CHANGES IN EUROPEAN WINEGRAPE PHENOLOGY AND RELATIONSHIPS WITH CLIMATE

LES CHANGEMENTS DANS WINEGRAPE PHENOLOGY EUROPEEN ET LES RELATIONS AVEC LE CLIMAT

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Abstract:
This research presents a summary of the observed winegrape phenological characteristics and trends across many regions and varieties in France, Italy, Spain, Germany, and Slovakia. In addition, the research examines concomitant climatic changes that have influenced the phenological timing. The results reveal significantly earlier events (6-18 days) with shorter intervals between events (4-14 days) across most regions. In addition, warming trends in most regions are evident and have clearly influenced these changes in the phenological cycle of winegrapes in Europe. Changes are typically greater in minimum temperatures than maximum temperatures, with an average warming of 1.7°C during the growing season and increases of nearly 300 growing degree-days or Huglin index values over the last 50 years.
Keywords: *Vitis vinifera*, grapevines, phenology, climate, climate change

Résumé:
Cette recherche présente un résumé des caractéristiques de phenological de winegrape observées et les tendances à travers beaucoup de régions et les variétés en France, Italie, Espagne, Allemagne, et Slovaquie. En plus, la recherche examine des changements climatiques concomitants qui ont influencé le moment de phenological. Les résultats révèlent événements significativement des précédents (6-18 jours) avec les intervalles plus courts entre les événements (4-14 jours) à travers la plupart des régions. En plus, chauffer des tendances dans la plupart des régions sont évidentes et a influencé clairement ces changements dans le cycle de phenological de winegrapes dans Europe. Les changements sont typiquement plus grands dans les températures minimums que les températures maximums, avec une moyenne chauffe de 1.7°C pendant la période de croissance et d'augmentations de presque 300 degré-jours croissants ou les valeurs d'index de Huglin durant ces 50 dernières années.
Mots clés: *Vitis vinifera*, les vignes, phenology, le climat, le changement de climat

INTRODUCTION

Phenology is the study of the relationships between climate and the timing of periodic natural phenomena such as migration of birds, insect growth stages, and the flowering of plants. Knowledge of phenological system characteristics is never more important than with *Vitis vinifera* grapevines where the optimum development of quality fruit for wine production is tied to phenological occurrence and timing (Jones and Davis, 2000). In addition, because grapevine phenology is strongly tied to climate and has been observed in many regions over many years, its study has received considerable attention as a tool to understand how changing climates impact crops (Chuine et al. 2004; Spanik et al. 2004; Duchêne and Schneider, 2005; and Menzel, 2005). Given its importance to wine production and the understanding of impacts of climate change, the purpose of this study is to provide an overview of the characteristics and trends in grapevine phenology across multiple varieties and regions in Europe (Figure 1). In addition, climate characteristics and trends are examined for each region and related to phenological timing.

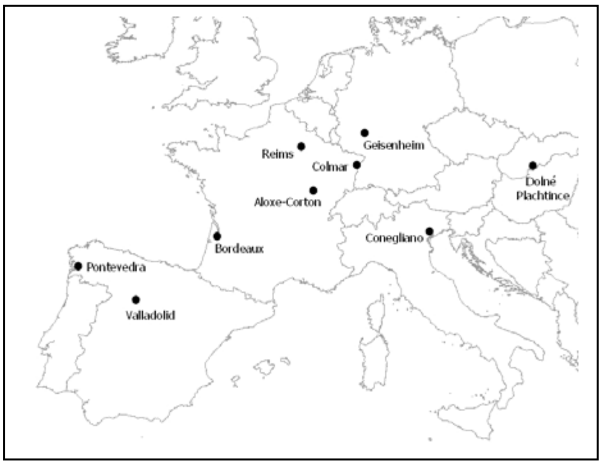

Figure 1 – *Locations where both phenology and climate were examined in this study.*
Figure 1 – *Les emplacements où phenology et le climat ont été examinés dans cette étude.*

DATA AND METHODS:

To examine phenological characteristics data was organized from nine regions across Europe and for fifteen varieties (Figure 1 and Table 1). The phenological data for most regions are for bud break, bloom, véraison, and harvest (harvest is the most subjective event with the date more dependent on the observer's determination of ripeness) for individual varieties as given by either the Bagglioni or equivalent Eichhorn-Lorenz grapevine growth descriptive systems (Baggiolini, 1952; Eichhorn and Lorenz, 1977). The main exception is that the two late season phenological events for Geisenheim are referenced to when the fruit obtained a given level of sugar (25° Oechsle and 60° Oechsle). Another exception is that the Bordeaux data do not include a bud break variable and are from reference vineyards that are noted for combined red varieties (Merlot and Cabernet Sauvignon). Furthermore, the data come from differing time periods that range from five years for Albariño in Pontevedra, Spain to 52 years for Pinot Noir at Aloxe-Corton in Burgundy (Table 1). To analyze the characteristics and trends in phenology, simple descriptive statistics and linear trends were calculated for each phenological event and the intervals between each event for each location (trends were not calculated for the shorter time periods for both locations in Spain).

Climate data were also obtained from stations located in the same regions as the phenology data (Figure 1 and Table 2). The climate data was collected on a daily timescale and the common parameters consisted of precipitation, average temperature, maximum temperature, and minimum temperature. The data where further summarized into annual values for each season (winter-DJF, spring-MAM, summer-JJA, and fall-SON) and the overall growing season (Apr-Oct). Other variables derived for further analysis include the Huglin Index for Apr-Sept (Huglin, 1978) and growing degree-days (GrDD) for Apr-Oct (Amerine and Winkler, 1944). The exception was for Slovakia where monthly data resulted in no calculation of the Huglin Index. To analyze the characteristics and trends in the climate parameters, simple descriptive statistics and linear trends were calculated for all variables at each location.

RESULTS:

Phenological characteristics across the studied regions (Table 1) indicate that bud break occurs on 14 April on average with a regional variation of nine days and a range of one month (Albillo Real in Valladolid on 29 March to Reisling in Geisenheim on 27 April). Bloom averages 13 June with a regional variation of five days and a range of 17 days (Chardonnay in Congeliano on 4 June and Pinot Noir and Reisling on 21 June in Reims and Geisenheim, respectively). Véraison occurs on 17 August on average with a regional variation of seven days and a range of 22 days (Chardonnay in Congeliano on 6 August and Reisling on 28 August in Dolné Plachtince). Harvest dates for the locations and observed varieties average 28 September with a regional variation of eight days and a range of one month (Chardonnay in Congeliano on 11 September and Reisling on 12 October in Dolné Plachtince). The window of time by which each event typically occurs varies slightly between varieties but are shown to be greater for bud break (10 days) and harvest (11 days), than for bloom and véraison (each 7 days) (Table 1). In addition, correlations between phenological events were found to be much stronger between bloom, véraison, and harvest ($0.6 < r < 0.9$) than bud break with any other event (not shown). The correlation magnitudes observed typically increase through the growing season with the highest correlations between véraison timing and harvest.

For the twelve variety/location combinations with long enough records for a trend analysis, the results showed that significant changes in bud break occurred in three locations; earlier in two locations (Reisling in Alsace and Pinot Noir in Burgundy) and later at one location (Trebbiano in Conegliano). Significant changes in bloom dates were seen for eleven of the twelve locations, with an average change of 11 days earlier (Table 1). Véraison dates were significantly earlier for eight of the twelve locations, with an average change of 15 days earlier. Significant changes in harvest dates are also evident with eleven of the twelve locations experiencing earlier harvests (17 days earlier on average). Trends in the intervals between events (i.e., number of days between bud break to bloom, etc) showed a general reduction in the interphases that was most significant for the later season events than those for the earlier season events (not shown).

Climate characteristics for the locations studied show that precipitation averages 463 mm during the growing season with a range of 207 mm in Valladolid to 815 mm in Conegliano (Table 2). The average growing season temperature across all regions is 16.1°C, but ranges from 14.4°C in Reims to 18.4°C in Conegliano. The maximum temperature average during the growing season is 21.8°C with a low of 19.7°C in Reims to a high of 23.9°C in Valladolid. The average growing season minimum temperature is 10.4°C with a high of 12.9°C in Conegliano to a low of 9.0°C in Reims. Growing degree-days (summed above a 10°C base temperature for Apr-Oct) average 1350 units with a low of 1042 in Reims to a high of 1803 at Conegliano. Huglin index values average 1855 across the regions with a low of 1524 in Reims and a high of 2257 in Conegliano (Table 2).

Trends in climate parameters are strong across most of the locations (Table 2). Growing season precipitation has showed the least change with only Pontevedra and Bordeaux experiencing trends to more rainfall. Growing season average temperatures increased in seven of the nine locations, averaging 1.7°C warmer. Average maximum temperatures during the growing season increased at seven of the nine locations with an average warming of 1.8°C. Growing season average minimum temperatures increased at all nine locations, averaging 1.9°C. In addition, seasonal warming (winter, spring, summer, and fall) is more pronounced in the spring and summer, than winter and fall (not shown). Growing degree-days increased for eight of the nine regions, resulting in an average change of 264 units, while Huglin index values changed in six of the nine regions with an average of 285 units.

DISCUSSION AND CONCLUSIONS:

Over the last 50 years grapevine phenological timing in Europe has tended earlier with more significant changes in later events than earlier events. Few changes in bud break timing across the locations indicate that spring temperature variability is very evident and may be masking climate trends during the early season. On the other hand, the more significant changes in bloom, véraison, and harvest hint at a cumulative plant response to growing season changes. Trends in climate parameters reveal a general warming across the grape growing regions studied. It is important to note that the warming observed in seasonal and growing season minimum temperatures, was more significant and at a higher magnitude than maximum temperatures for the majority of locations (Table 2). Correlations between grapevine phenology and climate parameters are strong ($-0.4 < r < -0.8$) with maximum temperatures more important for early season events (bud break and bloom), and average temperatures, growing degree-days, and Huglin index values more important for later season events (véraison and harvest) (not shown).

Jones et al. (2005) examined past and future climates in the majority of the world's best wine regions, including the majority of the locations studied in this research. The results showed warming over the last 50 years of similar magnitudes found in this study and found that vintage ratings during the same period increased and were significantly related to growing season temperatures. To examine future climate change, the authors used output from the HadCM3 climate model, and found that average growing season temperatures are projected to warm by 2.1°C by 2050 in Europe. While the observed warming of the late 20th century appears to have been mostly beneficial for high quality wine production, the Jones et al. (2005) analysis suggests that the impacts of future climate change will be highly heterogeneous across varieties and regions. If the relationships between climate and grapevine phenology found in this analysis hold for future predicted changes, then an additional 2.1°C of warming will likely advance phenological events by an additional 10-20 days. Critically, in some regions, warming may exceed varietally specific optimum climates such that the ability to ripen balanced fruit from the existing varieties grown and the production of current wine styles will be challenging.

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Table 1 – *Location, varieties, and time period of the phenological data for the regions studied in the analysis. Characteristics and trends are given for bud break, bloom, véraison, and harvest (except where noted).*

Table 1 – *L'emplacement, les variétés, et chronométrez la période des données de phenological pour les régions étudiées dans l'analyse. Les caractéristiques et les tendances sont données pour la coupure de bourgeon, la fleur, véraison, et la moisson (sauf où réputé).*

Region/Variety	**Time Period**	**Bud Break**		**Bloom**		**Véraison**		**Harvest**	
		X, SD[1]	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**
Alsace, France **Reisling**	1972-2004	23-Apr (9 d)	-14 days(0.24)	18-Jun (9 d)	-15 days(0.26)	28-Aug (11 d)	-22 days(0.34)	6-Oct (11 d)	-23 days(0.41)
Reims, France **Pinot Noir**	1975-2004	17-Apr (9 d)	NS	21-Jun (8 d)	-14 days(0.29)	15-Aug (12 d)	-22 days(0.28)	25-Sep (9 d)	-18 days(0.24)
Burgundy, France **Pinot Noir**	1952-2004	17-Apr (10 d)	-11 days(0.11)	13-Jun (10 d)	-11 days(0.13)	8-Aug (8 d)	-10 days(0.13)	25-Sep (10 d)	-16 days(0.21)
Bordeaux, France **Merlot/Cab.Sauv.**	1952-2001	No Data	No Data	11-Jun (9 d)	-6 days(0.08)	17-Aug (9 d)	-10 days(0.11)	30-Sep (10 d)	-16 days(0.24)
Conegliano, Italy	1964-2004								
Chardonnay		12-Apr (8 d)	NS	4-Jun (8 d)	-12 days(0.33)	6-Aug (8 d)	-13 days(0.39)	11-Sep (13 d)	-21 days(0.33)
Sangiovese		16-Apr (7 d)	NS	9-Jun (7 d)	-12 days(0.27)	13-Aug (8 d)	NS	28-Sep (10 d)	-14 days(0.19)
Cabernet Sauv.		23-Apr (6 d)	NS	10-Jun (7 d)	-10 days(0.22	15-Aug (8 d)	-12 days(0.26)	27-Sep (8 d)	-8 days(0.10)
Trebbiano		26-Apr (6 d)	+6.5 days(0.11)	13-Jun (6 d)	-6 days(0.10)	20-Aug (7 d)	NS	3-Oct (10 d)	NS
Geisenheim, Germany **Reisling**	1955-2004	27-Apr (7 d)	NS	21-Jun (8 d)	NS	**25° Oechsle** 24-Aug (12 d)	NS	**60°Oechsle** 17-Sep (15 d)	-21 days(0.24)
Dolné Plachtince, Slovakia	1971-2004								
Reisling		23-Apr (6 d)	NS	14-Jun (8 d)	-12 days(0.18)	28-Aug (10 d)	-12 days(0.30)	12-Oct (11 d)	-15 days(0.16)
Müller Thurgau		20-Apr (6 d)	NS	11-Jun (8 d)	-10 days(0.14)	12-Aug (8 d)	NS	23-Sep (11 d)	-14 days(0.14)
Chardonnay		16-Apr (7 d)	NS	8-Jun (8 d)	-12 days(0.19)	20-Aug (10 d)	-19 days(0.30)	4-Oct (10 d)	-17 days(0.23)
Valladolid, Spain	1996-2004		No Trend Analysis		No Trend Analysis		No Trend Analysis		No Trend Analysis
Verdejo		5-Apr (10 d)		14-Jun (5 d)		25-Aug (4 d)		29-Sep (9 d)	
Grenache		4-Apr (11 d)		18-Jun (6 d)		26-Aug (7 d)		5-Oct (10 d)	
Tinta del Páis		10-Apr (10 d)		14-Jun (4 d)		18-Aug (6 d)		3-Oct (9 d)	
Tinta de Toro		9-Apr (10 d)		16-Jun (4 d)		18-Aug (5 d)		30-Sep (9 d)	
Mencía		5-Apr (10 d)		14-Jun (5 d)		18-Aug (4 d)		4-Oct (9 d)	
Albillo Mayor		5-Apr (9 d)		15-Jun (5 d)		18-Aug (4 d)		2-Oct (13 d)	
Albillo Real		28-Mar (10 d)		12-Jun (5 d)		7-Aug (5 d)		17-Sep (16 d)	
Pontevedra, Spain **Albariño**	2001-2004	7-Apr (8 d)	No Trend Analysis	6-Jun (4 d)	No Trend Analysis	21-Aug (13 d)	No Trend Analysis	6-Oct (5 d)	No Trend Analysis

[1] X and SD are the mean (date) and standard deviation (days) of each variety analyzed.

[2] Trend is the trend in days over the time period for each region/variety. The number in parentheses is the R^2 of the trend with all trends shown significant at the 0.05% level.

Table 2 – *Location and time period of the climate data for the regions studied in the analysis. Characteristics and trends in average growing season average, maximum, minimum temperatures, and precipitation along with growing degree-days, and the Huglin Index are given (except where noted).*

Table 2 – *L'emplacement et chronomètre la période des données de climat pour les régions étudiées dans l'analyse. Les caractéristiques et les tendances dans la moyenne de période de croissance de aveage, maxmum, les températures de minmum, et la précipitation avec les degré-jours croissants, et l'Index de Huglin est donné (sauf où réputé).*

Location- Time Period	**Growing Season (April-October)**										**Huglin Index[3]**	
	Precipitation (mm)		**Taverage (°C)**		**Tmaximum (°C)**		**Tminimum (°C)**		**GrDD**			
	X, SD[1]	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**	**X, SD[1]**	**Trend[2]**
Colmar, France 1972-2004	No Data		15.0°C 1.0°C	+2.1°C 33 years (0.37)	20.6°C 1.1°C	+2.7°C 33 years (0.54)	9.6°C 0.7°C	+1.7°C 33 years (0.53)	1180 166	+376 33 years (0.44)	1687 208	+413 33 years (0.34)
Reims, France 1970-2004	385 mm 67 mm	NS	14.4°C 0.7°C	+1.2°C 35 years (0.29)	19.7°C 0.9°C	+1.2°C 35 years (0.15)	9.0°C 0.6°C	+1.3°C 35 years (0.32)	1042 128	+209 35 years (0.23)	1524 155	+205 35 years (0.15)
Aloxe-Corton, France 1959-2003	432 mm 103 mm	NS	16.0°C 0.8°C	NS	21.5°C 1.0°C	NS	10.5°C 0.9°C	+1.6°C 45 years (0.25)	1318 172	+165 45 years (0.08)	1818 201	NS
Bordeaux, France 1949-2003	487 mm 117 mm	+115 mm 55 years (0.08)	16.8°C 0.9°C	+2.1°C 55 years (0.41)	22.2°C 1.0°C	+1.6°C 55 years (0.21)	11.5°C 1.0°C	+2.5°C 55 years (0.56)	1486 193	+416 55 years (0.40)	1906 197	+351 55 years (0.27)
Conegliano, Italy 1959-2004	815 mm 172 mm	NS	18.4°C 0.8°C	+1.7°C 46 years (0.40)	23.5°C 1.0°C	+1.3°C 46 years (0.16)	12.9°C 1.0°C	+2.7°C 46 years (0.56)	1803 160	+340 46 years (0.38)	2257 170	+271 46 years (0.22)
Geisenheim, Germany 1951-2003	336 mm 73 mm	NS	14.7°C 0.7°C	+1.1°C 53 years (0.19)	19.9°C 0.9°C	+0.9°C 53 years (0.10)	10.0°C 0.7°C	+1.7°C 53 years (0.53)	1111 141	+215 53 years (0.20)	1612 170	+212 53 years (0.13)
Dolné Plachtince, Solvakia	392 mm 94 mm	NS	16.4°C 0.8°C	+1.3°C 34 years (0.21)	21.5°C 1.0°C	+2.0°C 34 years (0.33)	9.5°C 0.7°C	+1.3°C 34 years (0.31)	1225 148	+242 34 years (0.23)	No Data	
Valladolid, Spain 1994-2004	207 mm 95 mm	NS	16.5°C 1.2°C	+2.4°C 11 years (0.38)	23.9°C 1.3°C	+2.9°C 11 years (0.52)	9.3°C 1.1°C	+2.1°C 11 years (0.26)	1475 112	+168 11 years (0.24)	2094 129	+258 11 years (0.43)
Pontevedra, Spain 1952-2004	652 mm 215 mm	+303 mm 52 years (0.17)	17.1°C 0.7°C	NS	23.0°C 0.9°C	NS	11.2°C 0.7°C	+1.1°C 51 years (0.20)	1513 135	NS	1943 148	NS

[1] X and SD are the mean and standard deviation for each parameter analyzed.
[2] Trend is the trend in °C or units over the time period for each parameter. The number in parentheses is the R^2 of the trend with all trends shown significant at the 0.05% level.
[3] The Huglin Index is calculated over the April through September months.