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Climate and Phenology: Behavior of Autochthonous Italian Grapevine Varieties in the Uplands of Southern Brazil

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Abstract

The present study aimed to characterize the mesoclimate of the municipality of Água Doce, Brazil, and its influence on the phenological development and thermal requirements of autochthonous Italian varieties (*Vitis vinifera* L). The climate data were provided by a local automatic weather station. The principal phenological stages of red varieties (Aglianico, Ancellotta, Lambrusco, Malvasia Nera, Negroamaro, Nero d'Avola, Primitivo, Sangiovese, and Rebo) and white varieties (Fiano, Garganega and Vermentino) are analyzed. Results show that the mean temperature measured during the phenological cycles from September to April were higher than the climatological average (1961 to 2012). According to the Winkler, Huglin, and Cool Night bioclimatic indexes, the region is classified as "Region II", cold and with cool nights, respectively. The average heat summation for the phenological cycles of the varieties was 1740 GDD (205 days, 2009-2010), 1463 GDD (187 days, 2010-2011), and 1408 GDD (176 days, 2011-2012). The Lambrusco variety presented the longest phenological cycle (203 days), while Garganega presented the shortest one (178 days). The lower temperatures of Água Doce, when compared to those in other regions where the varieties are traditionally produced, determine longer growing cycles and a shift in the timing of the phenological stages.

Keywords: climatology, thermic requirement, variety adaptation, *Vitis vinifera* L.

1. Introduction

The state of Santa Catarina is Brazil's second largest producer of grapes (*Vitis vinifera* L.) for winemaking. Although this is a recent activity in the southern uplands of Planalto Serrano and Campos de Palmas (over 900 m a.s.l.), climate research have shown that these areas have a great potential to grow high quality grapes for the production of wines (Gris et al., 2010; Borghezan et al., 2011; Malinovski et al., 2012; Borghezan et al., 2014; Brighenti et al., 2015).

The timing and duration of the phenological stages of grapevines are strongly affected by environmental factors, particularly air temperature (Hall & Jones, 2010; Jones et al., 2010). Knowledge of thermal conditions is useful to predict the evolution of those stages. This is important in the planning of vineyard operations, the assessment of weather-related risks, and in the strategies for the use of pesticides. Various bioclimatic indices concerning air temperature were proposed for the classification of winegrowing regions and the estimation of thermal requirements for the complete development of grapevine varieties. The Winkler Index-WI (Winkler et al., 1974) and the Huglin Index-HI (Huglin, 1978) are the most used indicators.

Longer phenological cycles are observed in the uplands of Santa Catarina when compared to other winegrowing regions in Brazil. This is related to a great availability of solar radiation and lower night-time temperatures. With longer ripening periods, vines produce grapes of higher enological quality. In this paper, we characterize the mesoclimate of the municipality of Água Doce, and assess the phenological development and thermal requirements of autochthonous Italian varieties (*Vitis vinifera* L.).

2. Materials and Methods

2.1 Location and Sampling

The work was carried out at the experimental area of the Villaggio Grando winery in the location of Água Doce (26°43′53″S; 51º30′26″W; 1300 m a.s.l.). Chemical properties of the soil, classified as Humic Cambisol (EMBRAPA, 2006), are presented in Table 1.

Planting was realized in 2006, the plants were conducted on a vertical trellis system, spaced out 1.5 m between plants and 3.0 m between lines, with N-S orientation. Pruning was carried out using the double cordon spur pruning system, leaving two buds per spur.

Three consecutive phenological cycles (2009-2010, 2010-2011, 2011-2012) were evaluated for 12 grapevine varieties: Aglianico, Ancellotta, Lambrusco, Malvasia Nera, Negroamaro, Nero d'Avola, Primitivo, Sangiovese, and Rebo (red); Fiano, Garganega, and Vermentino (white).

Table 1. Chemical characteristics of soil (Humic Cambisol) in Água Doce, Santa Catarina, Brazil

Properties	**Layers (meters)**	
	0-0.20	**0.20-0.40**
pH - H_2O (1:1)	7,1	6,7
Index SMP	6,6	6,2
Ca ($cmol_c$ dm^3)	14,4	10,9
Mg ($cmol_c$ dm^3)	5,2	4,8
Al ($cmol_c$ dm^3)	0	0
H+Al ($cmol_c$ dm^3)	2,2	3,5
Organic matter (%)	3,6	2,6
Organic carbon (%)	2,1	1,5
Clay (%)	70	79
P Mehlich (mg dm^3)	1,2	1,1
Na (mg dm^3)	7	6
K (mg dm^3)	15	27
Cu Mehlich (mg dm^3)	4,3	5,2
Zn Mehlich (mg dm^3)	1,4	1
Fe Mehlich (mg dm^3)	96,7	107,6
Mn (mg dm^3)	5,6	8,2

2.2 Climatic Parameters

Climate data were provided by an automatic weather station located at the vineyard and run by the state meteorology service (EPAGRI/CIRAM). Daily data of maximum, mean and minimum air temperature, precipitation, air humidity, and sunlight were collected. Climatological averages in the period of 1961-2012 were provided by a meteorological database, adopting a basal temperature of 10 ^oC (Hall & Jones, 2010).

From the collected data of air temperature, the heat summations, expressed in Growing Degree Days (GDD), were calculated according to the Winkler and Huglin Index, adopting a basal temperature of 10 ^oC (Hall & Jones, 2010).

The Cool Night Index (CI) was calculated using a formula described by Tonietto and Carbonneau (1999) and considering the thermal conditions of the ripening period of the grapevines.

2.3 Phenology

The BBCH scale was used to define the phenological development stages (budbreak-BBCH07, flowering-BBCH65, *veraison*-BBCH85 and harvest) of the grapevines (Lorenz et al., 1995).

2.4 Statistical Analysis

Five replicates of eight plants each were taken at random, totaling 40 plants per variety. The mean, standard deviation, and coefficients of variation of the climate data were found and variance analysis was applied to the phenological data. Results significantly different were averaged and subjected to Tukey's test at a level of significance of 5%. Calculations were performed by the software Statistics 13 (StatSoft Inc., Tulsa, USA).

3. Results and Discussion

3.1 Climate Parameters

Table 2 shows climate parameters for the vegetative and reproductive stages of grapevines. The highest air temperatures occurred between flowering and *veraison*, from November to February. It should be noted that, in all three phenological cycles, the minimum temperatures were higher than the climatological average, i.e., they presented a positive anomaly. Higher annual minimum temperatures were also reported by Back et al. (2013), in Santa Catarina; by Malheiro et al. (2010), in different regions of Europe; and by Sadras et al. (2012), in Barossa Valley, Australia. This has been considered a global climate trend.

Table 2. Climate parameters and climatological averages (1961-2012) for the phenological stages of grapevines in the cycles of 2009-2010, 2010-2011, and 2011-2012, Água Doce, Santa Catarina, Brazil

Phenological Stages	Cycle	CD (days)	Climate Parameters						
			T max. (ºC)	T min. (ºC)	T mean (ºC)	RH (%)	Precip. (mm)	Rainfall days (n)	Sunlight (hours)
Budbreak/Flowering	2009/2010	64	21.3	11.7	15.5	76.8	387	22	333
	2010/2011	54	20.8	10.9	15.0	71.7	196	17	376
	2011/2012	55	21.0	10.8	14.8	82.7	238	22	385
	CA	58	20.7	10.7	14.8	74.6	351	15	328
Flowering/*Veraison*	2009/2010	78	24.9	15.2	18.8	77.7	458	30	426
	2010/2011	84	23.6	14.4	17.9	80.6	675	49	439
	2011/2012	73	24.0	13.8	17.3	81.0	322	35	559
	CA	78	24.0	13.6	17.6	74.3	414	16	494
***Veraison*/Harvest**	2009/2010	63	23.8	14.0	17.5	78.9	394	25	363
	2010/2011	49	22.5	14.2	17.3	83.9	336	22	213
	2011/2012	48	25.0	13.7	18.3	85.8	218	25	386
	CA	53	23.5	13.4	17.1	78.2	290	16	344
Budbreak/Harvest	2009/2010	205	23.3	13.6	17.3	77.8	1240	77	1122
	2010/2011	187	22.4	13.1	16.7	78.7	1207	88	1028
	2011/2012	176	23.4	12.8	16.8	83.2	778	82	1330
	CA	190	22.7	12.6	16.5	75.7	1053	47	1166

Note. CA: climatological average; CD: chronological duration; T max, T min, T mean: average maximum, minimum, and mean air temperature; RH: relative humidity; Precip.: precipitation.

In the Winkler Index, Água Doce is ranked "Region II", the same as the renowned winegrowing regions of Bordeaux, in France; Perugia, in Italy (Winkler, 1974); and San Francisco Bay, in the United States (Hall & Jones, 2010).

In the Huglin Index, the area is classified as "Cold". For comparison, the southern region of Bento Gonçalves is classified as "Warm temperate", and the northern region of Petrolina is classified as "Very warm" (Tonietto & Carbonneau, 1999).

In the Cool Night Index, the area is classified as "Region of cool nights" (12 ºC < T ≤ 14 ºC), the same as the regions of Bordeaux, in France; and Treviso, in Italy (Tonietto & Carbonneau, 1999). Cool conditions at night-time are favorable to the growing of grapes with better color and aroma (Back et al., 2013).

A mean precipitation of 1075 mm was calculated for the three growing season. In the 2009-2010 cycle, rainfall was higher due to the climatic phenomenon of "El Niño" and the incidence of diseases increased, especially during the *veraison* stage. On the other hand, in the 2011/2012 cycle, rainfall was lower than the climatological average, which favors quality of the grapevine.

Sunlight was highest in the phenological cycle of 2011-2012 (budbreak to harvest), even higher than the climatological average (Table 2). For comparison, in 2010, the region of São Joaquim was exposed to an average sunlight of 1380 hours (Gris et al., 2010). In a study on historical data from 2000 to 2009, Ribolli (2011) reports that the region of Trento, Italy, was exposed to 1400 hours of sunlight during the vegetative and reproductive cycles of the Marzemino variety (March to September in the northern hemisphere). On the other hand, the climatological average of sunlight in the region of Água Doce is about 16% smaller than that in Sao Joaquim and Trento.

3.2 Phenology

Figure 1 shows the duration of phenological stages per variety per cycle, and the dotted lines are the averages of the beginning phenological stage of all varieties studied. Budbreak occurred mostly in September for all varieties. Rebo was the earliest variety to budbreak (15 September, average) and Garganega was the latest (3 October, average). Rebo also presented the smallest cycle-to-cycle variability (standard deviation) in budbreak, while Primitivo presented the greatest one. The difference is probably due to edaphoclimatic conditions. Similar results were observed for other grapevine varieties in Santa Catarina (Brighenti et al., 2013, Brighenti et al., 2014) and in Veneto, Italy (Tomasi et al., 2011). In high altitude zones, early budbreak varieties are more susceptible of the frost demage (Brighenti et al., 2013), and because of this it is important the right choice of the varieties to be cultivated.

Flowering occurred from mid-November. Varieties presenting earliest and latest budbreaks also presented earliest and latest flowering, as observed by Tomasi et al. (2011) and Brighenti et al. (2013). Ancellotta presented the lowest cycle-to-cycle variation. Malvasia Nera presented the highest cycle-to-cycle variation and the largest time interval (26 days) between the earliest and latest flowering stages (Figure 1).

From Figure 1, for all the phenological cycles, *veraison* occurred in early February (average) within a range of 37 days between the earliest and latest start dates. The *veraison* period of the Vermentino variety started in 30 January (the earliest), while the *veraison* of Negroamaro started 21 days later, in 20 February (the latest). Fiano presented the lowest cycle-to-cycle variation (about 4.6 days) while Lambrusco presented the highest one (about 11.5 days).

Harvest occurred in early April (average). The earliest harvest occurred on 15 March, in the 2010-2011 cycle (Vermentino), while the latest harvest occurred on 14 April, in the 2009-2010 cycle (Lambrusco, Malvasia Nera, and Primitivo). Garganega presented the lowest cycle-to-cycle variation, while Primitivo presented the highest one.

In a study with 22 varieties of *Vitis vinifera* L. of Água Doce (Feldberg et al., 2011), Chardonnay and Cabernet Sauvignon were considered early and late varieties, respectively. Budbreak and harvest of Chardonnay were earliest (10 September and 13 March, respectively). Budbreak and harvest of Cabernet Sauvignon were latest (15 October and 14 April, respectively). In the present work, concerning budbreak and harvest timings, most of the varieties investigated are considered of intermediate cycle and classified as medium-late. In general, cultivation of early budbreak varieties at high altitudes (over 900 m a.s.l.) in Santa Catarina is limited due to the occurrence of late frosts.

From Table 3, the three phenological cycles (budbreak to harvest) averaged 190 days for all varieties. Garganega and Vermentino presented the shortest average cycles (178 and 179 days, respectively), while Lambrusco and Sangiovese presented the longest ones (202 and 203 days, respectively). The varieties of Água Doce possess longer phenological cycles when compared to the varieties in Italy, their place of origin. For example, the Rebo variety, in Trentina, presented an average phenological cycle of 170 days, from 1990 to 1997 (Malossini et al., 1999), 27 days shorter than in Água Doce. The Sangiovese variety, in Conegliano, presented an average cycle of 165 days, from 1964 to 2004 (Jones et al., 2005), 37 days shorter than in Água Doce. The Garganega variety, in Venice, presented an average cycle of 156 days, from 1964 to 2009 (Tomasi et al., 2011), 22 days shorter than in Água Doce. These differences are explained by the lower air temperatures of Água Doce, which results in less thermal requirements and consequently longer cycles.

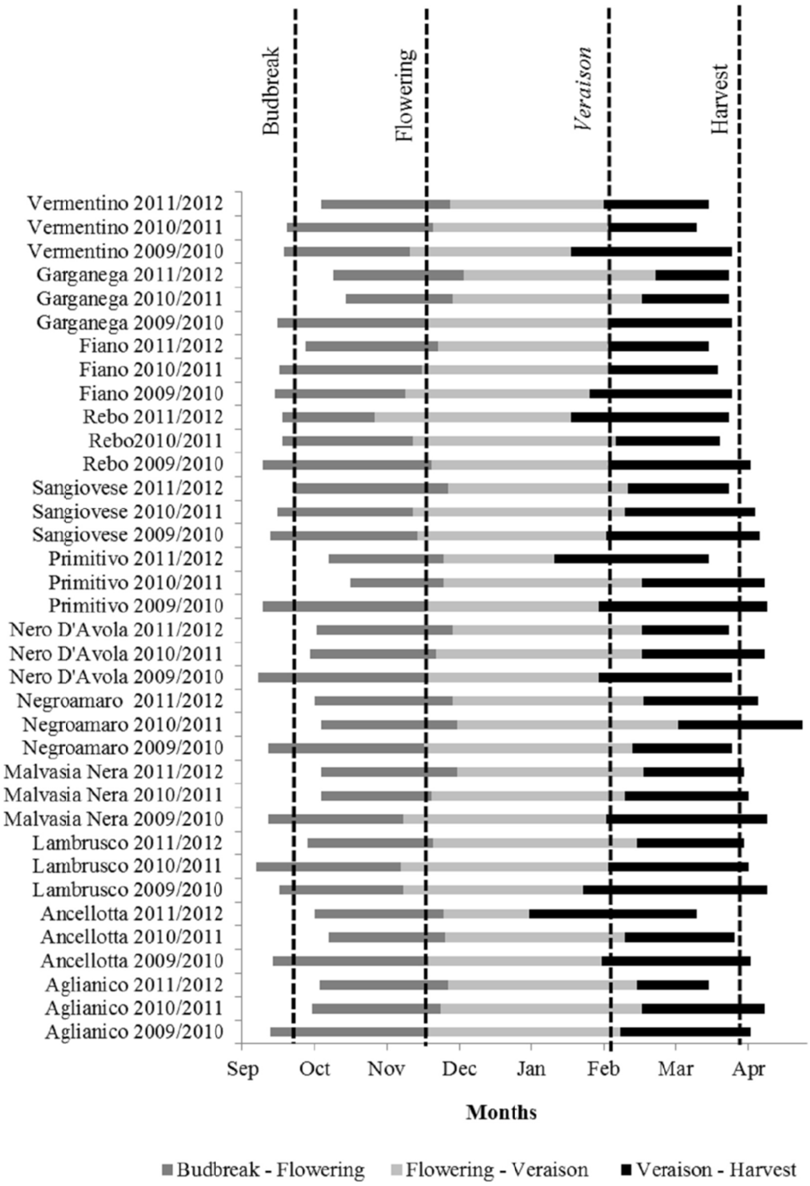

Figure 1. Duration of the phenological stages of grapevines in the cycles of 2009-2010, 2010-2011, and 2011-2012. Água Doce, Santa Catarina, Brazil

The duration of the phenological cycle is affected by weather conditions, as found by Hall and Jones (2010); Tomasi et al. (2011); Sadras et al. (2012); and Brighenti et al. (2014). Since the average air temperatures at high altitudes are lower than those of other renowned winegrowing regions, the vegetative and reproductive cycles of the vines become longer. Consequently, the exposure to solar radiation becomes higher, the timing of the phenological stages is shifted, and *veraison* becomes longer. Thus, the plants tend to present longer phenological cycles.

Differences were also observed between the timing of the phenological stages of the varieties grown in Água Doce and in São Joaquim, another important winegrowing region in Santa Catarina. Brighenti et al. (2014) report an average phenological cycle of 229 days for the Sangiovese variety, in São Joaquim. In comparison with Água Doce, budbreak was earlier (13 September) and harvest was later (17 April). This is due to climate differences between the two regions. São Joaquim ("Region I" in the Winkler scale) is cooler than Água Doce (Region II) (Gris et al., 2010; Borghezan et al., 2011, 2014).

Table 3. Average heat summation for each phenological stage of of grapevines in the cycles of 2009-2010, 2010-2011, and 2011-2012, Água Doce, Santa Catarina, Brazil

Varieties	Phenological Stages								Duration of cycle (days)
	Budb.-Flow.		Flow.-*Ver*.		*Ver*.-Harvest.		Budb.-Harvest.		
	∑GDD	CV(%)	∑GDD	CV(%)	∑GDD	CV(%)	∑GDD	CV(%)	
Aglianico	354 A	17.8	810 A	8.2	379 BC	7.7	1543 A	9.1	190 A
Ancellotta	347 A	20.2	685 B	10.1	472 AB	12.7	1503 A	11.3	182 A
Lambrusco	318 A	7.7	781 A	4.8	451 BC	8.0	1550 A	6.3	203 A
Malvasia Nera	361 A	15.0	691 B	27.6	354	8.5	1406 A	13.5	194 A
Negroamaro	325 A	6.2	845 A	13.1	457 AB	7.4	1627 A	5.7	194 A
Nero D'Avola	314 A	14.3	809 A	9.2	438 BC	11.5	1561 A	9.7	193 A
Primitivo	334 A	20.0	788 A	12.1	394 BC	12.4	1517 A	8.3	187 A
Sangiovese	375 A	17.2	775 A	7.7	421 BC	2.4	1571 A	6.2	202 A
Rebo	306 A	31.5	746 AB	12.2	531 A	18.0	1583 A	8.8	197 A
Fiano	335 A	14.0	751 A	10.3	494 AB	10.2	1580 A	7.9	187 A
Garganega	327 A	4.1	816 A	14.0	329 C	4.7	1472 A	9.1	178 A
Vermentino	354 A	22.4	698 B	12.7	476 AB	11.9	1528 A	10.4	179 A
Mean	**338**	**15.9**	**766**	**11.7**	**433**	**9.6**	**1537**	**8.9**	**190**

Note. Budb.-Flow.: budbreak to flowering; Flow.-*Ver*.: flowering to *veraison*; *Ver*.-Harvest: *veraison* to harvest; Budb.-Harvest.: budbreak to harvest; GDD: Growing Degree Day; CV: coefficient of variation.

Values with same letter within column are not significantly different by Tukey's test at a 5% probability.

The stage from budbreak to flowering presented an average thermal requirement of 338 GDD and average duration of 58 days. The induction of flowering stimulus occurs with rising air temperatures and high sunlight availability in the year preceding the harvest, as observed in the region studied in the present work (Table 2). The stage from flowering to *veraison* presented an average thermal requirement of 766 GDD (highest) and average duration of 79 days. The stage from *veraison* to harvest presented an average thermal requirement of 433 GDD and average duration of 54 days. Negroamaro, Rebo, and Fiano presented the highest thermal requirement, while Malvasia Nera, Garganega, and Ancellotta presented the lowest one. Differences in the duration of the *veraison* stage are due to varietal characteristics and environmental influences such as solar radiation, air temperature, photoperiod, and water availability.

There was an annual variation in the duration of the phenological stages of each variety (Figure 1) which may be related to the interaction between genotype and weather conditions. Similar variations were observed in the phenological cycles of 22 grapevine varieties in Conegliano, Italy, from 1964 to 2009 (Tomasi et al., 2011).

The average heat summation for each phenological cycle were 1740 GDD (205 days, 2009-2010), 1463 GDD (187 days, 2010-2011), and 1408 GDD (177 days, 2011-2012), with daily average of 8.5 GDD, 7.8 GDD, and 8.0 GDD, respectively. For comparison, the Cabernet Sauvignon variety (considered late cycle) presented a heat summation of 1430 GDD (214 days) and daily thermal requirement of 6.7 GDD in São Joaquim/SC (Brighenti et al., 2013); and a heat summation of 2072 GDD (174 days) and daily thermal requirement of 11.9 GDD in Campanha, Rio Grande do Sul (Radünz et al., 2015). Thus, the weather parameters of the varieties cultivated in Água Doce are found to lie between those of São Joaquim e Campanha and are due to location and regional thermal conditions.

4. Conclusion

Água Doce was found to possess appropriate thermal conditions for adequate phenological development of the grapevine varieties investigated.

The duration of the phenological stages of each grapevine variety is dependent on the interaction between genotype and environment, particularly local average ambient temperatures. The Rebo variety presented the earliest budbreak timing, while Garganega presented the latest one. Vermentino presented the earliest harvest timing, while Malvasia Nera e Lambrusco presented the latest one.

The heat summation (averaged 1537 GDD) varies with phenological cycle and variety. The phenological stage from flowering to *veraison* presented the highest thermal requirement.

The lower average temperatures observed in Água Doce, when compared to those in other regions where the varieties are traditionally produced, cause longer growing cycles and consequently a shift in the timing of the phenological stages of the grapevines.

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