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Viticultural Performance of Merlot and Cabernet Sauvignon (*Vitis vinifera* L.) Cultivated in High Altitude Regions of Southern Brazil

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Abstract: Different studies show that the altitude regions of the State of Santa Catarina have great potential for the production of grapevine varieties. The aim of this study was to characterize the phenological development, determine the thermal requirements in degree-days (DD), the index heliothermic (IH) and climatic variables during the vegetative and productive development of varieties Merlot and Cabernet Sauvignon grown in Campo Belo do Sul (27°40′04″ S, 50°44′48″ W, altitude 950 m a.s.l.) and São Joaquim (28°15′13″ S, 49°57′02″ W, altitude 1,400 m a.s.l.) during 2012/2013 cycle. Phenological stages evaluated were bud break, full bloom, veraison and maturity. Higher temperatures, global radiation, PAR and lower volumes of rainfall were the main climatic parameters that differentiated Campo Belo do Sul from São Joaquim. Due to occurrence of higher temperatures, Campo Belo do Sul presented thermal summation around 40% higher than São Joaquim. The low temperatures of São Joaquim extended the period of grape ripening and were responsible for the highest levels of titratable acidity and the higher concentrations of anthocyanins and total polyphenols in both varieties. The results show that in the altitude ranges studied (900 and 1400 m), climatic behavior and viticultural performance of Cabernet Sauvignon and Merlot were suitable for producing quality wines.

Key words: Climate, phenology, technological maturation, total polyphenols.

1. Introduction

In the highland regions of Santa Catarina State (regions with altitudes between 900 and 1,400 m a.s.l.) the viticulture has been acquiring great importance in the national scenery due to the high potential to produce fine wines [1]. According to researchers, the grapes produced in the highland regions of Santa Catarina show particular and distinct characteristics from other growing regions in Brazil, such as a complete phenological maturation, which allows the elaboration of higher quality wines [2-4].

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The air temperature during the vine development is one of the most important factors to set the time and the duration of phenological phases [5, 6].

Weather conditions have strong influence on the vine at all stages of phenological development [7]. Previous works relate climatic parameters and the maturity and quality of grapes [8].

Different authors show that the phenological cycle of several varieties is more extensive in these regions, compared with other wine regions of Brazil, due to climate peculiarities, [4, 9, 10]. However these regions need more information for the development of this activity, in order to determine the local potential and promising varieties.

In this sense, the present work aimed to study the main climatic variables, to characterize the phenology and the thermal requirement, two altitude regions of the State of Santa Catarina, during 2012/2013 cycle.

2. Methodology

Two experimental units were evaluated in Santa Catarina State: The unit of Campo Belo do Sul, is located 950 m above sea level, at latitude 27°40′04″ S, longitude 50°44′48″ W. The vineyard belongs to Abreu Garcia Winery. Merlot and Cabernet Sauvignon varieties were planted in 2006, spacing 3.00 m between rows and 1.00 m between plants.

The São Joaquim unity, is situated 1,400 m above sea level, latitude 28°15′13″ S, longitude 49°57′02″ W. The vineyard belongs to São Joaquim Experimental Station of EPAGRI (Santa Catarina State Agricultural Research and Rural Extension Agency). The Merlot and Cabernet Sauvignon varieties were planted in 2006, spacing 3.00 m between rows and 1.50 m between plants.

In both vineyards, plants were trained in vertical shoot positioning system and grafted on Paulsen 1103.

The study was conducted during the 2012/2013 cycle. In both vineyards each experimental unit consisted of 60 plants, where they had four replications, with 15 plants each, following a completely randomized design.

Climatic data were measured on site with automatic weather stations. The climatic parameters evaluated were: maximum, mean and minimum temperature (°C), relative humidity (%), precipitation (mm), global solar radiation (W/m^{-2}) and photosynthetically active radiation—PAR (micromol photons $m^{-2}s^{-1}$).

Growing degree-days (GDDs) and Winkler Index were calculated from the climate grids based upon the standard simple degree-day formulation using average temperatures above a 10 °C base for September through April, according to the equation: $WI = \sum_{max}\{[(T_{max} + T_{min})/2] -10.0\}$ [7, 11].

The phenological scale and the date of occurrence of each phenological event was recorded between pruning and maturity. The four main phenological events were budbreak, full bloom, veraison (change in berry skin color) and maturity [12].

The main stages of development have been described following the methodology of Brighenti et al. [4]:

B—budbreak: considered when 50% of the buds are green tip stage;

F—full bloom: considered when 50% of flowers are open;

V—*veraison* or berries color change, when 50% of berries change color;

Mat—maturity (harvest): considered based on the evaluation of the chemical composition of the grapes.

Thus, it was characterized the number of days between each phenological subperiod. Phenological parameters were evaluated periodically the number of days to budbreak, full bloom, berry color change and maturity.

The productive parameters evaluated were cluster number per vine, yield per vine (kg), and average cluster weight (g). Technological maturity analyses were performed at the Laboratory of Morphogenesis and Plant Biochemistry of Santa Catarina State Federal University. From grape must be performed analyzes of total soluble solids (°Brix), total acidity (Meq/L) and pH, according to the methodology proposed by OIV [13].

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 titration method with a 10 mL aliquot of juice with standardized 0.1 N NaOH.

Total monomeric anthocyanin content of must was determined by the pH difference, following the methodology described by Giusti and Wrolstad [14]. Total polyphenols content was quantified by the Folin-Ciocalteu method, with absorbance readings at 760 nm [15].

To analyze the results were utilized descriptive statistics for climatic and phonological data. The quantitative results were submitted to analysis of variance (ANOVA), and means were compared by Tukey test at 5% probability through Software Statistica 7.

3. Results and Discussions

Climatic data were evaluated for the period from budbreak to maturity (harvest) during the 2012/2013 cycle, comprising the months from September to April in São Joaquim (1,400 m a.s.l.) and from September to March in Campo Belo do Sul (950 m a.s.l.).

Figure 1 shows the monthly average of maximum temperatures for Campo Belo do Sul and São Joaquim between phenological stages of budbreak and maturity (harvest). Monthly values of the maximum temperature in São Joaquim (1,400 m a.s.l.) were on average 4.3 °C lower than Campo Belo do Sul (950 m a.s.l.).

Were observed monthly values of mean temperature 3.8°C higher in Campo Belo do Sul (950 m a.s.l.) (Fig. 2).

Figure 3 shows the monthly average minimum temperature to Campo Belo do Sul and São Joaquim, from budbreak to maturity. The minimum temperatures are on average 3.9 °C lower in São Joaquim.

In the high altitude area in São Joaquim, thermal amplitude was on average 1.2 °C lower than in Campo Belo do Sul, consequently, the difference between the maximum and minimum temperature is higher at lower altitude.

Thermal amplitude (Fig. 4) observed during sprouting to maturity, to São Joaquim and Campo Belo do Sul, were similar to those described by several authors [1, 10], who reported an average temperature range of 10 °C, being ideal for the production of quality grapes [16]. Thus, the thermal amplitudes observed for Campo Belo do Sul and São Joaquim can be considered suitable for the production of grapevines with high enological quality.

Considering the phenological cycle of budbreak to maturity of the variety Merlot (September-February in Campo Belo do Sul and from September to April in São Joaquim), it was found that the average maximum and minimum air temperatures, and were 25.8 °C and 14.5 °C for Campo Belo do Sul and 21.3 °C and 11.6 °C for São Joaquim.

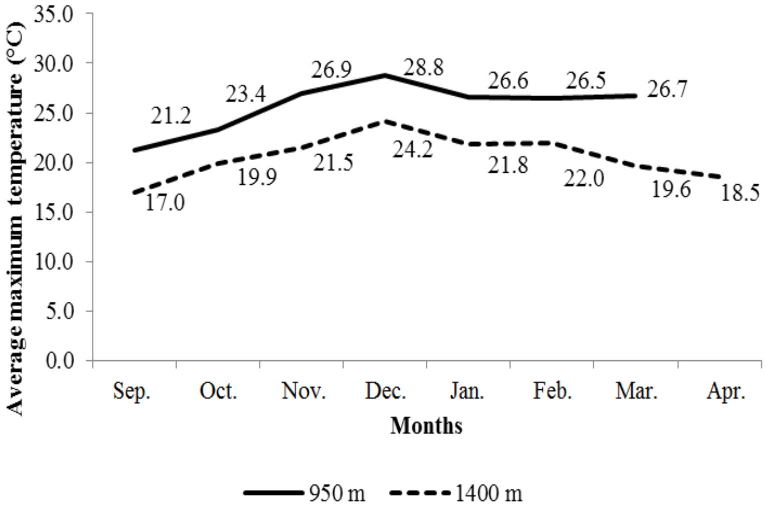

Fig. 1 Average monthly maximum air temperature (°C) during the vegetative and reproductive cycle of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

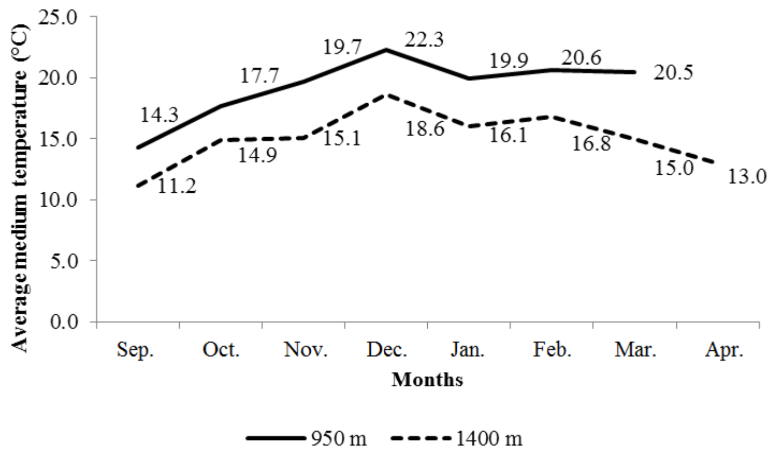

Fig. 2 Monthly averages of medium air temperature (°C) during the vegetative and reproductive cycle of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

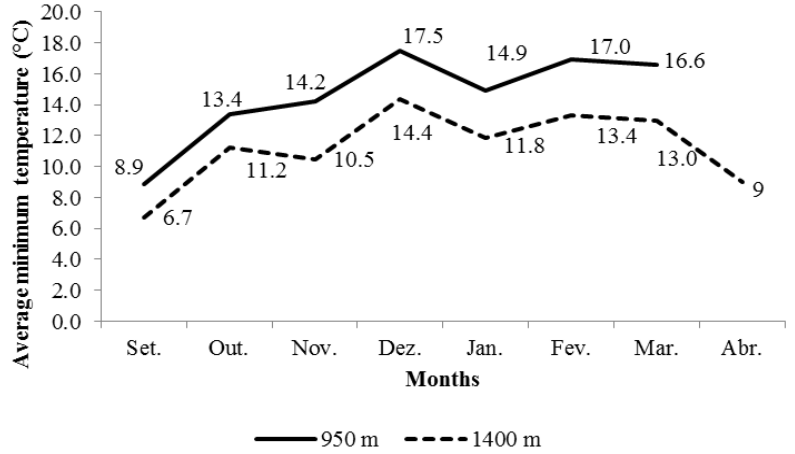

Fig. 3 Monthly averages of minimum air temperature (°C) during the vegetative and reproductive cycle of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

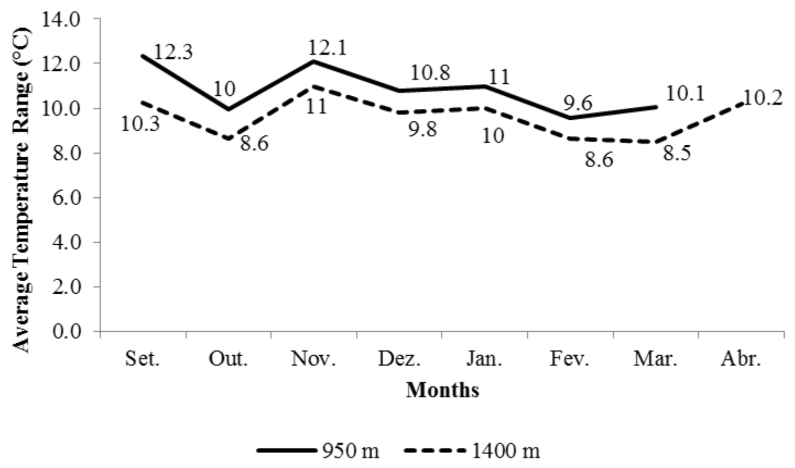

Fig. 4 Monthly average of thermal amplitude (°C) during the vegetative and reproductive cycle of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

Table 1 Averages of maximum, mean, minimum, thermal amplitude, and precipitation for the main phenological stages of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul and São Joaquim, during 2012/2013 cycle.

Variety	Phenological stage	Maximum Temp. (°C)		Mean temp. (°C)		Minimum temp. (°C)		Thermal Amplitude (°C)		Precipitation (mm)	
		950 m	1,400 m	950 m	1,400 m	950 m	1,400 m	950 m	1,400 m	950 m	1,400 m
Merlot	Budbreak-Full bloom	22.2	19.6	15.8	13.9	11	9.8	11.2	9.8	133	355
	Full bloom-Veraison	27.3	22.7	20.6	17.1	15.7	12.8	11.6	9.9	264	271
	Veraison-Maturity	26.5	21	20.2	15.7	15.7	12.1	10.8	9.2	310	345
	Budbreak-Maturity	25.8	21.3	19.3	15.7	14.5	11.6	11.3	9.6	707	967
Cabernet Sauvignon	Budbreak-Full bloom	24.5	19.9	18.2	14	14.2	9.5	10.3	10.4	148	269
	Full bloom-Veraison	27.5	22.9	20.8	17.2	16.3	13	11.3	9.9	265	272
	Veraison-Maturity	26.8	21.9	20.5	16.1	16.7	12.6	10.1	8.7	205	418
	Budbreak-Maturity	26.6	21.3	20.1	15.7	16	11.6	10.6	9.7	618	953

During Cabernet Sauvignon maturation, comprising the phenological stage of Veraison to Maturity (in February, March and April), the average values of maximum air temperatures were 26.8 °C and 21.9 °C to Campo Belo do Sul and São Joaquim, respectively. There was a difference of 4.9 °C between regions. The mean average temperatures were 20.5 °C and 16.1 °C, to Campo Belo do Sul and São Joaquim, respectively. The averages of the minimum air temperatures were 16.7 °C and 12.6 °C, to Campo Belo do Sul and São Joaquim, respectively.

During Merlot maturation, the average values of maximum and minimum air temperatures were 26.5 °C and 15.7 °C, to Campo Belo do Sul. In São Joaquim during the phenological stages of veraison to maturity (January, February, March and April), the average values of maximum and minimum air temperatures were 21 °C and 12.1 °C.

It was observed that for both varieties studied, the period of full bloom to veraison (onset of ripening) showed higher air temperatures, with average maximum temperatures of 27 °C to Campo Belo do Sul and 22 °C to São Joaquim, with a difference of 5 °C between the regions studied.

For variety Merlot during Budbreak to Maturity was observed that precipitation was higher in São Joaquim (967 mm) than in Campo Belo do Sul (707 mm) (Fig. 5).

During veraison to maturity, for the Merlot variety, there was 345 mm of rainfall and 81% RH at 1,400 m a.s.l. and 310 mm of rainfall and 82% RH at 950 m a.s.l.. From budbreak to maturity it was observed 967 mm of rainfall and 76% RH for the region of higher altitude (1,400 m a.s.l.) and 707 mm and 80% RH for 950 m a.s.l..

For Cabernet Sauvignon, during veraison to maturity, there was 418 mm of rainfall and 83% relative humidity (RH) at 1,400 m a.s.l. and 205 mm of rainfall and 82% RH at 950 m a.s.l.. High precipitation during grape ripening may result in damages and loss of wine quality [10, 17]. It is observed that regions with low rainfall during grape ripening are favorable for the organoleptic quality of the wine [10].

At both altitudes, average global radiation (Rg) and photosynthetically active radiation (PAR) showed similar curves during maturation; however, there was an increase in radiation in Campo Belo do Sul (Fig. 6).

The highest hourly average values recorded of global radiation (Rg) and photosynthetically active radiation (PAR) were, respectively, 837.4 W/m^2 and 1,364.3 μmol photons.m^{-2}s^{-1} to Campo Belo do Sul and 749.5 W/m^2 and 1,130.7 μmol photons/m^2·s to São Joaquim (Fig. 7).

It was also observed that in Campo Belo do Sul occurs higher radiation incidence and it lasts longer than in São Joaquim, there is a greater availability of radiation with longer duration for the vines grown in Campo Belo do Sul. In Campo Belo do Sul the saturation point (between 800 and 1,000 μmol photons m^{-2}s^{-1})

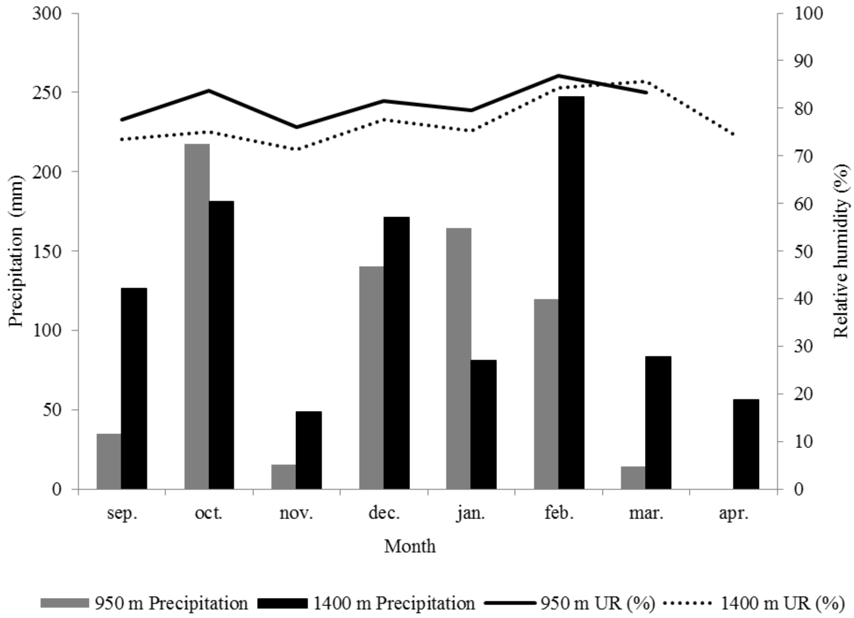

Fig. 5 Precipitation (mm) and Relative Humidity (%) during the vegetative and reproductive cycle of the varieties Merlot and Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), 2012/2013 cycle.

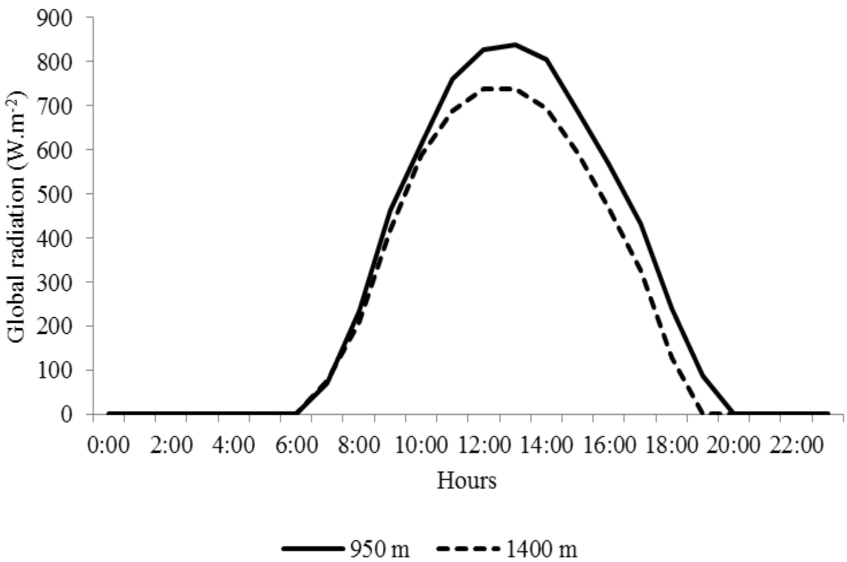

Fig. 6 Average hourly values of global solar radiation-Rg (W/m^2) during grape ripening, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

is reached between 8 to 9 a.m. and ends between 17 and 18 p.m.. In São Joaquim, the saturation point is reached between 9 to 10 a.m. and ended between 16 and 17 p.m.

The observed differences between the two altitudes studied may be related to latitude, longitude, altitude, humidity, land exposure and cloudiness, since these factors affect the quantity and quality of radiation at a given location [18], hence also affect the composition of the berries [19].

The light intensity usually increases with decreasing latitude, although the summer days are longer the higher latitudes [20]. Therefore, it can be said that Campo Belo do Sul (lat. 27°40′4″ S) has a higher availability

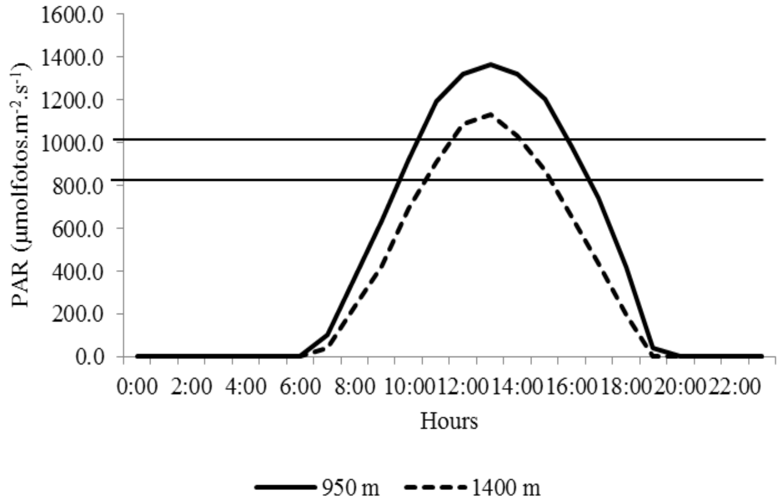

Fig. 7 Average hourly values of photosynthetically active radiation - PAR (μmol photons/m^2·s) and the saturation point between 800-1000 μmol photons/m^2·s during grape ripening in regions Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), 2012/2013 cycle.

of solar radiation than São Joaquim (28°15′13″ S).

The region of São Joaquim presents climatic phenomena that reduce radiation, Rg and PAR, causing effects on the vine and consequently the production of grapes. These factors can be explained by increased cloudiness, higher relative humidity and higher rainfall [10].

For both varieties, the 2012/2013 cycle, it is observed that Campo Belo do Sul (950 m a.s.l.) showed a higher thermal summation (1,754 and 1,660 degree days) than the region of higher altitude—São Joaquim (1,220 and 1,171 degree days) (Fig. 8 and 9). The Winkler index ranks the region of São Joaquim as region I, and Campo Belo do Sul as region III.

For 2012/2013 cycle, São Joaquim was classified as region I, being a colder region than Campo Belo do Sul (region III). For both varieties, Cabernet Sauvignon and Merlot, the largest accumulation of GDD occurs in Campo Belo do Sul and is related to higher average air temperatures relative to São Joaquim.

According to the calculation of Huglin Index, the region of São Joaquim presented 1,563.6 heat summation, classified as cold region (thermal summation between 1,500-1,800), for the 2012/2013 cycle. Campo Belo do Sul, presented 2,100 thermal sum and was classified as temperate region (thermal summation between 1,800-2,100).

The varieties presented earlier budbreak, later maturity in the region of higher altitude, São Joaquim (Table 2).

Merlot in Campo Belo do Sul had the period of budbreak to maturity (September 12 to February 20) of 161 days. In São Joaquim, the same period lasted 211 days (September 10 until April 09). The sub-period between budbreak and full bloom (September 12 until October 20) lasted 38 days in Campo Belo do Sul, while in São Joaquim it lasted 75 days (September 12 to November 24).

Cabernet Sauvignon in Campo Belo do Sul had the period of budbreak to maturity (October 04 to March 07) of 154 days. In São Joaquim, the same period lasted 210 days (September 18 until April 16). The sub-period between budbreak and full bloom (October 04 until November 05) lasted 32 days in Campo Belo do Sul, while in São Joaquim it lasted 69 days (September 18 to November 26).

Differences in the extent of the cycles can be explained by temperatures. When a region has higher average temperatures than other, the vine growth cycle is accelerated.

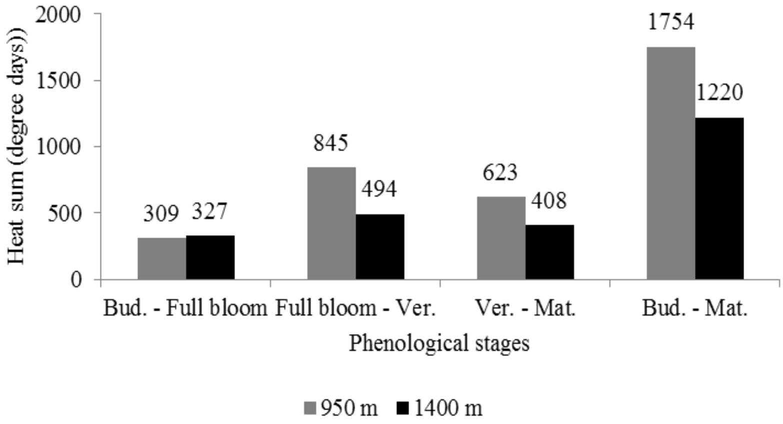

Fig. 8 Thermal requirement in degree days (GDD) for each phenological stage evaluated for Cabernet Sauvignon, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

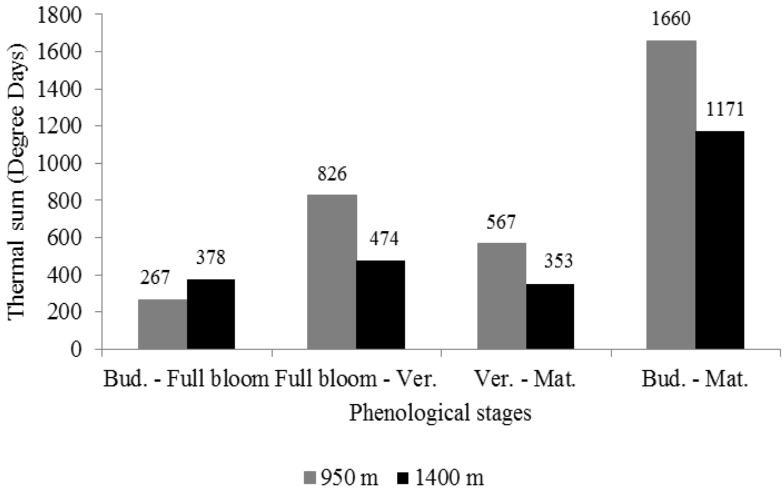

Fig. 9 Thermal requirement in degree days (GDD) for each phenological stage evaluated for Merlot, in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013.

Table 2 Phenology of Cabernet Sauvignon and Merlot in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), 2012/2013 cycle.

Variety	Altitude (m)	BudBreak	Full Bloom	Veraison	Maturity
	950	09/12/2012	10/20/2012	12/31/2012	02/20/2013
Merlot	1,400	09/10/2012	11/24/2012	01/31/2013	04/09/2013
	Mean	09/11/2012	11/06/2012	01/15/2013	03/16/2013
	950	10/04/2012	11/05/2012	02/01/2013	03/07/2013
Cabernet Sauvignon	1,400	09/18/2012	11/26/2012	02/05/2013	04/16/2013
	Mean	09/26/2012	11/15/2012	02/03/2013	03/27/2013

Among the evaluated growth stages, the biggest difference of chronological duration (days) was observed during budbreak—full bloom, for both varieties. The vegetative cycle was always longer in São Joaquim (1,400 m a.s.l.) (Fig. 10).

This result is explained by the low temperatures observed in the region of highest altitude in the months of September, October and November, resulting in a prolongation of vine early development stages.

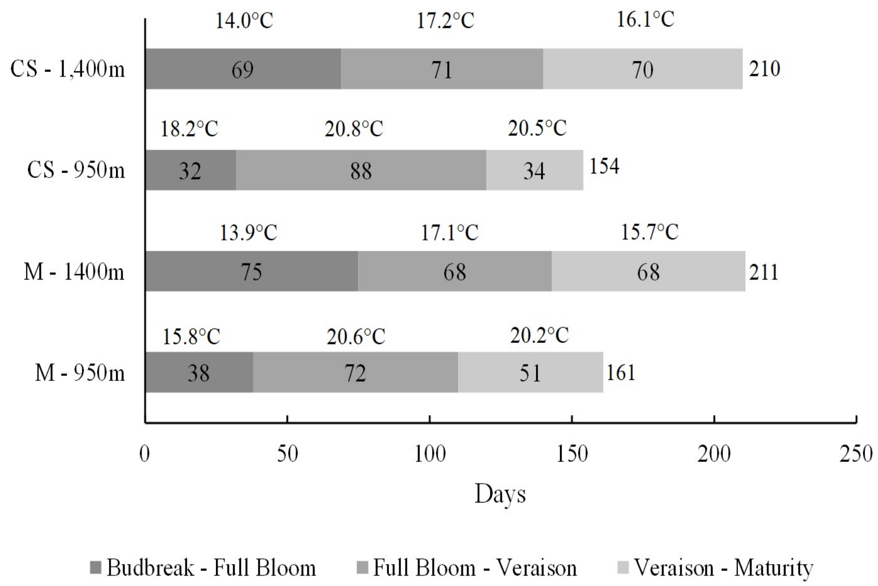

Fig. 10 Chronological duration (days) and average temperature (°C) for each phenological stage evaluated in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), cycle 2012/2013. CS: Cabernet Sauvignon, M: Merlot.

When comparing the average harvest dates of varieties with those obtained by Mandelli et al. [21] in Rio Grande do Sul State—Southern Brazil, it appears the effect of high altitude duration of the vine cycle. In São Joaquim, there was a delay of approximately 60 days to harvest Merlot.

Thermal duration is a good indicator of the development stages of the vine cycle. Varieties of early or mid-early budbreak as Merlot, will eventually be exposed to the risk of damage caused by the occurrence of late frosts in high altitude places like São Joaquim. Late ripening varieties like Cabernet Sauvignon require more heat accumulation during veraison—maturity to achieve grape ripeness grapes properly [4].

Merlot grown in Campo Belo do Sul showed values of clusters per plant, yield (kg/plant and Ton/ha), cluster weight and Ravaz Index statistically superior (Table 3).

Cabernet Sauvignon grown in Campo Belo do Sul showed values of yield (kg/plant and Ton/ha) and Ravaz Index statistically superior, while São Joaquim produced more clusters per plant (Table 3).

It is believed that the different planting densities, which affect plant productivity, can explain the yield differences. The vineyard located in Campo Belo do Sul has 3,333 plants per hectare, while the vineyard of São Joaquim has 2,222 plants per hectare. The lower density in São Joaquim possibly resulted in lower yield per hectare. However, in high density vineyards shading can become a big problem, as well as vineyards grown on trellis systems that produces excessive canopy density resulting in mutual shading [22].

The Ravaz Index is used as a parameter to establish balance and vigor of plants. For both varieties, the vineyard located at lower altitude, Campo Belo do Sul, presented Ravaz Index, of 4.7 for Merlot and 1.7 to Cabernet Sauvignon. In São Joaquim values obtained were 1.6 and 0.8 for Merlot and Cabernet Sauvignon respectively. The results are in agreement with Ravaz Index found by Borghezan et al. [9] for Merlot (1.4) and Cabernet Sauvignon (1.5) grown in São Joaquim.

According to Yuste [23], the Ravaz Index has great influence on the vine, which is balanced when the values are between 4 and 7. Indices major than 7 indicate excess crop load, and less than 4 indicate excessive vigor. The results therefore suggest that Merlot grown

Table 3 Productive indices of Cabernet Sauvignon and Merlot in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), 2012/2013 cycle.

Variety	Altitude (m)	Clusters per Plant	Yield (kg/plant)	Yield (Ton/ha)	Cluster Weight (g)	Ravaz Index
Merlot	950	21.8 a	3.2 a	10.6 a	188.6 a	4.7 a
	1,400	11.2 b	1.5 b	4.8 b	160.4 b	1.6 b
	CV(%)	35.9	36.7	36.7	21.9	26.6
Cabernet Sauvignon	950	19.0 b	2.1 a	6.9 a	119.4 a	1.7 a
	1,400	22.9 a	1.6 b	3.5 b	99.9 a	0.8 b
	CV(%)	31.3	35.9	32.4	20.3	29

*Averages followed by the same letter in column do not differ significantly for altitude by Tukey´s test ($P < 0.05$).

Table 4 Maturity indices of Cabernet Sauvignon and Merlot in the regions of Campo Belo do Sul (950 m a.s.l.) and São Joaquim (1,400 m a.s.l.), 2012/2013 cycle.

Variety	Altitude (m)	TSS (°Brix)	pH	TA (meq/L)	TMA (mg/L)	TP (mg/L)
Merlot	950	21.6a	3.3a	80.0b	929.2b	1,144.8b
	1,400	19.0b	3.1b	126.0a	1,827.3a	3,246.6a
	CV(%)	0.7	0.9	3.8	1.5	2.3
Cabernet Sauvignon	950	19.5a	3.3a	106.0a	1,560.8b	2,152.3b
	1,400	20.1a	3.3a	130.0a	2,241.4a	3,579.3a
	CV(%)	2.5	1.7	12.9	1.8	1.2

*Averages followed by the same letter in column do not differ significantly for altitude by Tukey´s test ($P < 0.05$).

at 950 m is balanced and Cabernet Sauvignon has excessive vigor. But the varieties grown in the higher altitude area, had high vigor, this situation could be minimized increasing crop load [24].

The variety Merlot grown in Campo Belo do Sul produced grapes with lower levels of titratable acidity (TA) and higher total soluble solids (TSS) and pH (Table 4). The higher temperatures at altitude of 950 m mainly influence these results. The increase in temperature causes an increase in plant respiratory activity, generating a decline in total acidity attributed to degradation of acidic compounds. The presence of such compounds determines grape pH [25].

For Cabernet Sauvignon there was no statistical difference for grape technological maturation in both evaluated sites, although it was observed a trend of higher values of total acidity in higher altitude region (1,400 m).

The temperatures influence the evolution of various grape qualitative parameters, including sugar content, acidity, pH and phenolic compounds [26]. During grape ripening, temperatures are extremely important because the accumulation of anthocyanin has a negative correlation with high temperatures and positive with low temperatures [27].

The titratable acidity (TA) values obtained for both varieties varied from 80 to 130 meq L^{-1} and were suitable for winemaking. Another author found similar results when studied the varieties Merlot and Cabernet Sauvignon in the regions of São Joaquim and Campo Belo do Sul [1, 9, 28]. Due to the cold weather in higher altitude regions of, as São Joaquim, the acid degradation is slower and, consequently, total acidity levels in grapes and wines produced are higher [4].

For phenolic maturation, the grapes produced in São Joaquim had higher total monomeric anthocyanin content (TMA) and total polyphenols (TP) (Table 4). In red grapes, the skin color is partially dependent on temperature. Studies suggest that very cold or very hot temperatures are associated with decreased color. The ideal temperature range for anthocyanin synthesis is from 17 °C to 26 °C [26].

It is believed that the higher levels of total monomeric anthocyanin (TMA) obtained in São

Joaquim occur due to low temperatures. Because when temperatures are very high, they reduce various metabolic processes, inhibiting the biosynthesis for the formation of berry anthocyanins, resulting in little skin color [29].

Total polyphenols (TP) contents depend on several factors, such as season, degree of grape maturation, water status, mineral nutrition, the harvest time and grape health [30]. The climate has the greatest influence on the polyphenols, for example, it is known that temperature and humidity are closely related to the altitude therefore at higher altitudes temperatures are usually lower, which favors the accumulation of total polyphenols [31].

It is believed that higher polyphenol contents found in São Joaquim are related to the low temperatures and higher rainfall. Usually in places where there are high rainfall, the plants are stressed, especially by the occurrence of fungal diseases, inducing the production of phenolic compounds as defense mechanism [32].

4. Conclusions

In the studied altitudes (950 and 1,400 m a.s.l.) ranges, climatic conditions show good thermal conditions and, therefore, an appropriate phenological development of Cabernet Sauvignon and Merlot.

Higher temperatures, global radiation, photosynthetically active radiation and lower volumes of rainfall were the main climatic parameters that differentiated Campo Belo do Sul from São Joaquim.

The lower temperatures autumn (March and April) of São Joaquim extended the grape maturation period and were responsible for the highest levels of titratable acidity and the higher concentrations of anthocyanins and total polyphenols in both the varieties.

The results prove that high altitude regions of Southern Brazil have high potential for production of quality wines.

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