes (*V. vinifera*), showing an increase in production and planted area in recent years (CALIARI, 2020).

Recently, the high altitude regions of Santa Catarina, characterized by altitudes ranging from 900 to 1400 meters, have shown to be a new frontier for wine production, producing grapes with distinct characteristics when compared to the other growing regions, enabling the production of high quality wines (FALCÃO et al., 2007; BORGHEZAN et al., 2011; MALINOVSKI et al., 2012, ALLEBRANDT et al., 2015; MACEDO et al., 2015; MARCON FILHO et al., 2015).

In this sense, climatic conditions have a great influence on the vine in all its phenological stages and on the development of patho-

gens. It is therefore necessary to understand these climatic factors, in order to obtain the greater potential for vineyards in a given region (DELOIRE et al, 2005). Distinct characteristics can be attributed to the climatic particularities of these regions, since the high rate of rainfall combined with high temperatures observed in traditional producing regions, increases the incidence of fungal diseases interfering in fruit quality (BACK et al, 2013; EPAGRI/CIRAM, 2020).

Downy mildew and powdery mildew are considered the main vine fungal diseases in Brazil and around the world, causing losses up to 100% when not controlled (CARISSE; BEAULIOU 2018; SAIFERT et al. 2018).

In addition to phytosanitary treatments, the use of resistant varieties that are the result of interspecific crosses between Mediterranean (*Vitis vinifera*), North American and Asian species (*Vitis spp*) has been recognized as a way of overcoming the problem of fungal diseases. The use of marker-assisted selection, combined with backcrosses with vinifera varieties, allowed the development of genotypes resistant to fungal diseases, which combine disease resistance genes and a significant percentage (over 85%) of *V. vinifera*; these cultivars are known as PIWI (from the German "Pizwiderstandsfähige", meaning resistant to fungal diseases), accepted as vinifera varieties in European catalogs (SIVCEV et al., 2010; SAIFERT et al., 2018; VEZZULLI et al. 2018).

One of the advantages of these varieties is the reduction of the number of pesticide applications (FULLER et al. 2014), especially in warm humid areas such as southern Brazil. The use of PIWI cultivars can be considered an option for Brazilian growers, as a way to reduce the use of pesticides, consequently reducing costs and improving grape quality (DE BEM et al., 2016; BONIN et al., 2017). Also, more recent wine tastings have shown that it is possible to make wine from these varieties with a quality similar to that of traditional varieties (BASLER; PFENNINGER, 2003).

The fungal resistant grape are more vigorous and present a higher productivity when compared to *V. vinifera* in organic systems (REYNOLDS; VANDEN HEUVEL, 2009; SUN et al. 2011; ROSSEUAU et al., 2013; BARTHE, 2015). According to De Bem et al. (2016), the PIWI cultivars 'Regent', 'Cabernet Carbon' and 'Bronner' cultivated in São Joaquim/SC, presented higher resistance to downy mildew in field and laboratory tests; also, those cultivars presented high potential for production of quality wines. Regarding to downy mildew resistance, Zanghelini et al. (2018) indicated that cultivars 'Calardis Blanc', 'Felicia' e 'Helios', had a partial resistance to downy mildew in the climatic conditions of Santa Catarina State. Bonin et al. (2017) observed that PIWI cultivars 'Bronner', 'Cabernet Cortis' and 'Regent' showed little resistance to Anthracnose. And finally, De Bem et al. (2020) in a study carried out in the region of Trento, in northern Italy, found that the white PIWI varieties Muscaris and Jasmine showed a high degree of resistance to downy mildew, while Bronner, Pölöskei Muscotály and Solaris showed intermediate resistance and Bianca presented the highest susceptibility to downy mildew.

Siegfried and Temperli (2008), reported yields ranging from 7,0 to 11,8 t ha^{-1} from fungal resistant grape, growed under conventional management with minimal treatment in Switzerland. These studies showed the potential of PIWI cultivars, however, the different genotypes must be evaluated in different regions and countries, to identify which ones are best adapted and present satisfactory production.

This study is aimed to evaluate the viticultural behavior of the PIWI varieties 'Helios', 'Calardis Blanc' and 'Felicia' grown in two regions with different altitude and climate conditions: Videira-SC (840 m) and Água Doce (1250 m) in Santa Catarina State, South region of Brazil.

Material and Methods

The experiment was carried out in the vintages 2020, 2021 and 2022 in vineyards located at the Epagri (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa

Catarina) Experimental Station, located in the municipality of Videira - SC (27°02'33" S, 51°08'08" W and 840 m a.s.l.) and at Villaggio Grando Winery, located in the municipality of Água Doce (26°43'31" S, 51°30'35" W and 1,250 m a.s.l.). The accumulated chilling hours from April to September for the years 2019/2020; 2020/2021 and 2021/2022 were below or equal to 7.2°C, the monthly accumulated precipitation averages, maximum and minimum temperature data were obtained from the Environmental Variables of Database Santa Catarina (Epagri/CIRAM) and are described in Figure 1 and Figure 2.

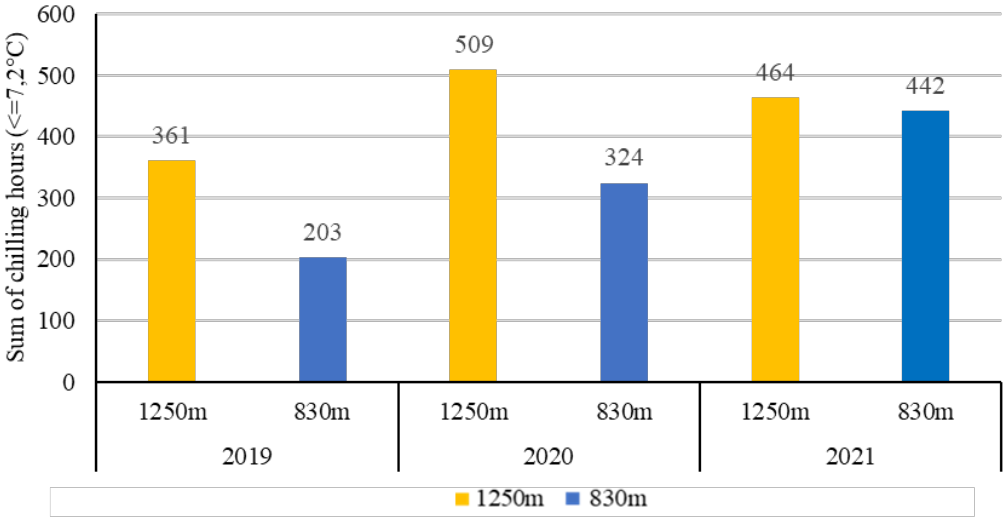

Figure 1: Sum of chilling hours accumulated in the municipalities of Água Doce (1250m) and Videira (840m) in the vintages 2020, 2021 and 2022.

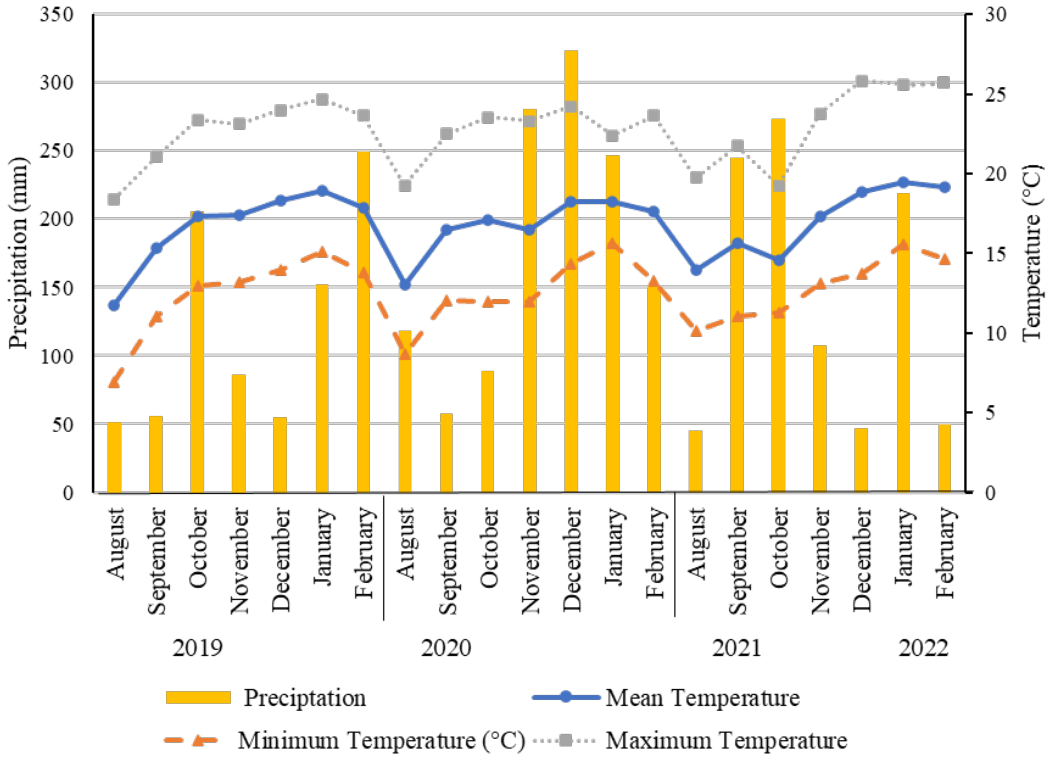

Figure 2.A: Precipitation (mm) and mean, maximum and minimum temperature (°C) in the municipalities of Água Doce (1250m) and Videira (840m) in the vintages 2020, 2021 and 2022.

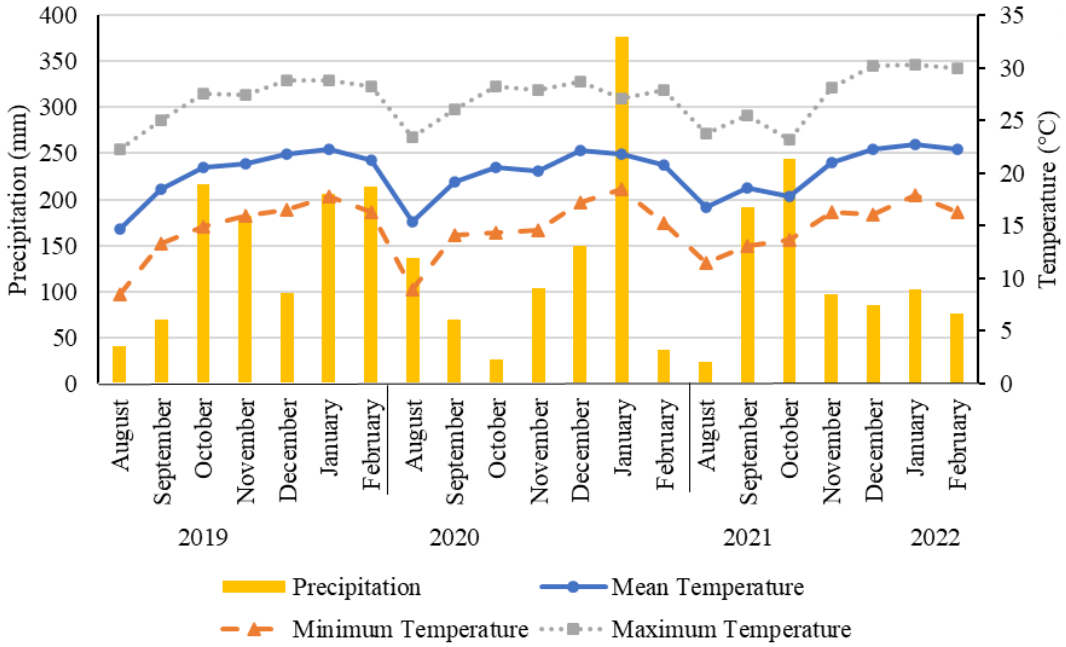

Figure 2.B: Precipitation (mm) and mean, maximum and minimum temperature (°C) in the municipalities of Água Doce (1250m) and Videira (840m) in the vintages 2020, 2021 and 2022.

The evaluated PIWI varieties were Felicia (Sirius x Vidal Blanc), Calardis Blanc (Calardis Musque x Seyve Villard 39-639) and Helios (Merzling x Freiburg 986-60). Both locations had identical vineyards installed in the year 2015, the plants were grafted on Paulsen 1103, planted at a spacing of 3.0 m between rows and 1.2 m between plants. Fertilization was carried out in accordance with the Fertilizer and Liming Manual for Temperate Fruit Trees (Regional South Nucleus of Brazilian Society of Soil Science).

No irrigation was performed, plants were trained in VSP and pruned in a double spur cordon, leaving two buds per spur in a total of 50 buds per plant. Pruning was performed in August and early September in both areas. In the beginning of October was performed the shoot thining, leaving on average one shoot per sprouted bud. Leaf removal was performed in early December, after fruit set and before veraison. Vines were trimmed once shoots outgrew 20 cm above the top wire. Secondary shoot removal were performed at the end of spring until the beginning of summer, when vegetative growth was more intense. When necessary, mowing was carried out between the rows. Fungicide sprays were made at both locations, the first one for downy mildew at flowering time and the others according to specific needs identified during vineyard evaluations, the total number of phytosanitary treatments during the productions cycle were 50% less when compared to *V. vinifera*.

The experimental design was in completely randomized blocks, with five blocks and ten plants of each variety per plot. For every three plants per plot, the vine phenological stages were defined, based on the BBCH scale (LORENZ et al., 1995). The dates of occurrence of each phenological event were recorded between pruning and harvest. The four main phenological stages were budbreak, considering the date when 50% of the buds were at the green tip stage (BBCH 7); full bloom, when 50% (BBCH 65) of the inflorescences were open; beginning of ripening or *veraison,* when the berries have softened or changed color (BBCH 81); and maturity/ harvest, when physiological maturity was reached, that is, when the harvest point was reached according to chemical evaluation of the berries (BBCH 89).

Evaluations of productive variables, number and average weight of clusters (g), productivity per plant (Kg) and estimated yield (Ton) were carried out from three plants per plot. At the time of pruning, the Ravaz index was determined from the ratio between productivity per plant (kg) and the mass of pruned material from the same plant (Kg) (CUS, 2004).

After harvest, a sample of 50 berries per plot was sent to the Videira Experimental Station laboratory, where physical chemical analyzes were performed. Soluble solids content, expressed in °Brix, was determined by refractometer (Quimis®) reading; total acidity (mEq L^{-1}) and pH obtained by automatic titrator Easy PlusTM (Metller Toledo) and total polyphenols obtained by the Folin-Ciocalteu colorimetric method in a spectrophotometer (RAY Leigh – UV 2601) reading at 760 nm (OIV 2019).

Phenology data were analyzed using descriptive statistics (mean and standard deviation). The grape production and quality data were submitted to analysis of variance (ANOVA) and when treatment effects were detected, the average comparison test was carried out by the Tukey Test at 5% error probability, using the R software. A standardized principal component analysis (PCA) was used to describe the effect of varieties on the mean of the variables cluster weight, number of clusters, yield, Ravaz index, soluble solids, total acidity, pH and total polyphenols.

Results and Discussion

The average dates of occurrence of the main phenological events are presented in Table 1. 'Felicia' and 'Helios' produced in Água Doce (1250 m) presented an anticipation of budbreak of 8 to 10 days when compared to Videira (840 m). For 'Calardis Blanc', no difference was observed in the average budbreak date in both evaluated sites (Table 1).

Table 1. Dates of main phenological events of 'Felicia', 'Calardis Blanc' and 'Helios' cultivated in two altitude ranges of Santa Catarina. Average of 2020, 2021 and 2022 vintages.

Variety - Altitude	Budbreak	Full Bloom	Veraison	Maturity/Harvest
Felicia 840 m	30-aug ± 9	16-oct ± 9	02-dec ± 12	16-jan ±12
Felicia 1250 m	20-ago ± 9	17-oct ± 10	19-dec ± 14	03-feb ± 8
Calardis B. 840 m	13-sep ± 13	21-oct ± 9	16-dec ± 6	14-jan ± 11
Calardis B. 1250 m	12-sep ± 12	26-oct ± 13	01-jan ± 11	03-feb ± 17
Helios 840 m	03-sep ± 18	18-oct ± 9	08-dec ± 10	21-jan ± 16
Helios 1250 m	26-aug ± 12	20-oct ± 11	04-jan ± 10	05-feb ± 10

In the vineyard located at 840 m, budbreak ocurred between August 30th ('Felicia') and September 13th (Calardis B.). In the vineyard located at 1250 m, budbreak ocurred between August 20th ('Felicia') and September 12th (Calardis B.). In a previous study, it was verified that in the 2018 vintage, in Videira (840 m), the budbreak date of 'Felicia', 'Helios' and Calardis B. occurred on August 29th, September 5th and September 6th, respectively (BRIGHENTI et al., 2019). 'Felicia' and Calardis B. varieties grown in São Joaquim (1100 m) in 2018 vintage showed budbreak on August 30th and September 4th, respectively (SOUZA et al., 2019). Baietto (2022) observed the budbreak of the PIWI 'Fleurtai' in Canelones (Uruguai) at September 10th, very similar as the 'Calardis Blanc' studied in both altitudes. Studying the phenology of 19 resistant varieties in northern Italy, Pacifico et al. (2013) observed a high variability among genotypes in the budbreak phase, reflecting a higher and different sensitivity to spring weather compared with the vinifera Pinot Gris.

It is assumed that the earlier budbreak observed in the higher altitude vineyard may be related to the low temperatures and the greater number of accumulated cold hours. According to Anzanello et al. (2018), the time required for budbreak decreases as the number of chilling hours increases, at a rate of one day for every 62 chilling hours for Chardonnay, Merlot and Cabernet Sauvignon.

Late budbreak is an interesting feature as it reduces the risk of damage that can be caused by late frosts, especially in vineyards located above 1000 m (BRIGHENTI et al., 2017; BORGHEZAN, et al., 2014). For vineyards located at altitudes of 800 m, the probability of late frosts occurring in late August and early September is lower, but important.

For the date of full bloom, practically no differences were observed between the altitude ranges. Full bloom occurred on average 2.6 days in advance in the lower altitude vineyard. The average date of full bloom of 'Felicia' was between October 16 and 17, 'Helios' between October 18 and 20 and Calardis B. between October 21 and 26 (Table 1).

The average date of *veraison* also occurred earlier in the lower altitude vineyard (840 m), between December 2 and 16. In the highest altitude vineyard (1250 m) the average date of veraison occurred between December 19th and January 4. 'Felicia' presented the *veraison* on December 2 (840 m) and December 19 (1250 m). 'Helios' presented the *veraison* on December 8 (840 m) and January 4 (1250 m). And Calardis B. showed the *veraison* on December 16 (840 m) and January 1 (1250 m) (Table 1).

Maturity/harvest occurred on average 16 days earlier in the lower altitude vineyard. In the lower altitude vineyard, the harvest took place between January 14th and 21st, while in the higher altitude vineyards, the grapes were harvested between February 3rd and 5th. In a previous study, it was verified that in the 2018 vintage, in Videira (840 m) the maturity/harvest date of the 'Felicia', 'Helios' and Calardis B. occurred on January 9th, January 12th and January 23rd, respectively (BRIGHENTI et al., 2019). 'Felicia' and Calardis B. grown in São Joaquim (1100 m) in the 2018 vintage showed harvest on January 16th and January 30th, respectively (SOUZA et al., 2019). The harvest date depends greatly on the point of technological maturation, which can be anticipated or postponed depending on local climatic conditions.

It seems that resistant varieties have lower requirements in terms of heat accumulation to shift from vegetative activity to a prioritized reproductive activity. The early *veraison* renders these varieties more suitable for cool climates or areas located at higher altitudes (FRIONI et al., 2020). In a previous study, evaluating 19 resistant varieties, Pacifico et al. (2013) verified that on average, the blooming, veraison and harvest dates for resistant varieties in northern Italy occurred later than observed with "Pinot gris".

The duration of budbreak–full bloom sub-period is 10 to 14 days shorter in the lower altitude vineyard (840 m). Among the evaluated varieties, Calardis B. has the shortest duration of budbreak–full bloom sub-period in both evaluated locations (Figure 3).

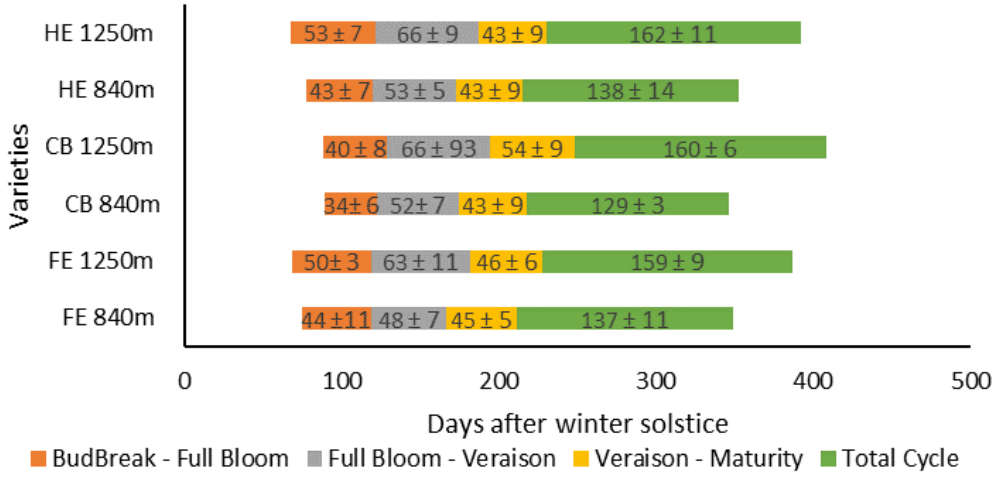

Figure 3: Mean duration of phenological events of 'Felicia' (FE), 'Calardis Blanc' (CB) and 'Helios' (HE) after the winter solstices in two locations of Santa Catarina State, average values of 2020, 2021 and 2022 vintages.

In the full bloom-*veraison* sub-period, its duration was on average 14 days shorter in the lower altitude vineyard. There was little variation in the duration of this sub-period between the different varieties, but 'Helios' showed the shortest duration (Figure 3).

In the *veraison*-maturity sub-period, practically no differences were observed between the locations and the varieties 'Helios' and 'Felicia'. The variety Calardis B. grown in the vineyard located at higher altitude had an average duration of 54 days for this sub-period, 11 days longer than the vineyards at lower altitude (Figure 3).

Long maturation periods can increase the possibilities of problems such as cluster rot, and early maturation is a very advantageous feature in tropical and subtropical conditions due because of high precipitation during grape ripening period in these production sites (SCHAEFER, 2016). The results obtained in these works demonstrate a good adaptation of the studied cases in both studied regions.

When evaluating the same fungus resistant varieties in Videira (840m) in 2018 vintage, the same pattern of cycle duration was observed between the sub-periods evaluated (BRIGHENTI et al., 2019). Similar results were obtained for 'Felicia' and Calardis B. produced in São Joaquim (1100 m) (SOUZA et al., 2019).

As a result, the total cycle duration of the varieties was on average 25 days longer in the vineyard at the highest altitude (1250 m). Temperature helps to explain the differences between cycle lengths. Milder temperatures delay fruit development, prolonging the period of berry growth (KELLER, 2010). When a region has higher average temperatures, the grape growth cycle is shorter, due to the greater accumulation of heat that causes early maturation (MUNIZ et al. 2016). The mean temperature over the cycle in the vineyard located at 840 m was 20.4°C, while the mean temperature in the vineyard located at 1250 m was 17.2°C.

The characterization of phenological sub-periods duration is important in the introduction of new grape varieties, as they allow the determination of vine development phases (vegetative growth, flowering, fructification, and fruit maturation), which occur seasonally, in relation to the climate, especially seasonal variations, in addition to being used to interpret how different regions interact with the plant (MATTAR, 2016, GRIS 2010, GIL; PSZCZÓLKOWISKI, 2007, BOLIANI, 1994).

Regarding the productive variables, it was observed that 'Calardis Blanc' stood out for the high number of clusters and, when produced at 840 m, it was the variety that presented the highest cluster number in all evaluated vintages. In all evaluated vintages and in both locations, 'Felicia' produced the lowest number of clusters. On the other hand, 'Felicia' cultivated at 840 m produced the heaviest clusters in all evaluated vintages (on average 186 g), while 'Calardis Blanc' cultivated at 1250 m produced the lowest weight clusters in all evaluated vintages (on average 94 g) (Table 2).

Table 2. Cluster number and cluster weight of 'Felicia', 'Calardis Blanc' (C. Blanc) and 'Helios' cultivated in two different altitudes in vintages 2020, 2021 and 2022.

Variety - Altitude	Cluster Number			Cluster Weight (g)		
	2020	2021	2022	2020	2021	2022
Felicia 840 m	31.3 b	32.0 b	41.5 b	210.0 a	153.0 a	195.2 a
Felicia 1250 m	36.6 b	30.9 b	41.3 b	169.6 b	116.1 bc	100.8 cd
C Blanc 840 m	51.16 a	52.0 a	61.8 a	112.7 c	109.1 bc	108.4 bc
C. Blanc 1250 m	52.3 a	50.5 a	54.0 ab	115.3 c	96.4 c	71.4 d
Helios 840 m	27.7 b	35.5 b	45.3 ab	138.8 bc	139.8 ab	133.2 b
Helios 1250 m	35.7 b	35.5 b	40.9 b	128.0 c	115.9 bc	80.1 cd

* Averages followed by the same letter, in the column, belong to the same group by Tukey test at 5% probability.

Similar results were obtained by other authors when studying the same varieties in Santa Catarina. In the 2018 vintage, in the vineyard located at 840 m, an average of 28 clusters were observed for 'Helios' and 50 clusters for 'Calardis Blanc' and 'Felicia'. In the same experiment, 'Felicia' also presented the heaviest clusters (on average 176 g) and was followed by 'Calardis Blanc' (133 g) and 'Helios' (128 g) (BRIGHENTI et al., 2019). Still in the 2018 vintage, but in a vineyard located at 1100 m, an average of 50 clusters were observed for 'Calardis Blanc' and 'Felicia'. In this experiment 'Felicia' also presented the heaviest clusters (on average 177 g) and was followed by 'Calardis Blanc' (134 g) (SOUZA et al., 2019). In a recent work that evaluated the adaptation of resistant varieties in northern Italy, it was found for 'Soreli' values of 3.5 kg per plant, 30 clusters per plant and an average of 120 g per cluster; for 'Sauvignon Kretos' it was found 2.4 kg per plant, 25 clusters per plant and an average of 107 g per cluster; and for 'Sauvignon Rytos' it was found 2.4 kg per plant, 29 clusters per plant and an average of 85 g per cluster (FRIONI et al., 2021).

When evaluating the productivity per plant and estimated yield per hectare, it is possible to affirm that 'Felicia' and 'Calardis Blanc' produced at 840 m have the highest productive potential, with an average productivity of 6.0 kg per plant or 18 tons per hectare. With the exception of 2020 vintage, 'Helios' produced at 840 m also showed high yields, with an average of 5.0 kg per plant or 13 tons per hectare (Table 3).

Table 3. Productivity, estimated yield and Ravaz Index of 'Felicia', 'Calardis Blanc'(C Blanc.) and 'Helios' cultivated in two different altitudes in vintages 2020, 2021 and 2022.

Variety - Altitude	Productivity (Kg)			Yield (Ton per hectare)			Ravaz Index		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Felicia 840 m	6.5 a	4.9 ab	8.1 a	18.1 a	13.7 ab	22.6 a	8.0 ns	7.9 bc	9.7 a
Felicia 1250 m	6.2 a	3.5 b	4.2 bc	17.2 a	9.7 b	11.6 bc	7.1	6.3 c	6.1 bc
C. Blanc 840 m	5.8 ab	5.7 a	6.7 a	16.0 ab	15.9 a	18.5 a	7.8	12.2 a	8.4 ab
C. Blanc 1250 m	6.0 ab	4.8 ab	3.7 bc	16.5 ab	13.2 ab	10.4 bc	7.4	8.9 abc	5.0 c
Helios 840 m	3.9 c	5.0 ab	6.0 ab	10.6 c	13.8 ab	16.6 ab	6.0	11.1 ab	8.4 ab
Helios 1250 m	4.6 bc	4.1 ab	3.2 c	12.7 bc	11.4 b	8.8 c	6.0	7.2 c	5.1 c

* Averages followed by the same letter, in the column, belong to the same group by Tukey test at 5% probability.
ns = not significant by analysis of variance (ANOVA) at 5% probability.

Related results were obtained by other authors when studying the same varieties in Santa Catarina. In the 2018 vintage, in a vineyard located at 1100 m, an average productivity of 2 kg per plant or 6 tons per hectare was observed for 'Felicia' and 'Calardis Blanc' (SOUZA et al., 2019), values below those found in the vineyard located at 1250 m in the present study. Still in the 2018 vintage, but in the vineyard located at 840 m, an average productivity of 9.0 kg was observed for 'Felicia', 6.6 kg for 'Calardis Blanc' and 3.7 kg for 'Helios', which corresponds to 20 tons, 6.7 tons and 3.7 tons per hectare respectively (BRIGHENTI et al., 2019). Pedò et al, (2019), observed for 'Helios' in Trento Province 0,6 kg wich corresponds 3 tons per hectare. Casanova-Gascon et al. (2019) studying the PIWI varieties 'Sauvigner gris' and 'Muscaris' in Spain the harvest weight were 2,15 kg and 1,74 kg, wich corresponds to 8,5 tons and 6,9 tons per hectare respectively. Pacifico et al. (2013) studying 19 hybrids varieties, observed a production average of 8,1 kg per plant, where the most productive hybrid was observed with over 20 t/h and 4 - 5 t/ha obtained for the least productive varieties.

These results confirm the high productive potential of the PIWI varieties, as well as their adaptation to the edaphoclimatic characteristics of different regions. When comparing the results obtained with PIWI varieties with wine grapes such as Merlot

and Cabernet Sauvignon produced in São Joaquim (1400 m) and Campo Belo do Sul (900 m), regions with altitudes similar to Videira and Água Doce, the productive rates of resistant varieties were much higher than those obtained by Muniz et al (2015). When studying the Chardonnay variety in the 2018 and 2019 vintages in São Joaquim (1200 m), other authors found productivity values between 1.7 and 8.4 tons per hectare (PANCERI et al., 2018; WÜRZ et al., 2021).

Nowadays, remunerative productivity is a necessary requirement for new genotypes, and it should be associated with desired grape quality and low to moderate susceptibility to biotic and abiotic stress. Moreover, high basal bud fruitfulness allows the implementation of spur-pruning systems prone to the mechanization of winter operations (PONI et al., 2018). The Ravaz index is a parameter used to establish the balance and vigor of the plants, the ideal is that these indexes are between 4 and 10. Values below 4 indicate an excess of vigor or low grape production, while values a from 7 onwards, may indicate excess of production and risk of plant depletion (carbohydrates and nutrients) (ZALAMENA, et al. 2013; KLIEWER; DOKOOZLIAN, 2005 YUSTE, 2005). The Ravaz index values found in this work indicate that the plants are in balance, or with a tendency towards excess production, especially in the vineyard located at 840 m (Table 3). Overproduction did not affect the quality of the grapes and can be resolved by bud number adjustment during pruning or cluster thinning.

The highest pH values were found in the 'Felicia', the average of the three evaluated vintages was 3.61 to 840 m and 3.52 to 1250 m. 'Calardis Blanc' showed intermediate pH values, on average 3.48 at 840 m and 3.36 at 1250 m. And 'Helios' had the lowest pH values in 2020 and 2021 vintages, on average the values obtained in this experiment were 3.37 at 840 m and 3.33 at 1250 m. In general, regardless of the variety, the grapes produced in the lower altitude vineyard had higher pH values (Table 4).

Table 4. Total polyphenols and pH of 'Felicia', 'Calardis Blanc' (Calardis B.) and 'Helios' cultivated in two different altitudes in vintages 2020, 2021 and 2022.

Variety - Altitude	pH			Total Polyphenols (mg L^{-1})		
	2020	2021	2022	2020	2021	2022
Felicia 840 m	3.87 a	3.61 a	3.34 ab	1134.9 a	802.3 a	724.9 a
Felicia 1250 m	3.74 b	3.52 b	3.31 b	442.2 c	502.5 bc	780.5 a
C. Blanc. 840 m	3.69 b	3.51 b	3.26 b	807.8 b	333.2 d	570.5 b
C. Blanc. 1250 m	3.50 c	3.47 b	3.12 c	221.6 d	653.6 ab	303.9 b
Helios 840 m	3.59 c	3.34 c	3.19 c	567.2 c	385.2 cd	401.0 b
Helios 1250 m	3.41 d	3.18 d	3.41 a	434.4 c	417.2 cd	661.7 a

* Averages followed by the same letter, in the column, belong to the same group by Tukey test at 5% probability.
ns = not significant by analysis of variance (ANOVA) at 5% probability

The pH values observed by Brighenti et al. (2019) evaluating the varieties 'Felicia', 'Calardis Blanc' and 'Helios', were superior when compared to those obtained in Videira and Água Doce for these same varieties. Pedò et al. 2019 observed pH values of 3,30 for 'Helios' produced in Trento, and Casanova-Gascon et al. (2019) noted 3,37 and 3,43 pH values for 'Souvignier gris' and 'Muscaris' respectively. When studying the adaptation of resistant varieties in northern Italy, Frioni et al. (2021) found the following values of pH, 3.42 for Soreli, 3.33 for Sauvignon Kretos and 3.23 for Sauvignon Rytos.

The pH values obtained in this experiment were also higher than those obtained in Sauvignon Blanc grapes by Marcon et al. (2020) and in Chardonnay by Panceri et al. (2018) in high altitude regions. The ideal pH for producing quality wines is between 3.10 and 3.50 and values outside this range can affect the wine final quality (JACKSON, 2010). Values of pH above 3.6 are undesirable as they can cause low color intensity,

impair microbial stability and increase sensitivity to oxidation (KELLER, 2010).

'Felicia' produced at 840 m showed the highest concentrations of total polyphenols in the three evaluated vintages. The lowest concentrations of total polyphenols were found in the variety 'Calardis Blanc' (1250 m) in 2020, in 'Calardis Blanc' (840 m) in 2021, in 'Calardis Blanc' (840 and 1250 m) and 'Helios' (840 m) in 2022 (Table 4). The values obtained in this study ranged from 1134.9 mg L^{-1} for 'Felicia' to 221.6 mg L^{-1} for 'Calardis Blanc'. When evaluating the concentration of total polyphenols in white grape varieties produced in São Joaquim (1400 m), values of 995 mg L^{-1} were found for Trebbiano Toscano, 648 mg L^{-1} for Chardonnay, 506 mg L^{-1} for Moscato Giallo and 283 mg L^{-1} for Riesling Renano were found (BRIGHENTI et al., 2017).

Many authors have reported that polyphenol composition is due not only to the type of cultivar but also to the location where the grapes are grown and to environmental and management practices, as well as to the growing season (JONES; DAVIS, 2000; MATEUS et al., 2002). Climatic variables such as precipitation and solar radiation play an important role in the accumulation of phenolic compounds in grapes.

Precipitation is an important climatic factor in terms of the formation of phenolic compounds in the skin of the grapes (JONES; DAVIS, 2000). Polyphenols have the function of protecting plants from physical (such as the sun UV radiation) and biological (fungi, viruses, bacteria) attacks. Typically, in places where there are high rainfall levels, there is stress from the plant to combat, mainly, fungal diseases, inducing the production of phenolic compounds (DOWNEY et al., 2006; DAI et al., 2011).

The incidence of solar radiation in grape clusters also contributes to the activation of metabolism and the formation of substances responsible for wine quality, such as phenolic compounds, especially flavonols (DOWNEY et al., 2006). This difference can give the wines produced in high altitude regions of Santa Catarina State more intense coloration, more complex aroma, greater structure and persistence (GRIS et al., 2010; MALINOVSKI et al., 2012).

For soluble solids, 'Felicia' grown at 840 m showed high values in all evaluated vintages. For the other varieties there was a marked effect of the vintage, in 2020, 'Felicia' (840 m) presented values of 20.7 °Brix, while the lowest values were obtained for 'Calardis Blanc' (1250 m) and 'Helios' (1250 m), with 15.6 ° Brix and 17.4 °Brix respectively. In the vintage 2021, 'Helios' (1250 m) presented the lowest values of soluble solids, with 16.5 °Brix, while the other varieties did not differ. In the vintage 2022, in both locations, 'Calardis Blanc' produced grapes with the lowest concentration of soluble solids, 16.9 °Brix at 840 m and 18.3 °Brix at 1250 m, the other varieties did not differ from each other (Table 5).

Table 5. Soluble solids and total acidity of 'Felicia', 'Calardis Blanc' (Calardis B.) and 'Helios' cultivated in two different altitudes in vintages 2020, 2021 and 2022.

Variety - Altitude	Soluble Solids (°Brix)			Total Acidity (mEq L^{-1})		
	2020	2021	2022	2020	2021	2022
Felicia 840 m	20.7 a	18.0 a	19.7 a	78.5 ab	75.4 ab	79.0 ns
Felicia 1250 m	18.8 b	18.0 a	20.9 a	73.3 a	80.4 b	89.5
C. Blanc. 840 m	18.5 b	17.2 ab	16.9 c	67.0 a	66.8 a	78.7
C. Blanc. 1250 m	15.6 d	18.0 a	18.3 b	87.8 b	73.5 ab	78.1
Helios 840 m	18.4 bc	18.0 a	20.0 a	88.9 b	87.4 c	83.2
Helios 1250 m	17.4 c	16.5 b	19.0 ab	88.1 b	97.0 d	74.2

* Averages followed by the same letter, in the column, belong to the same group by Tukey test at 5% probability.
ns = not significant by analysis of variance (ANOVA) at 5% probability.

Oscillations in soluble solids values in different vintages can be associated with high variations in precipitation during the grape ripening period, as can be seen in Figure 2. The soluble solids contents verified in this study were like those found by Brighenti et al. (2019) in São Joaquim for the 'Felicia', 'Calardis Blanc' and 'Helios'. For Helios, in Trento – Italy, Pedò et al. (2019) observed a high amount of soluble solids in 'Helios' (21, 3°Brix) and Tuchshmid et al (2006) observed 21,6°Brix for Helios and 19,0°Brix for 'Bronner'. When studying the adaptation of resistant varieties in northern Italy, Frioni et al. (2021) found values above 22° Brix for Soreli, Sauvignon Rytos and Sauvignon Kretos.

The lowest values of total acidity, approximately 67 mEq L^{-1}, were obtained in 'Calardis Blanc' (840 m) in 2020 and 2021 vintages. Low acidity values were also obtained in 'Felicia' (in both locations) in 2020 and 2021 and in 'Calardis Blanc' (1250 m) in 2021. In the vintage 2022 there was no difference between the different varieties.

The results obtained by Brighenti et al. (2019) in São Joaquim (1100 m) were higher when compared to those produced in Videira and Água Doce for both varieties. These values are lower than those obtained by other authors, who obtained 130.5 mEq L^{-1} and 127.3 mEq L^{-1} evaluating the variety Chardonnay (PANCERI et al., 2018; WÜRZ et al., 2020). Tuchshmid et al (2006) noted total acidity in Swizerland for 'Helios' 113,5 mEq/L. Pedò et al. 2006 observed the values of 71,9 mEq/L for 'Helios' in Trento – Italy; and Baietto (2022) in Canelones - Uruguai observed values of 81,17 for 'Fleurtai'.

Among two the production sites, the total acidity of grapes produced in Videira was lower than in Água Doce, which can be explained by the shorter maturation cycle due to lower altitude and higher temperatures. High altitude regions tend to produce grapes with higher levels of acidity and aromas, which favors the production of white and sparkling wines (MANSOUR et al. 2022).

It is important to point out that the final quality of a wine is related to the grape stage of maturation, especially the concentration of soluble solids and total acidity, in the case of the production of sparkling wines, a medium sugar content and the presence of acidity result in products with high market acceptance (CALIARI et al, 2014; MANSOUR et al, 2022). Thus, based on the results obtained for soluble solids and acidity, it is possible to infer that still wines and quality sparkling wines can be produced from grapes produced in the evaluated locations.

In Figure 4 it is possible to observe the PCA of the PIWI varieties grown at different altitudes, in this case factor 1 (PC1) and factor 2 (PC2) explain, respectively, 55.12 and 34.09% of the data variation; together, they explain 89.21% of the total variability. The dispersion of treatments can be observed from their distribution in the coordinate system.

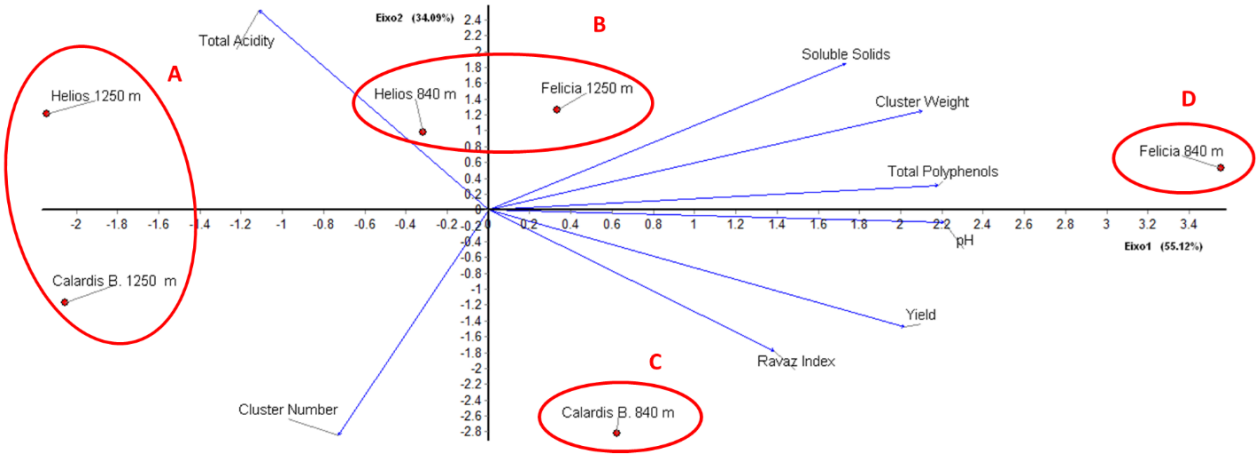

Figure 4: Projection of the principal component analysis of 8 variables used to evaluate the performance of vine fungal resistant varieties (PIWI), during the 2020, 2021 and 2022 vintages in Videira (840 m) and Água Doce (1250 m).

According to the PCA, it was possible to separate the varieties into 4 groups according to similarity standards. In group A are the varieties 'Helios' and 'Calardis Blanc' grown at 1250 m, they are associated with higher levels of total acidity, higher number of bunches, lower cluster weight, lower levels of total polyphenols, lower yield, lower levels of solids soluble and lower Ravaz index. In group B are 'Helios' cultivated at 840 m and 'Felicia' cultivated at 1250 m, these varieties are associated with a smaller number of clusters per plant and intermediate values of soluble solids, pH, yield and cluster weight. In group C is the 'Calardis Blanc' variety grown at 840 m, it is associated with a high Ravaz index, high number of clusters, high yield and low acidity. And in group D is the variety 'Felicia' grown at 840 m, which is associated with higher values of soluble solids, cluster weight, total polyphenols, pH and higher yield.

Conclusions

The varieties produced at 840 m had a shorter cycle and proved to be more productive when compared to those produced at 1250 m.

The Calardis Blanc variety produced at both altitudes, sprouted later, and it can be considered an advantage to avoid the late frosts, which eventually occur in these regions.

The studied varieties showed good phenological adaptation, high yield, and maturation indices suitable for the production of quality still and sparkling white wines at both altitudes.

'Felicia' and 'Calardis Blanc' proved to be the most promising varieties for cultivation in both altitude ranges.

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