VINEYARD ALTITUDE AND MESOCLIMATE INFLUENCES ON THE PHENOLOGY AND MATURATION OF CABERNET-SAUVIGNON GRAPES FROM SANTA CATARINA STATE

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Abstract

Santa Catarina State (SC) is a new grape growing region in Southern Brazil where 300 ha have been planted with *Vitis vinifera* L. since 2000. The annual production of this region is 3,944 tons of grapes and 1,549,000 liters of wine.

Aims: To evaluate the influence of climate and vineyard altitude on the phenology and ripening as well as the suitability of five new grape growing regions of SC for Cabernet-Sauvignon variety for two vintages (2005 and 2006).

Methods and results: Physicochemical analyses were performed on grape berries at 10-day intervals from véraison to harvest. Classification of the bioclimate according to the Winkler and Fregoni indices was also carried out for a long time period for these areas. Climate was strongly correlated with phenological precocity indices. Four Winkler Regions were established and the Fregoni index ranged from 402 to 1,466 for these regions.

Conclusions: A positive relationship was observed between altitude, air temperature and the annual vine cycle duration. In general, these Cabernet-Sauvignon grapes showed a good potential for winemaking mainly in Regions II and III of the Winkler scale.

Significance and impact of the study: Given the present and possible future changes in the global climate, the wine industry may be required to find new locations for viticulture. In this context, this research presents new grape growing regions which are promising for the cultivation of *Vitis vinifera* grape varieties in Brazil.

Keywords: phenology, ripening, Cabernet-Sauvignon grapes, vineyard altitude

Résumé

L'État de Santa Catarina (SC) est une nouvelle région viticole dans le sud du Brésil où 300 ha de *Vitis vinifera* L. ont été plantés depuis 2000. La production annuelle de cette région est de 3 944 tonnes de raisins et de 1 549 000 litres de vin.

Objectifs : Évaluer l'influence du climat et de l'altitude sur la phénologie de la vigne et la maturation du raisin, aussi bien qu'étudier l'adaptation du raisin Cabernet-Sauvignon à cinq différents sites ; deux millésimes consécutifs (2005 et 2006) ont été étudiés.

Méthodes et résultats : Des analyses physico-chimiques ont été réalisées sur des baies de raisin à intervalles de dix jours, de la véraison jusqu'à la récolte. Une classification bioclimatique des sites selon les indices de Winkler et de Fregoni a été également effectuée sur une longue période. Le climat a été fortement corrélé avec l'indice phénologique de précocité de la vigne. Quatre régions de Winkler ont été établies avec l'index de Fregoni compris entre 402 et 1 466.

Conclusions : Une corrélation positive entre l'altitude, la température de l'air et la durée annuelle du cycle de la vigne a été observée. Les raisins Cabernet-Sauvignon ont montré un bon potentiel pour la vinification surtout dans les régions II et III de l'échelle de Winkler.

Signification et impact de l'étude : Étant donné le climat actuel et ses futurs possibles changements, la filière viticole sera peut-être amenée à trouver de nouvelles zones viticoles. Dans ce contexte, cette recherche présente une nouvelle et prometteuse région viticole, dans des différents mésoclimats au sud du Brésil, où les conditions sont favorables au développement des raisins *Vitis vinifera*.

Mots-clés : phénologie, maturation, Cabernet-Sauvignon, altitude

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INTRODUCTION

It is well known that the world's great wines are produced in regions with an appropriate climate for growing specific grape varieties. Based on the environmental interactions, the viticultural profession has provided a world « zoning », mapping the ecopedological and geographical characteristics of the grape-growing territory in relation to the adaptive response of wine grapes (Morlat, 1992). These areas are also referred to as « terroir ». According to a modern concept, « terroir » is a delimited geographic area characterized by collective knowledge of the interaction between the physical and biological environment and applied vitivinicultural practices (Flutet *et al.*, 2008).

In recent years, several integrated and interdisciplinary studies have been carried out to determine the aptitude of vines for cultivation in different viticultural zones. These studies show the impact of different environmental characteristics such as hydrology (Petrie *et al.*, 2004), geology (Pereira *et al.*, 2007), climate (van Leeuwen *et al.*, 2004), and the surrounding ecology (van Leeuwen and Seguin, 2006), factors defining the singularity of an area in terms of grape production. Various studies have been carried out to investigate the terroir influence on grape and wine quality. However, in general, the analysis of the climate of a winegrowing region is often reduced to the analysis of data collected at one site, considered as representative of the whole winegrowing area (Jones and Davis, 2000; van Leeuwen *et al.*, 2004; Tonietto and Carbonneau, 2004). However, many regions exhibit a considerable variation at the mesoscale level (Hall and Jones, 2009). In the new winegrowing region of Santa Catarina, Cabernet-Sauvignon as been planted at five different altitudes above sea level (asl), which might affect dramatically the climate, grapevine development and grape quality.

Grape quality varies according to the daily temperature range during the ripening period, because this parameter affects the sugar and anthocyanin composition, as well as the aroma; photosynthesis occurs during the day and at night the photosynthesis products move from the source leaves to the fruit. During grape ripening, cool night temperatures favor the sugar accumulation and restrict the vegetative growth. Temperature effects on the exponential increase in respiratory activity, above 10 °C, have been reported (Champagnol, 1984;Mori *et al.*, 2005; Mori *et al.*, 2007), shedding light on the role of night-time temperature. It is known that the biological development of the grapevine is linked to temporal exchanges and it can be accelerated or delayed by climatic conditions. During grape ripening, temperature, sunlight exposure (Bergqvist *et al.*, 2001) and water balance (van Leeuwen *et al.*, 2004) are the main factors controlling wine quality. Grapes should be harvested when optimum levels of sugar, color and acidity are reached.

Thus, different bioclimatic indices have been proposed to characterize vine growing regions and the aptitude of different grape varieties for cultivation in the environment of a particular region (Winkler, 1974; Huglin, 1986, Fregoni and Pezzutto, 2000; Tonietto and Carbonneau, 2004). The Winkler index (heat summation as growing degree-days) is one of the most used in viticulture and it expresses the energetic aspect of the climate, considering temperatures above 10 °C during the grape-growing season. The Fregoni quality index (FI) is also widely applied for bioclimatic characterization of a vine-growing region; it considers daily temperature range during the ripening month (September in the northern hemisphere and March in the southern hemisphere) and the number of days with temperatures below 10 °C (Fregoni and Pezzutto, 2000).

Over the past 30 years, Santa Catarina State has had a history of cultivating *Vitis labrusca* varieties, which was initiated by Italian descendants who colonized this region. From the year 2000 onward, Santa Catarina can be divided into two primary grape producing regions designated as viticultural areas for *Vitis vinifera*: the river valley region of Vale do Rio do Peixe (sites at 774 and 1350 m asl) and the high plains region of Planalto Sul Catarinense (sites at 960, 1160 and 1415 m asl) (figure 1).

Given the importance of understanding climate impact on grape and wine quality, this paper reports the suitability of new grape growing regions in Brazil for Cabernet-Sauvignon variety, with regards to the mesoclimate and vineyard altitude and their relationship with vine phenology and berry attributes. This study focuses mainly on the role of air temperature and vineyard altitude on the vegetative rhythm of the vine cycle.

MATERIALS AND METHODS

1. Plant growth

The experiment was conducted across five commercial vineyards located at different altitudes in Santa Catarina State, South Brazil, on *V. vinifera* cv. Cabernet-Sauvignon in the 2005 and 2006 seasons. Data on the locations, altitudes, plant clones, vine training systems and soil types (U.S. soil taxonomy) are shown in figure 1. For all sites the row and vine spacing is 3.0 x 1.5 m, respectively, the rootstock is Paulsen 1103 (*V. berlandierli* Planch x *V. rupestris* Scheele), the clone is mostly R-5, except at Bom Retiro where it is 685, and the age of the vines is between 5 and 6 years. The vineyards yielded between 8 and 10 t/ha per year.

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2. Phenology

Pruning dates for the 2004/05 and 2005/06 seasons were respectively: SJA: 20/09/04 and 25/09/05; AD: 17/09/04 and 10/10/05; SJB: 11/09/2004 and 28/08/2005; BR: 15/09/04 and 25/09/05; VID: 10/09/2004 and 15/09/2005. Budbreak, flowering, véraison and harvest dates were recorded at each site according to Baillod and Baggiolini (1993). The method of Barbeau *et al.* (1998) was used to calculate the indices of precocity. This phenological classification incorporates the values for flowering (IPF), véraison (IPV) and annual cycle (IPCY), as following:

IPF = 100*[1 + (Fm – Fi)/Fm]
IPV = 100*[1 + (Fm – Fi)/Fm]
IPCY = IPF + 100*[(Vm – Fm) (Vi – Fi)/(Vm-Fm)]
where,
Fi = mean flowering (at 50%), year i
Fm = whole flowering in the same period
Vi = mean véraison (at 50%), year i
Vm = whole véraison in the same period

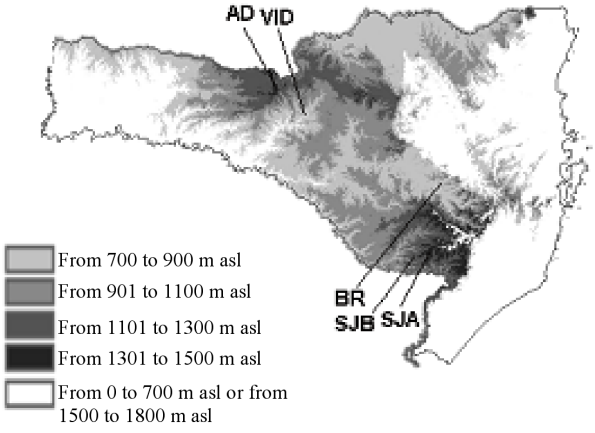
3. Climate data

The data were supplied by EPAGRI-SC (Empresa de Pesquisa e Extensão Agropecuária de Santa Catarina) and consisted of daily observations of maximum, minimum and mean temperatures, thermal amplitude and rainfall. Meteorological stations were located either within or in close proximity to the vineyards, except for the São Joaquim B site where the station located 4 km from the vineyard was used. The potential evapotranspiration (ET_o) was calculated according to Thornthwaite and Mather (1955); the Thornthwaite water balance uses an accounting procedure to analyze the allocation of water among various components of the hydrologic system. Inputs to the model are temperature and precipitation. Outputs include monthly potential and actual evapotranspiration and soil moisture storage.

The majority of Santa Catarina State is covered with Atlantic Forest vegetation. All of the grape-producing regions are near these forest areas, in valleys or elevations, from the south to the north of the State, between latitudes 26° and 28°. The altitudes of the five studied locations are between 774 and 1,415 m asl. Given the differences in the terrains of the valleys or elevations, the mesoclimates may vary considerably (figure 1).

4. Bioclimatic characterization

The Winkler index (Winkler *et al.*, 1974) was applied to the climatic data for the whole growing season (from budbreak to harvest) (Winkler Index) and for the phenologic periods (phGDD) (dates used to calculate annual Winkler Index and phGDD are shown in the figure 4), and the Fregoni quality index (FI) (Fregoni and Pezzuto, 2000) was applied to the temperature data, considering March as the ripening month (southern



Site	Altitude[a]	Latitude	Longitude	Clone	VCS[b]	Soil Type
SJA	1415	28°16' 41"	49°55' 96"	R-5	Y[d]	Inceptisol
AD	1350	26°43'30''	51°33'22'''	R-5	VSP[c]	Inceptisol
SJB	1160	28°19'0''	49°34'51''	R-5	Y[d]	Inceptisol
BR	960	27°53'5''	49°34'51''	685	VSP[c]	Inceptisol
VID	774	27°0'14''	51°9'0''	R-5	Y[d]	Oxisol

Figure 1 - Map of the Santa Catarina State, Southern Brazil, with detailed planting characteristics of each studied vineyard.

SJA = São Joaquim A, AD= Agua Doce; SJB= São Joaquim B; BR= Bom Retiro; VID = Videira. Acknowledgement: EPAGRI/CIRAM. [a]Meters above sea level (asl). [b]Vine Conduction System (Y = form). [c]Vertical Shoot Positioning Trellis System.

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hemisphere). These indices were calculated using the following equations:

$$GDD = \sum (T_{>10°C} - 10°C)\ (Winkler\ index)$$

Where:

Winkler's Regions	Winkler Index (°C)
Region I (cold)	< 1,389
Region II (moderately cold)	1,390-1,667
Region III (warm)	1,668-1,944
Region IV (moderately warm)	1,945-2,222
Region V (hot)	> 2,222

(Winkler *et al.*, 1974).

$$FI = \sum_{i=1/III}^{30/III} (T\max_i - T\min_i).(n°dd < 10°C)$$

(Fregoni quality index, South Hemisphere)

The cool night index (CNI) was considered as the minimum average air temperature of the last month of the growing period. The class of viticultural climate is described as follows: ≤ 12 °C = very cool nights; >12 °C ≤ 14 °C = cool nights; > 14 ≤ 18 °C = temperate nights; >18 °C warm nights (Tonietto and Carbonneau, 2004).

5. Berry samples and commercial maturity analysis

Sampling began at véraison which was defined as the time when approximately 50 % of the berries have changed color. Between véraison and harvest a total of 5-7 samples were collected at 10-day intervals from the five vineyards. At each vineyard, 30 vines in two central rows were selected for testing. A total of 240 berries (eight berries per vine) were collected per sampling date. Harvest began when each crop reached commercial maturity (TSS at 20-24 °Brix). Berry samples were rapidly collected, counted, weighed and submitted to physicochemical analysis. Each sample of 240 berries was divided into three sub-samples (90, 90 and 60 berries). For berry maturity analysis, juice was squeezed from a fresh, randomly selected 30-berry sample, in triplicate (total of 90 berries). Juice samples were analyzed according to OIV (1990) procedures for pH, titratable acidity (TA), total soluble solids (TSS, °Brix).

6. Berry composition analysis

a) Anthocyanin extraction and quantification

A sub-sample of 90 fresh berries was divided into three lots (30 berries per lot). The skins were gently removed and then macerated overnight at 4.0 ± 1 °C, in the dark, using 12N HCl:methanol (1:99) as solvent at a ratio of 1:5 weight (g):volume (mL). The crude extract of the grape skins obtained was filtered under vacuum through a Whatman nº 1 filter paper using a Büchner funnel. Total monomeric anthocyanins (TMA) was determined by the pH-differential method of Giusti and Wrolstad (2001), using Σ = 28000 and MW = 529 (Amerine and Ough, 1976).

b) Total Polyphenols Index (TPI)

The Folin-Ciocalteu assay was used and total phenolic content was expressed as gallic acid equivalents (GAE) in milligrams per 100 gram of fresh grape skins.

7. Color measurement

Color intensity (CI), teinte (tint, T) and combined anthocyanins (d*A*, %) were calculated according to Glories (1984) using a 1 mm path-length cuvette: CI = Abs 420 + Abs 520 + Abs 620 nm;

$$dA\ (\%) = Abs\ 520 - \frac{(Abs\ 420 + Abs\ 620)}{2} \times \left(\frac{1}{Abs\ 520}\right) \times 100$$

8. Statistical analysis.

Analysis of Variance (ANOVA) and the Tukey Honestly Significant Differences (HSD) tests were performed using Statistica 6 (2001) (StatSoft Inc., Tulsa, OK, USA). Regression analyses were performed using Origin 6 (1991-1999) (Microcal Software Inc., Northampton, MA, USA).

RESULTS AND DISCUSSION

1. Santa Catarina as a new growing region for *V. vinifera* grapes

Given the great climatic variation in this state (Winkler's Regions from I to IV, figure 1), it is expected that new appellations may appear in the future. The total rainfall (mm) registered by the meteorological stations from budbreak to harvest at the different locations and for the two vintages evaluated varies from ~ 480 to 980 mm, as shown in figure 2. A significant variation in the mean daily temperature between seasons can also be observed for the studied sites (figure 2); however, the sites in Region IV and Region I, located at the lowest and highest altitudes (asl) of this study, were found to be the warmest and coolest, respectively, during all of the phenological events. In general, data published on the cumulative water consumption during the growing season ranges from 500 to 1,200 mm (Doorembos and Kassam, 1979). In the case of California, Winkler *et al.* (1974) showed that this parameter varies from 405 to 1,370 mm, according to the climate, soil and grape variety.

The variable intensity of the atmospheric factors measured, such as evapotranspiration (ET_o), indicates that the evaporative demand of the vines was variable over seasons and sites. Monthly ET_o values during the 2005 and 2006 seasons are given in figure 3. For the sites

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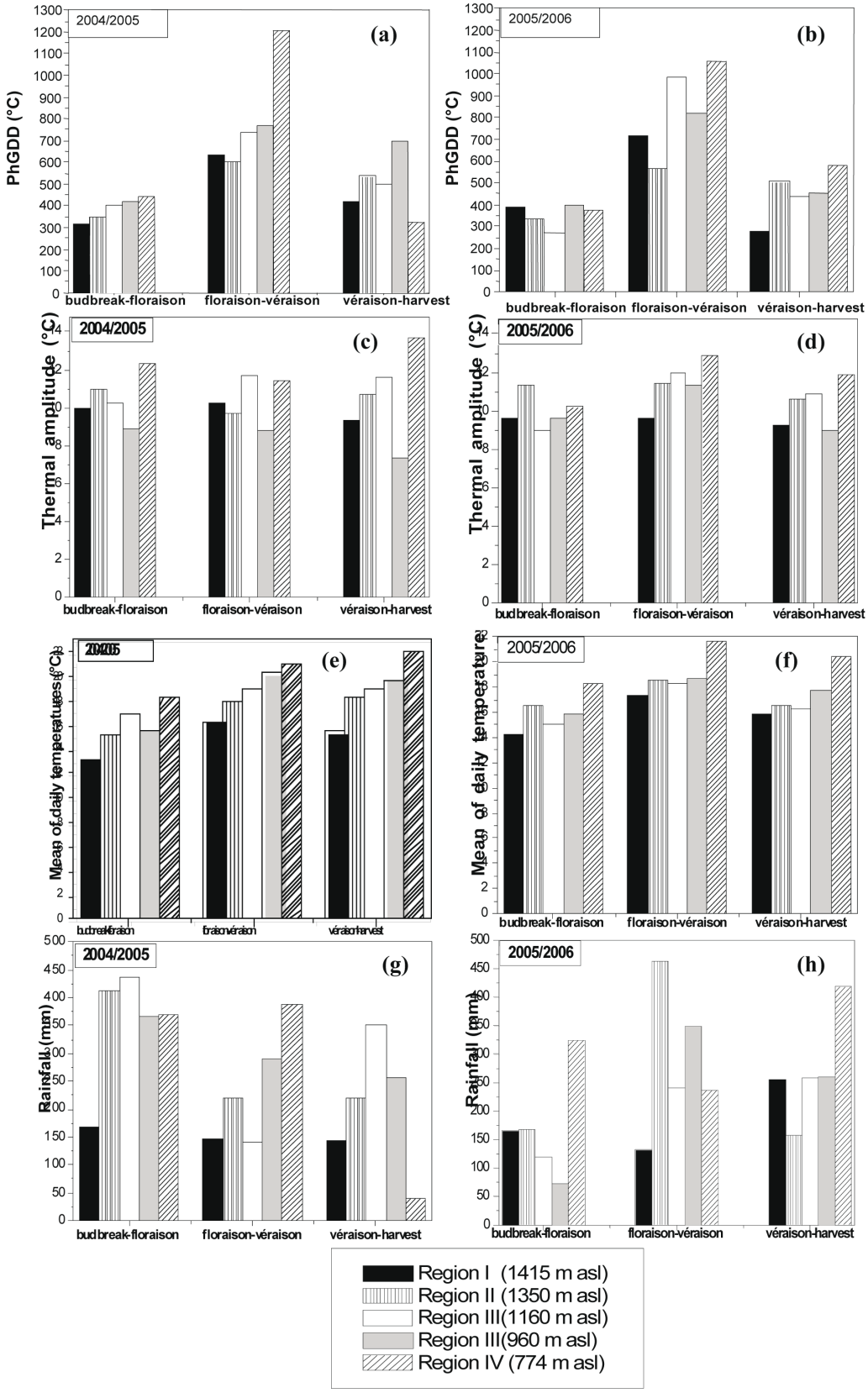


Figure 2 - Mesoclimate in the vineyards at different altitudes (asl) during the main phenological events in the 2004/05 and 2005/06 seasons.

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studied, the evaporative demand ranged from 677 to 933 mm for the 2004 and from 664 to 885 mm for the 2005 season, with minimum and maximum values observed in Regions II and IV, respectively (figure 3).

Thermal amplitude values were more significant in the vineyards located in a valley rather than on a high plains, as expected: Region IV, located at the lowest altitude and with the shortest ripening period, showed the highest values for thermal amplitude (Δ) during the maturation period (Δ = 12 and Δ =13.7 °C, respectively, in 2004/05 and 2005/06) in relation to all the other Winkler Regions (values ranged from 7.3 to 1.6 °C) (figure 2). These values are lower than those observed in Santiago-Chile (Δ =15.8 °C) and close to those observed in the Bordeaux Region during the ripening period Δ Δ= 10.5 °C (Tonietto and Carbonneau, 2002). Owing to the annual thermal profiles in some regions, the night-time temperature during ripening can be so low that it minimizes the pool depletion of carbohydrate excess for nocturnal growth. However, under isothermal conditions, the balance between photosynthesis and respiration is critical for the vine.

With regard to the Glories parameters, Region IV showed lower values of CI and Abs 520 nm when compared to the other sites; for this site, low anthocyanin content was also observed (table 1, figures 8 and 9). This finding is in agreement with Lebon (2002), who postulated that significant warming during maturation, and especially at night, would disrupt flavor and color development and ultimately the wine's typicity. Thus, we can assume that not only the thermal amplitude is important to provide a high quality wine region but, above all, cool nights at ripening are required, which are practically not observed in Region IV (CNI ~16.8 over 27 years, table 3). Moreover, it seems that the potential of a grape in terms of winemaking is directly related to the amount of time the cluster remains attached to the vine. This suggests that cool climates may be responsible for an increase in wine quality, because the plants accumulate degree days at a slower rate during the vine annual cycle than those in warmer climates, and also the grapes can stay on the vine longer. Another important observation is that, in general, the sooner the vine cycle begins, the later it finishes (figures 8 and 9); taking this fact into consideration along with the grape profile at harvest (figures 8 and 9, table 3), we can consider Region III interesting for the development of the Cabernet-Sauvignon variety.

The average climatic data for the growing season over a long period of time showed that the wind strength is high at the highest altitudes (table 3), with values varying from 1.2 (at 774 m, asl) to 5.7 Km/h (at 1,350 m, asl) and that the 774 m site has the lowest values for relative air humidity (74.3 %) among the sites studied (table 3). Wind has both positive and negative effects on viticulture. Strong winds in spring and early summer can inhibit new growth and injure young bunches, as well as reduce the fruit set (Carey *et al.*, 2002). Moderate winds stronger than 3-4 $m.s^{-1}$ can result in closure of stomata in the leaves resulting in inhibition of photosynthesis (Hamilton, 1989). However, in areas where the soil has a potential for high vigor, strong winds may be conducive to quality by limiting the vegetative growth of the vine, also preventing high relative humidity and excessively high temperatures

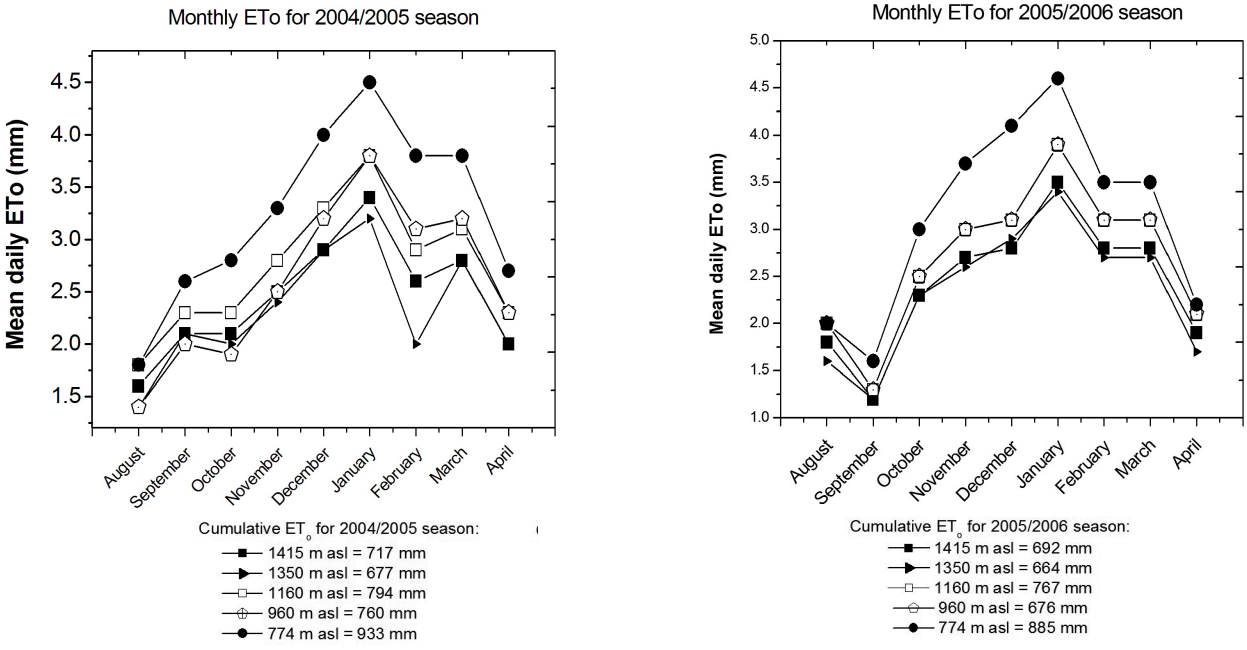


Figure 3 - Normal daily and cumulative ET_o values for 2004/05 and 2005/06 growing seasons.

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Table 1 - Results of repeated measurements of berry composition at commercial maturity for the 2005 (in normal font) and 2006 (in italics) vintages.

Analyses	Berry composition at commercial maturity				
	Winkler's Region I	Winkler's Region II	Winkler's Region III		Winkler's Region IV
	1415 m asl 2005 $^{\alpha}$: 15.1 °C *2006 $^{\beta}$: 15.8 °C*	1350 m asl 2005: 17.1°C *2006: 17.3°C*	1160 m asl 2005: 18.0 °C *2006: 16.5 °C*	960 m asl 2005: 18.5 °C *2006: 17.5 °C*	774 m asl 2005: 20.4 °C *2006: 20.1 °C*
TSS (°Brix)	21.4 ± 0.07 ^{a}	22.5 ± 0.36 ^{a}	23.0 ± 0.71 ^{a}	22.5 ± 0.50 ^{a}	21.7 ± 0.29 ^{a}
	21.8 ± 0.15 ^{a}	*20.8 ± 0.25 ^{a}*	*24.2 ± 0.55 ^{b}*	*20.2 ± 0.38 ^{a}*	*21.0 ± 0.06 ^{a}*
pH	3.60 ± 0.09 ^{a}	3.79 ± 0.05 ^{b}	3.80 ± 0.00 ^{b}	3.73 ± 0.03 ^{b}	3.59 ± 0.05 ^{c}
	3.42 ± 0.02 ^{a}	*3.45 ± 0.02 ^{a,b}*	*3.55 ± 0.04 ^{b,d}*	*3.85 ± 0.02 ^{c}*	*3.57 ± 0.01 ^{d}*
TSS *x* pH^2	277± 3.00	323 ± 2.00	332 ± 1.00	313 ± 2.00	279 ± 1.00
	255 ± 1.00	*247 ± 1.00*	*305 ± 4.00*	*299 ± 2.00*	*268 ± 3.00*
Total acidity (TA)*	0.75 ± 0.03 ^{a}	0.65 ± 0.02 ^{b}	0.67 ± 0.00 ^{c}	0.76 ± 0.02 ^{c}	0.85 ± 0.00 ^{c}
	0.95 ± 0.03 ^{a}	*0.90 ± 0.06 ^{a,b}*	*0.87 ± 0.07 ^{a,b}*	*0.70 ± 0.02 ^{b,c}*	*0.59 ± 0.02 ^{c}*
TSS/TA	29 ± 1.00 ^{a}	35 ± 0.40 ^{b}	34 ± 1.06 ^{b}	29 ± 0.50 ^{c}	26 ± 0.31 ^{a}
	23 ± 1.03 ^{a}	*23 ± 2.00 ^{a}*	*28 ± 1.17 ^{a,b}*	*29 ± 1.12 ^{b,c}*	*36 ± 1.20 ^{c}*
200 Berry weights (g)	296	280	284	274	292
	335	*292*	*254*	*294*	*325*
TMA**	365 ± 0.40 ^{a}	379 ± 1.41 ^{b}	380 ± 17.68 ^{b}	401 ± 1.41 ^{c}	310 ± 0.29 ^{d}
	421 ± 14.60 ^{a}	*477 ± 4.50 ^{b}*	*392 ± 1.00 ^{c}*	*304 ± 0.71 ^{d}*	*332 ± 2.08 ^{e}*
TPI***	653 ± 6.14 ^{a}	906 ± 12.40 ^{b}	727 ± 52.72 ^{a,b}	890 ± 46.52 ^{b}	757 ± 85.29 ^{a,b}
	639 ± 18.35 ^{a}	*766 ± 10.40 ^{b}*	*761 ± 15.95 ^{b}*	*621 ± 35.10 ^{a}*	*782 ± 8.03 ^{c}*
Abs 420 nm	0.92 ± 0.02 ^{a}	1.05 ± 0.01 ^{b}	1.25 ± 0.02 ^{c}	0.87 ± 0.00 ^{a}	0.65 ± 0.01 ^{d}
	0.87 ± 0.03 ^{a,b}	*1.02 ± 0.01 ^{a}*	*0.86 ± 0.02 ^{a,b}*	*0.61 ± 0.02 ^{c}*	*0.88 ± 0.01 ^{b}*
Abs 520 nm	2.07 ± 0.01 ^{a}	2.93± 0.00 ^{b}	3.02 ± 0.01 ^{a}	2.3 ± 0.02 ^{c}	1.67 ± 0.02 ^{d}
	2.72 ± 0.04 ^{a,b}	*3.10 ± 0.04 ^{a}*	*2.52 ± 0.02 ^{b}*	*1.46 ± 0.06 ^{c}*	*2.51 ± 0.05 ^{b}*
Abs 620 nm	0.27 ± 0.01 ^{a}	0.17 ± 0.01 ^{b}	0.34 ± 0.00 ^{c}	0.16 ± 0.01 ^{d}	0.11 ± 0.00 ^{e}
	0.08 ± 0.01 ^{a}	*0.11 ± 0.00 ^{a,b}*	*0.10 ± 0.00 ^{a}*	*0.11 ± 0.00 ^{a}*	*0.15 ± 0.00 ^{b}*
Colour intensity (CI)	3.25 ± 0.01 ^{a}	4.15 ± 0.01 ^{b}	4.60 ± 0.01 ^{b}	3.33± 0.02 ^{c}	2.44 ± 0.02 ^{d}

α and β represent the mean of average temperatures during the growing season. *Expressed as g of tartaric acid/100 mL of grape juice; **Expressed as mg of malvidin-3-glucoside/100 g of fresh grape skins; ***Expressed as mg of gallic acid equivalent/100 g of fresh grape skins. Different letters on the same line indicate a statistical difference (Tukey HSD Test, $p < 0.05$).

from developing in the vine canopies (Carey *et al.*, 2002). We can assume that in these areas a beneficial effect of the wind strength is observed at the vineyards located above an altitude of 900 m.

The variation in measured environmental parameters for a vineyard, such as temperature, is considered as part of the assessment of a terroir. Cabernet-Sauvignon is grown in regions that span from intermediate to hot climates with growing seasons in the range of 16.5 to 19.5 ºC (e.g., Bordeaux or Napa) (Jones, 2007). In Santa Catarina State, the average growing season temperatures varied from 15.4 to 20.2 °C in the 2005 and 2006 seasons (table 2). The 1,415 m (asl) site is the coldest area of all those studied. The temperatures increase with a decrease in altitude (figure 2) and at the site at 774 m (asl), where the highest temperatures are observed in summer, the grape harvest occurs between late February and mid March, while in the other regions it occurs between mid April and early May (Falcão *et al.*, 2007). We can note from table 1 that commercial maturity was reached at all sites; our results for the maturation indices are close to those observed by Ryona *et al.* (2008) with Cabernet franc berries from New York State. However, we have recently published that there is a strong negative correlation between seasonal temperatures or vineyard altitude and the 2-methoxy-3-isobutylpyrazine content of Cabernet-Sauvignon wines (MIBP, « bell pepper » aroma); also, high contents of MIBP were measured in the wines made with Cabernet-Sauvignon grapes from the sites above 1,000 m asl (Falcão *et al.*, 2007). However, this viticultural activity began too recently to foresee the future of these winegrowing regions and efforts are being made to improve the aromatic characteristics of these wines (new canopy management, rootstocks, winemaking techniques, etc.). Our real challenge is to understand why completely ripe berries of Cabernet-Sauvignon from some cooler regions maintain a high content of MIBP at harvest whereas wines from low altitudes have more red fruit character and sweet fruit esters (Falcão *et al.*, 2007).

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Table 2 - Average climate data and Fregoni and Winkler classifications for the different sites in 2005 and 2006 vintages.

Sites	Bioclimatic classifications for 2005 and 2006 vintages								
	Winkler index[a] (WI)			Cool night temperatures (CNI)			Fregoni index[b] (FI)		
	2005	2006	Mean WI 2005-2006	2005	2006	Mean CNI 2005-2006	2005	2006	Mean FI 2005-2006
Region I [c] (1415 m)	1378	1383	1380	10.6	9.3	10.0	930	1789	1203
Region II [d] (1350 m)	1483	1406	1444	14.3	11.7	13.0	357	988	672
Region III [c] (1160 m)	1638	1695	1667	12.6	12.4	12.5	270	518	389
(960 m) [c]	1882	1672	1777	15.9	13.7	14.8	253	1747	1000
Region IV [d] (774 m)	1975	2008	1992	15.6	15.7	15.7	433	371	402

[a]Carried out on the temperature data of growing season; [b]Carried out on the temperature data of March (southern hemisphere); [C]Atlantic climate. [d]Continental climate. *WI calculated from September to April.

Table 3 - Typical mesoclimate data and bioclimatic classifications for different studied sites over a long time period.

	Mean growing season climatic data for a long period of time									
Sites	Growing season Period*	Wind speed (Km/h)	UR %	Rainfal (mm)	Tmin (°C)	Tmax (°C)	Tmean (°C)	WI average	CNI average	FI average
Region I [a] (1415 m)	From 1955 to 2005	2.6	78.7	1245.5	11.2	20.5	15.0	1213	10.6	μ = 1011 σ = (249 -2250)
Region II [b] (1350 m)	From 1961 to 2005	5.9	77.1	1188.1	12.7	22.2	16.7	1660	12.9	μ = 605 σ = (234 -2665)
Region III [a] (1160 m)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	μ = 310 σ = (207 -1044)
Region III [a] (960 m)	From 2003 to 2005	2.0	77.3	1237.1	13.3	20.0	16.1	1643	14.5	μ = 316 σ = (251-940)
Region IV [b] (774 m)	From 1978 to 2005	1.3	79.0	1114.4	14.3	26.4	19.5	2219	16.8	μ = 657 σ = (313-2464)

[a]Atlantic climate; [b]Continental climate. *Growing season period for each region are presented in figure 4. UR% and Wind speed are average of mean growing season data. WI = Winkler index ; CNI = Cool night temperatures; FI = Fregoni Index.

2. Bioclimatic indices and phenology

The Winkler index (growing degree days) (Winkler *et al.*, 1974) attributes the vintage quality to thermal environmental conditions during the growth period. The Winkler Index values observed at the studied sites vary from approximately 1380 to 2000 during the whole growing season (figure 2, table 2). This characterizes the 1,415 m site as « Region I » (São Joaquim A < 1,389 °C), the coldest of Winkler Scale five regions, the 1,350 m site as « Region II » (Água Doce, 1,390 – 1,667 °C), a « moderately cold » region, and the 1,160 m and 960 m sites as « Region III » (São Joaquim B and Bom Retiro, 1,668 – 1,944 °C), mild regions in terms of temperature. The 774 m site was classified as « Region IV » (Videira, 1945 – 2,222 °C), considered as « moderately warm » according to the Winkler scale (Winkler *et al.*, 1974). Similar temperature conditions are observed in well-known regions for grape planting around the world: Region I – Rhine Valley (Germany) and the French regions of Champagne and Côte d'Or; Region II – Bordeaux

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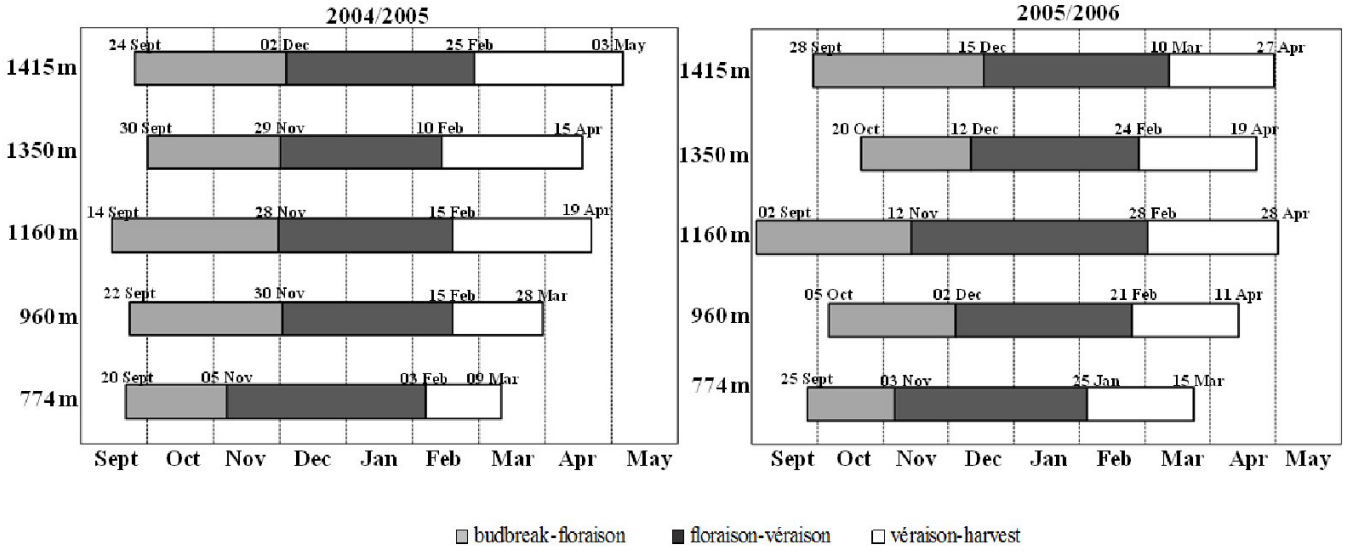


Figure 4 - Duration of phenological events for the vineyards selected at different altitudes, for the 2004/05 and 2005/06 vintages.

(France); Region III, Rhône Valley (France); and Region IV-San Diego and San Joaquin, California (USA). Region II of the Winkler Scale is assumed to be the best for cultivation of the Cabernet-Sauvignon variety. Nevertheless, this classification is too simplistic. Although it is worth considering the local daily temperature, factors which concern « terroir » (terrain, rainfall, latitude, altitude, soil conditions, and pollution, among others) should also be taken into account in order to evaluate the viticultural capacity of a region.

It is known that the phenology of wine grape development is predominantly temperature-driven (Jones and Davis, 2000). With regard to the Winkler Index, Region II was the only site where practically no difference in the total Winkler Index distributions occurred between the 2005 and 2006 seasons. Conversely, for all the other Winkler Regions, the distribution of phGDD varied considerately within a season. We can assume that phGDD distribution exerts an influence on the phenological cycle of the vine, but it varies according to the specific Winkler Region. In Region I (São Joaquim A), the 2005 vintage showed lower phGDD values for the budbreak-flowering period (313 in 2005 against 390 in 2006), but significantly higher phGDD values for the véraison-harvest period (423) when compared with the 2006 season (278) (figure 2). As a consequence, the véraison-harvest period in 2006 was shorter (figure 4).

In warmer climates, the véraison-harvest period is shorter when compared with colder regions. This was observed for Region IV (« moderately warm »), when compared with the other cooler Winkler Regions (figure 4, table 3). However, in Region IV a great difference in the véraison-harvest period was observed between vintages, with 2005 showing the shortest period. In 2005, an atypical season was observed for this site. More precisely, 40 mm of rainfall were observed during ripening, whereas the typical value is ~200 mm (data not shown). This shorter véraison-harvest period may be attributed to the fact that water deficit increases the berry ripening speed, as it reduces competition for carbohydrates between shoot growth and grape ripening (van Leeuwen and Seguin, 1994).

Phenological characteristics among the sites indicate that the variation in the budbreak and flowering dates was considerably high for the 2006 vintage. The mid-budbreak date ranged from 02 September to 05 October in 2006, while in the 2005 season it ranged from 14 to 30 September (figure 4).

Two-year averages of the precocity indices varied considerably for the five sites (figure 5). Except for Region IV, all the Regions were late in relation to the annual cycle (IPCY > 100) (Barbeau *et al.*, 1998). Overall, Region I had the latest cycle (IPF, IPV and IPCY < 100) and Region IV had the earliest cycle among the studied vineyards. In addition, Region I showed the lowest variability of all sites in the precocity indices.

Our results are in agreement with a study carried out by Barbeau *et al.* (1998), who observed a positive correlation between IPCY and degree-days during the vegetative period for different *Vitis vinifera* grape varieties. Also, Tesic *et al.* (2001) verified an important and positive correlation between temperature (average for the month of January) and the precocity indices IPV and IPCY for Australian Cabernet-Sauvignon grapes.

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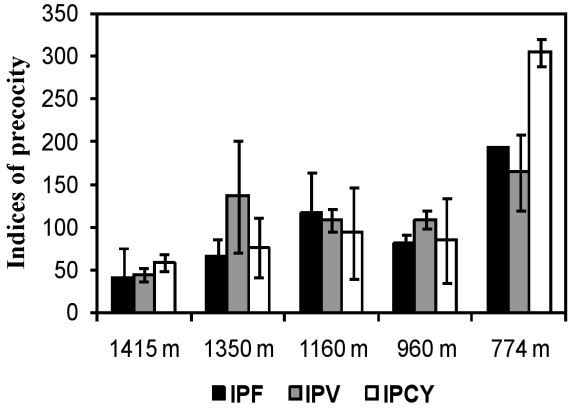


Figure 5 - Two-year averages of the indices of precocity for Cabernet-Sauvignon vines at the different sites.

Index of precocity for flowering (IPF), véraison (IPV) and annual cycle (IPCY) for the sites at different altitude (asl). Vertical bars denote ± standard inter-annual deviation (N= 2 seasons).

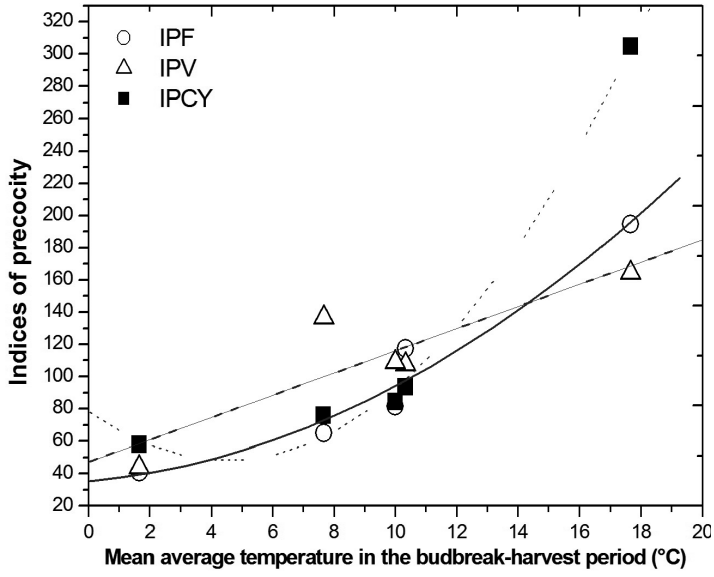


Figure 6 - Relationship between indices of precocity and the mean air temperature at the sites at different altitudes.

The average air temperatures for the entire growing season were correlated with vineyard altitude levels. It should be noted that when the altitude increases, the growing season climate becomes colder (R^2=0.993, p=0.10); this observation becomes more significant if we compare the mean temperatures for winter and summer seasons among sites (Falcão *et al.*, 2007). Thus, at the high locations, where the climate is colder, in general, the annual cycle of the grapevine occurs later than at the lower altitude sites (figures 3 and 5). Undoubtedly, this varies according to the viticultural region and for this reason our findings differ from the results of a similar study on Cabernet Franc by Morlat (1992), who found no relation between air temperature in the Loire Valley and site precocity (altitudes ranged from ~ 50 to ~250 m asl).

On the whole, mean temperature values were similar for seasons 2005 and 2006 in the Regions I (cold), III (mild) and IV (moderately warm). Conversely, for the sites located in Region II (moderately cold), a decrease in the mean temperatures was observed in the 2006 season. From véraison to harvest, São Joaquim B and Bom Retiro (Region II) showed mean temperatures of 19 and 19.7 in the 2005 and of 16.3 and 17.8°C in the 2006 vintages, respectively. It was observed that the coldest temperature during ripening in 2006 coincided with a strong increase in the TA values at maturity (figure 2, table 1).

The Fregoni quality index (FI) is obtained using thermal differences and the number of days with temperatures < 10 °C at ripening (which is not considered by the Winkler index) (Fregoni and Pezzutto, 2000). Since cool nights at ripening result from the vineyard altitude, wind strength, areas being located on elevations or in valleys, and proximity to the ocean, the optimum or minimum FI varies remarkably from one region to another and also between seasons within a region. In our results, the average FI values ranged from 402 to 1,466 for the 2005 and 2006 seasons, and high variability was observed for Region II and Bom Retiro (Region III), as shown in table 3. It is apparent that more vintages should be added to this study to verify the climate characterization of the different sites. However, we did observe that there is no association between the Winkler index and FI, and that Region IV, the warmest of the regions, showed the lowest FI values (402) when compared to the sites located in the other Winkler Regions. According to Bavaresco *et al.*, (2008), published data show that FI values range from 200 to 20,000 and the optimal FI varies according to different climates. In regions with cool climates, like Germany and Switzerland, the best vintages correspond to intermediate FI values (2,000-3,000 in Germany and 5,000-6,000 in Switzerland), while in the warmer region of South Africa, the best vintages correspond to the highest FI (~400).

3. Berry development at maturity

The most common indicators of grape must quality are pH, total soluble solids and acidity, which correspond to « commercial » or « industrial » maturation. An optimum « technological maturation » is reached when the grapes have a certain chemical composition (normally related to the phenolic composition), which gives specific characteristics to the wine. Nevertheless, it is known that there is no synchrony between commercial and technological maturation (Robredo *et al.*, 1991).

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Figure 7 gives the results of grape maturation monitoring in the 2005 and 2006 vintages. At the beginning of ripening, for both vintages, the titratable acidity (TA) of grapes was higher for vineyards located in Regions I and II (1,415 and 1,350 m asl). Acidity dropped abruptly over the first 10 maturation days at these sites in both vintages. For Region I, this drop was 0.90 and 0.58 g/L for 2005 and 2006, respectively, while for Region II these differences were 0.65 and 0.42 g/L for the same vintages, respectively.

The importance of grape must pH is well recognized since it is directly associated with prevention of microbiological deterioration, malolactic fermentation and color stability of wines (Amerine and Ough, 1976). Comparing the pH values obtained from all locations during ripening, significant differences are observed between the vintages (figure 7). In 2005, the pH values increased in a similar way for the grapes from the studied sites; Region II and São Joaquim B (Region III) showed the highest harvest pH values. In 2006, a strong difference in the pH evolution of Bom Retiro grapes (Region III) was observed in relation to the other sites. At this site, the highest harvest pH values were registered in the 2006 rather than the 2005 vintage, which were closely associated with a decrease in the CI and TMA values.

In general, total monomeric anthocyanins (TMA) reached the maximum concentration approximately 40 days after véraison. For the 2005 vintage, a decrease in the TMA concentration for 10-20 days before harvest was observed in the grape must from the Region I to III vineyards. A linear evolution of the TMA was observed at Region IV, which may be attributed to an atypically low rainfall at this site during the 2005 season (figures 1 and 6). The anthocyanin content and color intensity of grapes from Region IV were the lowest and differed significantly from the other locations studied ($p < 0.05$) (table 1). Comparing the seasons, with the exception of the Bom Retiro site (Region III), an increase in the CI from 2005 to 2006 can be noted at the time of the grape harvest.

The 2005 rainfall during ripening was higher, when compared to the 2006 vintage (figure 2), and this may have influenced the phenolic compounds content in the grape skins. As reported by Ryan and Revilla (2003) and Canals *et al.* (2005), the evaluation of anthocyanins present during the grape ripening is difficult, due to the strong effects of environmental and cultural conditions.

For the 2006 vintage, a decrease in total polyphenols (TPI) before harvest was observed only at Region I and at São Joaquim B (classified as Region III). For the 2005 vintage, a sudden drop in the TPI and TMA concentrations was observed for São Joaquim B grapes (Region III), ten days before harvest. This was strongly associated with the high rainfall index during this period (~100 mm during the 10-day period prior to harvest). Despite an important difference in the rainfall indices for the 2005 and 2006 vintages, the Region IV grapes showed a similar phenolic content evolution for the two vintages.

Concerning the TSS values, there was no significant difference among the evaluated sites ($p < 0.05$) for the 2005 vintage, while the maturation indices (MI) were higher when compared to the grapes cultivated in Regions I and II.

In 2006, grapes from Regions I and II had much lower TSS/TA values than those recommended by Gallander (1983, 30-32) or Amerine *et al.* (1980, 37-38). This is the most used index for commercial quality grapes; however, according to Boulton *et al.* (1996), the TSS/TA ratio is a universal index which can have a low real impact on the global quality of a wine. Another historic maturation index used frequently by viticulturists is TSS x pH^2 for which values between 202 and 266 indicate an optimum maturation state (Coombe *et al.*, 1980). It can be observed that for all locations, and both vintages, the values for this maturation index lie between 247 and 332. These results show that the TSS/TA index used alone is not sufficient to define the commercial maturity. For both vintages, São Joaquim B – Region III had the highest TSS values, whereas São Joaquim A – Region I had the highest values for berry weight (table 1).

As a rule, it is assumed that warmer climates result in high sugar and low acidity levels whereas cooler climates result in low sugar and high acidity levels. From our results, for both vintages, an inverse relationship between vineyard elevation and juice pH ($R^2 = 0.40$, $p = 0.002$) was observed, however, a high sugar content was measured at all sites (table 1).

Principal components analysis (PCA) considering the principal indicators of grape maturity (pH, TA, berry weight, TSS x pH^2, TSS/TA, Abs 520nm; CI, TMA, TPI, dA%) and the Winkler index, Fregoni index, thermal amplitude, ET_0 and cool night temperatures was carried out on correlation matrix.

Figure 8 gives the PCA results for the 2005 vintage. The Factor 1 x Factor 2 axes account for 82.3 % of the total variance among the data; the first axis represents 53.18 % and the second axis 29.18 % of the total dispersion. The Factor 1 axis shows that all of the grape quality parameters are strongly positively correlated with this factor. In 2005, Regions II and III appear to be more strongly correlated with the grape quality parameters, such as polyphenols, maturity indices and color characteristics (figure 8). In contrast, region I was correlated to berry weight and the Fregoni index.

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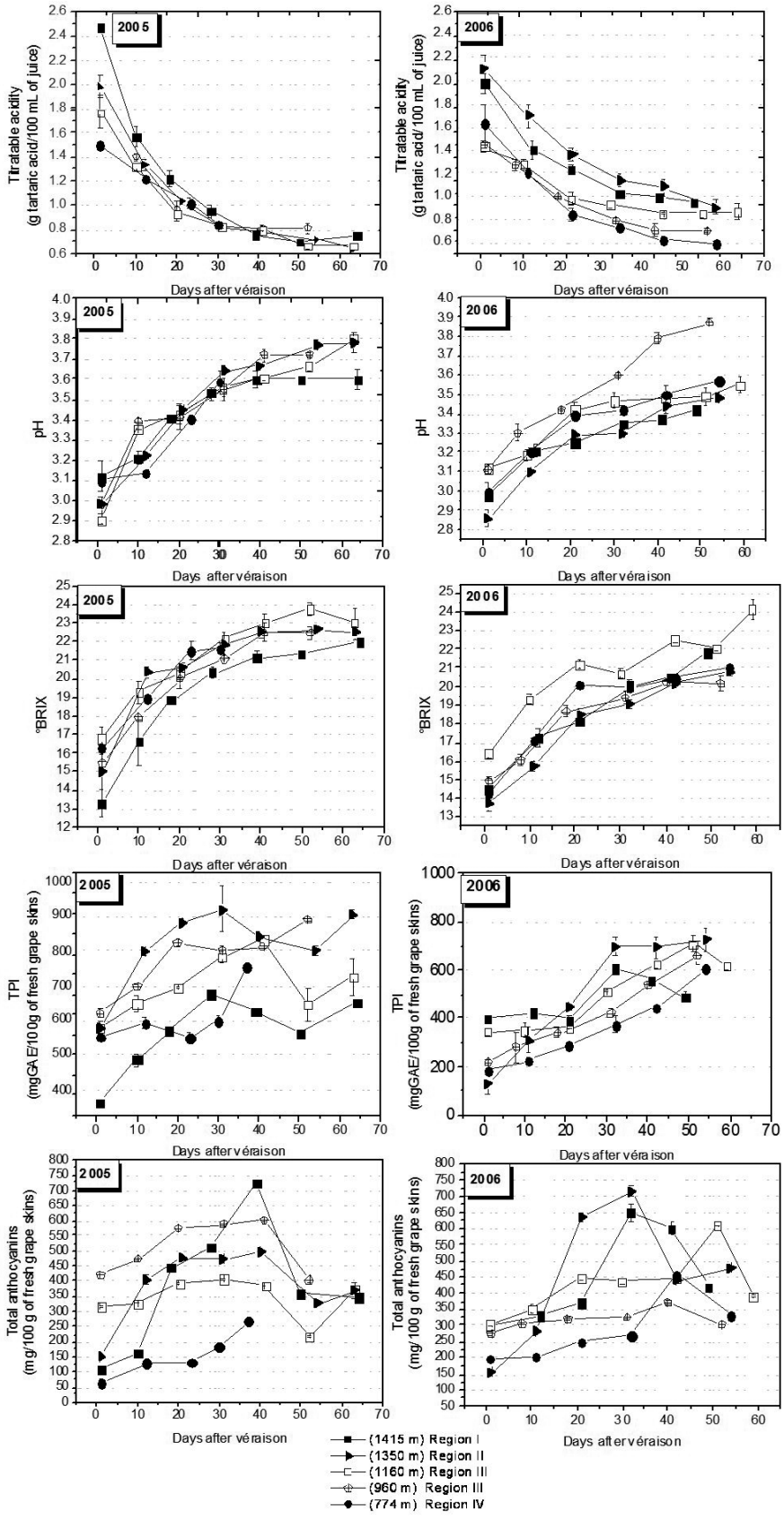


Figure 7 - Maturation monitoring of the 2005 and 2006 seasons.
Vertical bars denote ± standard deviation.

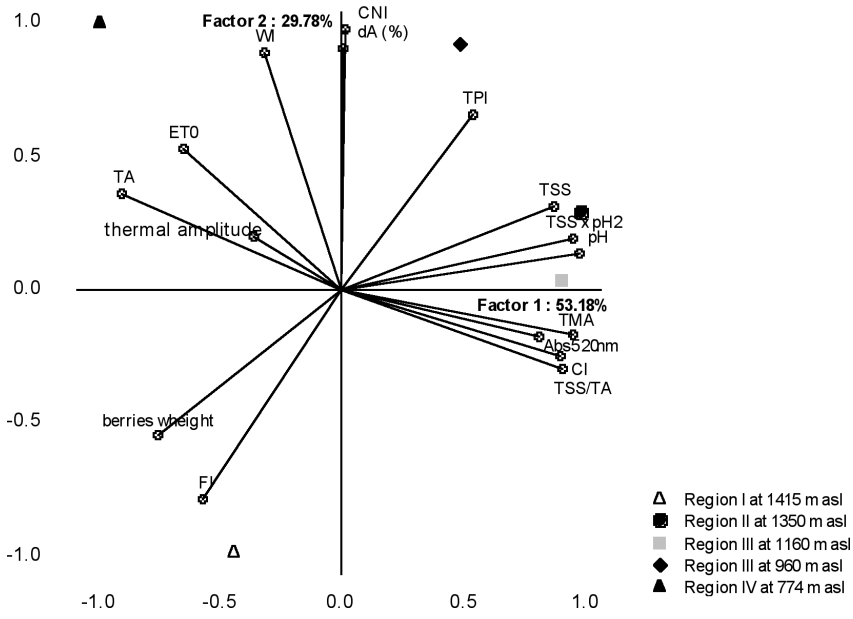


Figure 8 - PCA of grape quality parameters at maturity and bioclimatic indices for the 2005 season.
CI= color intensity; CNI= cool night temperatures, TPI= total polyphenols index; TMA = total monomeric anthocyanins; TSS= total soluble sugars; TA= total acidity; FI= Fregoni index; WI= Winkler index.

Figure 9 gives the PCA results for the 2006 vintage. The Factor 1 x Factor 2 axes account for 80.72 % of the total variance among the data; the first axis represents 50.03 % and the second axis 30.09 % of the total dispersion. The Factor 1 axis shows WI, TSS/TA and ET_0 to be associated with dA%, while the thermal amplitude is more strongly associated with TPI. In 2006, cool night temperatures were clearly associated with the grape color parameters and TSS. Factor 2 shows that the Fregoni index is negatively correlated with thermal amplitude and the grape quality parameters. Region I as in 2005, is associated with the Fregoni index and berry weight, while Regions II and III are directly associated with the polyphenols and color parameters. Region IV is directly correlated with thermal amplitude.

A complete understanding of the grapevine-climate relation is difficult to achieve and remains a challenge for researchers seeking to describe the diversity of the « terroir » and define its influence on the grape composition. In this study, we have attempted to address some issues related to the « zones of altitude » for the cultivation of wine grape varieties in Santa Catarina State. In summary, the findings reported here support the current awareness that climatic influences determined by the location of a vineyard are very important factors in the determination of the final grape quality. More precisely, this is based on the assumption that for vineyards at high altitudes, which have a cooler growing season, the vine annual cycle (IPCY) of Cabernet-Sauvignon grapes occurs later: Region IV (at 774 m asl) and I (1,415 m asl) showed, respectively, the lowest and the highest IPCY. For the four different Winkler Regions the average results for the Fregoni quality index ranged from 402 (Region IV) to 1466 (Region III). The performance of Cabernet-Sauvignon grapes varied according to the climatic characteristics of the sites; nevertheless, the grapes adequately completed their ripening process, showing interesting characteristics at the time of harvest, such as a high concentration of TSS and phenolic compounds (TMA and TPI). Of the areas studied, Regions II and III appear to be the most promising for cultivation of the Cabernet-Sauvignon variety. Few research data on the wine quality characteristics of these young wine growing sites have been collected to date, and it is thus difficult to provide a complete profile of the suitability of each Winkler Region in Santa Catarina State.

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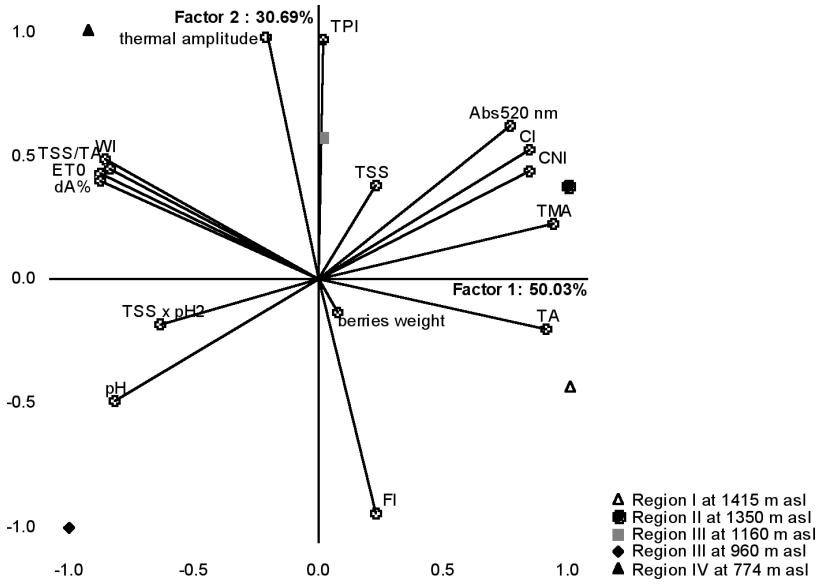


Figure 9 - PCA of grape quality parameters at maturity and bioclimatic indices for the 2006 season.
CI= color intensity; CNI= cool night temperatures, TPI= total polyphenols index; TMA = total monomeric anthocyanins; TSS= total soluble sugars; TA= total acidity; FI= Fregoni index; WI= Winkler index.

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