

Effects of Climate Change and Phenological Monitoring of the Indigenous Godello Variety in a Territory of Heroic Viticulture and Biosphere Reserve

ABSTRACT

In the year 2023, the phenological behaviour of the indigenous Godello variety of vineyard was evaluated at Souto Chao, located in the north-west of the Iberian Peninsula, which is a wine-growing region and considered as the place of Designation of Origin (Ribeira Sacra DO). In 2017 and 2018, a similar study was carried out on the same plants of Godello variety, but this latest study aimed to ascertain the nature and extent of changes in the crop's phenology within the timeframe between the initial two years analysed (2017 and 2018) and the present year, 2023. The scale used for study was the one proposed by the BBCH of Lorenz. The average length of the vegetative cycle in the initial two years was 167 days (161 and 174 days in 2017 and 2018, respectively), while in 2023 it was 164 days. The results obtained show a longer vegetative cycle in 2018, with significant differences between the beginning and end of the different phenological phases. Of the three years analysed, 2018 stands out showing a significant deviation from the average. Moreover, there is a close relationship between the phenological behaviour of the Godello variety and certain climatic parameters. Temperature is the most decisive factor, specifically the average annual minimum temperature, which was lower in 2018. In addition, the highest thermal requirements were observed in that same year, with figures slightly above 5200 GDD. As for the historical harvest dates, there are only two recorded years in which the grape harvest took place in August, namely in 2017 and 2023. In this geographical region, the grape harvest, with the exception of the two years mentioned above, usually takes place in September, as was the case in 2018. The vulnerability of viticulture to climate change depends on the magnitude of the impacts. Global warming is the great challenge for the wine business and will force changes in vineyard management to curb its most damaging effects. Its most obvious effects, such as the rise in average global temperature or the decrease and redistribution of rainfall, increasingly in the form of occasional and intense storms, have gone from perception to certainty.

Keywords: Phenology, Vitis, Godello variety, Heroic Viticulture, Biosphere Reserve

INTRODUCTION

Ribeira Sacra is considered one of the greatest examples of what is known as heroic viticulture. This term refers to the terrain conditions which makes it very difficult to work on the vineyards, as it is cultivated on terraces and the slope of the land which are very steep. It is located in the interior of Galicia (Northwest Spain), it is an area of great scenic wealth, recognised worldwide as a Biosphere Reserve by UNESCO in 2021, by Resolution of 5 October [1]

The territory includes areas in the south of the province of Lugo and the north of Ourense. The rivers Miño, Sil and Cabe flow through the area, forming meanders and impressive canyons. This is the territory for vine cultivation on high slopes, with landscapes of great biological richness from both the faunal and floral perspectives. The cultivation is located at the places that are very difficult for winegrowers to access, because the orography prevents mechanised cultivation. The information of grapevine phenology over several seasons provides essential information on the characteristics of wine-growing regions, allowing cultural practices and phytosanitary treatments to be better planned. The phenological studies are very important because they are closely related and easily affected by global warming and climate change. The characterisation of its possible behaviour could serve as a reference for the definition of strategies in crop planning, especially for vineyards due to their great importance in this area.

The information about and major changes in the development cycle of the plants due to rising temperatures would lead to better understanding of the management of the crop. Addressing the impact of potential climate change on vine phenology will allow the wine industry in future to define some strategies that could be useful for further vineyard planning, such as shifting the cultivation of grape to more northerly areas that have comparatively milder temperatures. One of the examples is the major expansion seen in United Kingdom (UK), where the area under vines has increased by about 150% in recent years as a result of global warming and climate change [2, 3].

The study focuses on a Designation of Origin (DO) of enormous importance in the production of various wines, with great character and wide acceptance in international markets. The initial studies on phenology and phytopathology in Ribeira Sacra vineyards were conducted in 2017 [4, 5]. Recent data could help us to understand the effects of climate change on vine cultivation, a plant that is very sensitive to climatic variations, and to know its response to the different scenarios produced [6]. The study of the phenological phases of the vine reflects how the development and growth of vegetative and fruiting organs takes place, and there is a close relationship with climatic and cultural conditions [2]. It has been observed that the harvesting dates have been brought forward considerably in the period between the end of the 20th century and the beginning of the 21st century to avoid the accumulation of excess alcohol content and also to preserve the freshness of the wines, but this in turn brings another major problem; the skins and seeds, which gives the wine important organoleptic properties such as astringency, colour and aromas, do not ripen at the same time and rate as the pulp and develop slowly. In white wines, this results into the wines that is heavier and harder on the palate, less agile and also difficult to preserve. However, this problem is not universal for all grape varieties and different regions. For example, Galician white wines, such as the Godello variety, where viticulture is adapted to cooler areas, have become fresher and more aromatic, therefore have gained a greater market share [7].

Climate change has become one of the world's major concerns for wine production, as vine cultivation is very sensitive to changes in climatic conditions, especially changes in temperature and solar radiation. These factors are crucial for the ripening of the fruit, which means that harvests are being shifted little earlier, with the aforementioned risks of altering the chemical composition of the grape and the organoleptic characteristics of the product obtained [8, 9]. In addition to the changes in the chemical composition of the wine, the increase in temperature

causes pests and plants to react to these changes. Temperatures are not only the result of warmer summer days, but also of fewer cold days and less frost, which favours the growth of fungi and pests, altering the interaction of the disease triangle (host-agent-environment) and thus ultimately reducing the crop production [10, 11].

MATERIALS AND METHODS

Location and Climatic Characteristics of the Study Area

The study was conducted in one vineyard in Ribeira Sacra (Souto Chao) during the year 2023, and previously the studies were conducted in years 2017 and 2018 (Fig. 1).

Ribeira Sacra comprises 2,500 ha of vineyards. The orography of the terrain requires the vines to be planted on very steep slopes, which the *Centro di Ricerca, Studi, Salvaguardia, Coordinamento e Valorizzazione per la Viticoltura di Montagna*, CERVIM, describes as "heroic viticulture" [12]

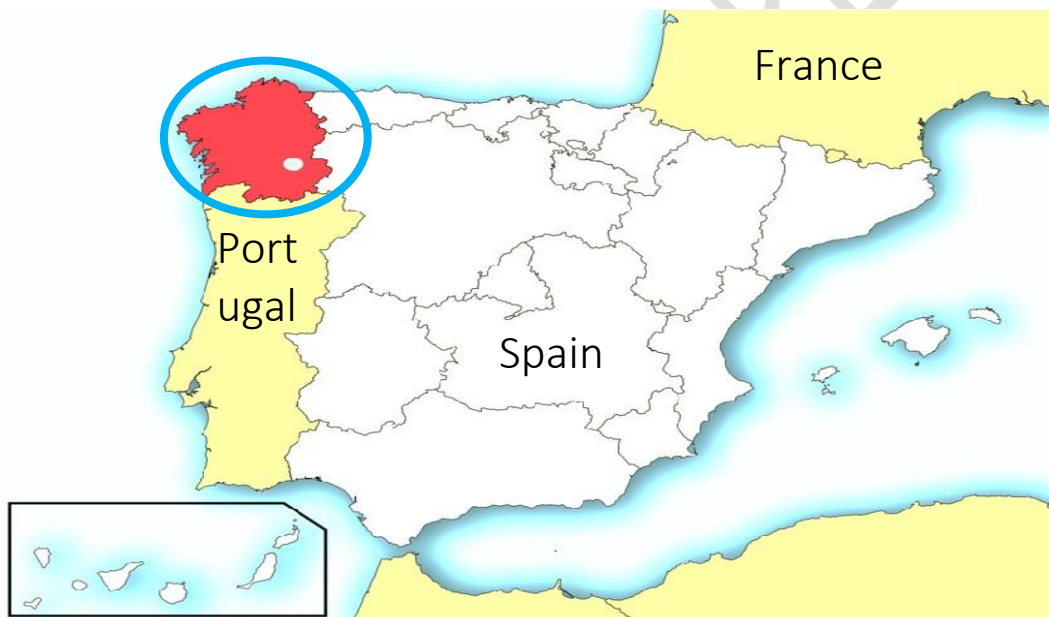


Fig. 1. Location of the Ribeira Sacra area in the North-West of the Iberian Peninsula (Spain)

The Souto Chao vineyard is located at 438 m.a.s.l. on the lower terraces along the banks of the River Sil, following the contours and with slopes of up to 80% ($42^{\circ}24'27.67''$ N, $7^{\circ} 28'20.06''$ W). The soils are shallow and of low fertility, which limits the growth of the vine shoots [13].

During the warmest month, temperatures on the terraces closest to the river (Souto Chao) can be up to one and a half degrees higher than the average for Ribeira Sacra as a whole. The river has a significant thermoregulatory effect, especially when combined with the favourable South-Southeast exposure of the vineyards. On the other hand, in the higher parts, especially in the areas where orientation is not so favourable for viticulture, there is a negative temperature variation of similar magnitude [14]. The Godello variety has small to medium sized grapes, conical in shape, with fairly uniform berries of medium to high compactness, with a medium sized stalk and little lignification at the base. The leaf is medium to large, pentagonal and has five lobes [15]. The weather data was collected and the average maximum and minimum temperature, relative humidity, hours of sunshine and rainfall are presented in Table 1. The data was collected from the station located near to vineyard study area, which belongs to the Meteogalicia (Meteorological Observation and Prediction Unit of Galicia) weather service.

Table 1 Weather data of the study area during de crop season(2017, 2018 and 2023)

		Ribeira Sacra			
Annual average meteorological data	Year	2017	2018	2023	
	Tmax (°C)	21.2	21.2	22.15	Phe
	Tmin (°C)	9.2	7.9	10.9	nol
	Tmean (°C)	13.6	14.2	15.05	ogic
	RH mean (%)	74.3	77.5	74.8	alPr
	Sunshine (hours)	5.7	4.6	6.3	
Annual total	Rainfall (L/m ²)	693.9	804.4	248.6	oto
	Daily rainfall (L/m ²)	64.9	39.2	19.1	col
Maximum	Date	Mar 10 th	Mar 11 th	Jun 12 th	and

Fieldwork

The initial phenological studies in the Souto Chao plot were carried out in 2017 and 2018. After 5 years, the phenology was studied again on the plants of same variety from the same plot. Although the time interval is not very long, we tried to obtain some important data on how climate change affected the vine cultivation in this area of particular orography and terraced cultivation systems on the slopes of the river.

We studied the phenological stages of the Godello cultivar according to the scale adopted by the BBCH, which is the standardised scale by Lorenz [16] (Table 2). The phenological observations were applied to randomly selected 10 vines distributed throughout the plot. The study was carried out during the active grapevine cycle, from the 1st of March 2023 until the grape harvest in last week of August 2023. During the sampling period, the vineyard was visited weekly, except during the flowering period, when the number of visits was increased to twice a week. In order to determine the phenological calendar of the vines, the beginning of each stage was considered to be when 50% of the plants under study had reached that particular stage. From the BBCH scale, a total of 18 phenological phases belonging to the six main stages were selected for observation.

Table 2 Stages and Phases of the BBCH-Skala considered in this study

STAGES (St)

PHASES (Ph)

0: Sprouting	03 - End of bud swelling: buds swollen, but not green 05 - "Wool stage": brown wool clearly visible 09 - Bud burst: green shoot tips clearly visible
1: Leaf development	11 - First leaf unfolded and spread away from shoot 13 - 3rd leaves unfolded (continuous) 15 - 5th leaves unfolded
5: Inflorescence emerge	53 - Inflorescences clearly visible 55 - Inflorescences swelling, flowers closely pressed together 57 - Inflorescences fully developed; flowers separating
6: Flowering	61 - Beginning of flowering: 10% of flowerhoods fallen 65 - Full flowering: 50% of flowerhoods fallen 69 - End of flowering
7: Development of fruits	71 - Fruit set: young fruits begin to swell, remains of flowers lost 75 - Berries pea-sized, bunches hang 79 - Majority of berries touching
8: Ripening of berries	81 - Beginning of ripening: berries begin to develop variety-specific colour 85 - Softening of berries 89 - Berries ripe for harvest

UNDER PEER REVIEW

Thermal Heat Requirements

Heat requirements were calculated according to the criterion proposed by Galan [17], which took into account the daily sum of maximum temperatures (Growing Degrees-Days, GDD) from the end of the cold period to the beginning of each phenological phase. $GDD\text{ }^{\circ}\text{C} = \sum T_{i_{\max}}$

$T_{i_{\max}}$ = daily maximum temperatures in a number of days i .

The F-test of statistical analysis determines whether the variability between the means of the groups is greater than the variability of the observations within the groups. If this ratio is sufficiently large, it can be concluded that not all means are equal. In this study it gives a relatively high value, due to the fact that it is a one-year sample where the sample size was not too large (Table 3). The optimum temperature requirements for this crop are different at different stages of development, so it is necessary to determine these conditions.

Table 3 Duration of the stages and thermal requirements (growing degrees-days, GDD)

	2017		2018		2023	
	days	GDD	days	GDD	days	GDD
Stage 0 (St 0)	21	1425	23	1549	31	1175
Stage 1 (St 1)	21	1945	21	1810	23	1883
Stage 5 (St 5)	26	2552	32	2348	23	2405
Stage 6 (St 6)	14	2923	14	2939	19	2881
Stage 7 (St 7)	46	3387	45	3519	42	3712
Stage 8 (St 8)	33	5150	39	5233	26	4933
Cycle Duration	161		174		164	

Statistical Analysis

Two statistical tests were used to determine possible differences in the length of the stage variation, within and between groups: two-way analysis of variance (ANOVA) and Tukey's honest significant differences (Tukey's HSD).

Test ANOVA: by stage-Godello variety (Df: degrees of freedom; Sum Sq: Sum of square; Mean Sq: mean square; plevel=0.1) and Tukey HSD between Stages (Lower and Higher are the ends of the confidence interval; plevel=0.05). TUKEY HSD/KRAMER Q-test: between groups (mean; std err; q-stat; lower; upper, p-value; mean-crit).

RESULTS

Phenological Behaviour of the Godello Variety

The vegetative growth period of the Godello variety was calculated from the end of bud swelling, when the buds were swollen but not green (phase 03), stage 0: sprouting, to the berries ripe for harvesting (phase 89), stage 8: Ripening of the berries. During the first study in 2017, the vegetative cycle of the vine was from March to August, while in 2018 the vegetative cycle was from April to September. In the year 2017, which was the first year of study, the tagging was done and records have been kept of the plants in which harvesting was done for the first time in August 2017. In this wine-growing region, harvesting is usually carried out in the month of September. In this present study of 2023, the grape growing season was again from March to August, i.e., for the second time the grapes were harvested again in August 2023, specifically in the second fortnight.

The drought and high spring temperatures are resulting into early harvesting of the crop in the areas such as Ribeira Sacra, which is threatening and leading to reduced production. The variety Godello is easily affected and is also sensitive to this new situation. Due to the fact that the high temperatures arrive early and accelerate the ripening process, vine growers and wine makers are indicating that the harvesting must begin four to five days earlier each year, which also depends on the variety, with the white variety i.e., Godello which is being easily affected. In the three years of our study, the longest phenological phase (Ph) was 79 (majority of berries touching), with a duration of 34, 27 and 20 days in 2017, 2018 and 2023 respectively.

The shortest phase in 2017 was Ph 61 (Beginning of flowering: 10 % of flowerhoods fallen) with a duration of 3 days. In 2018, Ph 11 (First leaf unfolded and spread away from shoot); Ph 65 (Full flowering: 50 % of flowerhoods fallen) and Ph 69 (End of flowering), with a duration of 3 days each. In the present study carried out in 2023, the shortest phase was Ph 55 (Inflorescences swelling, flowers closely pressed together) with a duration of 5 days. The differences between the longest and shortest phases in 2017, 2018 and 2023 were 31, 24 and 15 days respectively. It follows that in the latter year there was less contrast in terms of the duration of the different phenological phases.

The difference between the longest and the shortest stage (St) in 2017, 2018 and 2023 was 32, 31 and 23 days, respectively (St 7: development of fruits and St 6: flowering). In terms of the phenological phases, the phenological stages in the last year of the study showed a smaller difference in duration between them (Table 4).

The average length of the growing season in the two years was 167 days (161 and 174 days in 2017 and 2018, respectively), while in 2023 it was 164 days. Considering 2017 as exceptional, where the harvest was brought forward to August for the first time, the year 2023 confirms once again this exceptionality; the harvest was again in August.

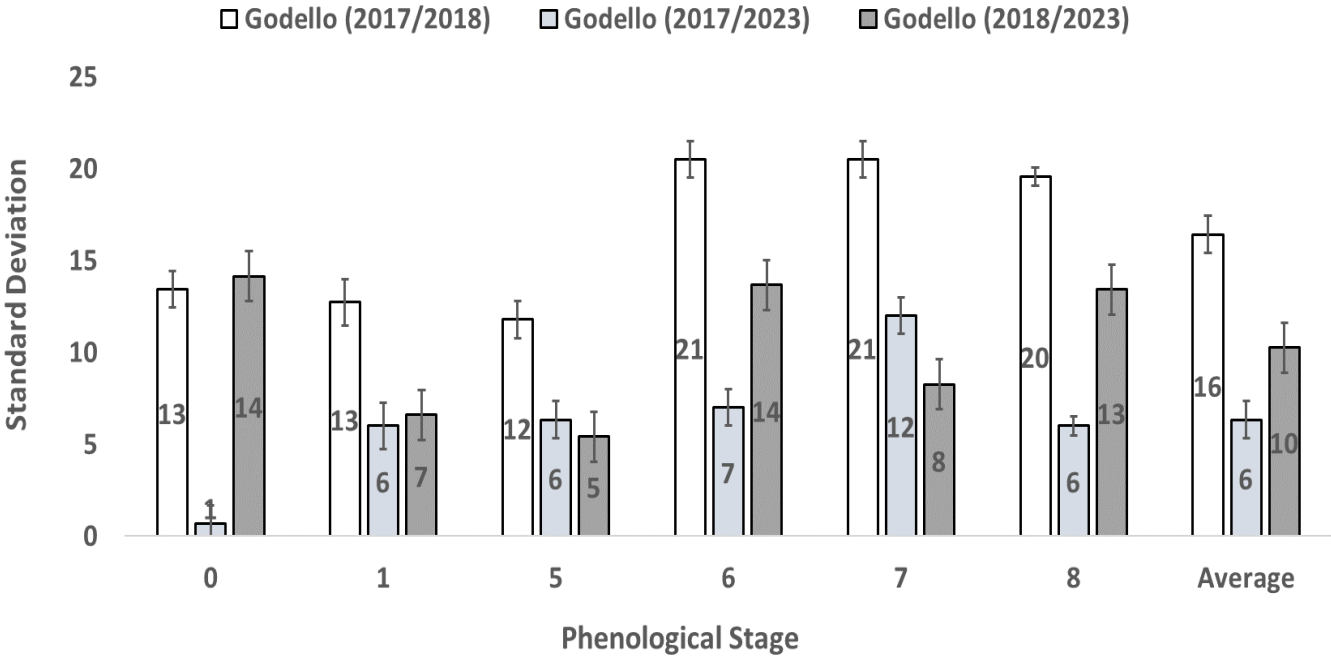
All the evidences, point us to change the trend to a relatively short period of time. Furthermore, phenological studies in the future should confirm this working hypothesis.

Table 4 Average dates of the beginning of each phenological phase and duration in the different years for the Godello variety

Godello Souto Chao								
Stages	Phases	Start Date		Duration of phase			Start date	Duration of phase
		2017	2018	2017	2018	Mean		
0	3	18-Mar	3-Apr	7	12	10	17-Mar	8
	5	25-Mar	15-Apr	8	7	8	25-Mar	7
	9	2-Apr	22-Apr	6	4	5	31-Mar	16
1	11	8-Apr	28-Apr	7	3	5	16-Apr	8
	13	15-Apr	1-May	7	9	8	24-Apr	7
	15	22-Apr	10-May	7	9	8	1-May	8
5	53	29-Apr	19-May	8	4	6	9-May	10
	55	6-May	23-May	14	10	12	19-May	5
	57	20-May	2-Jun	4	18	11	24-May	8
6	61	24-May	20-Jun	3	8	6	1-Jun	6
	65	27-May	28-Jun	7	3	5	7-Jun	6
	69	3-Jun	1-Jul	4	3	4	13-Jun	7
7	71	7-Jun	4-Jul	4	4	4	20-Jun	7
	75	11-Jun	8-Jul	8	14	11	27-Jun	15
	79	19-Jun	22-Jul	34	27	31	12-Jul	20
8	81	22-Jul	18-Aug	6	7	7	1-Aug	8
	85	28-Jul	25-Aug	22	22	22	10-Aug	12
	89	19-Aug	16-Sep	5	10	8	22-Aug	6

The standard deviation of the average start date of the various phenological stages exhibited lower values for the period 2017/2023 (6 compared to 16 for 2017/2018 and 10 for 2018/2023). This result indicates a lower variability of the start dates of the phenological stages from one period to another. Regarding the mean values of the duration of each phenological stage, the values are similar for the three periods studied (value of 3), indicating that there are no significant differences. The lowest variability in the average start date of the different phenological stages for the period 2017/2023 corresponds to the only two years recorded so far, where sprouting and harvest took place from March to August. (Fig. 2a; 2b).

Godello Start Date S.D.



Start Date S.D.

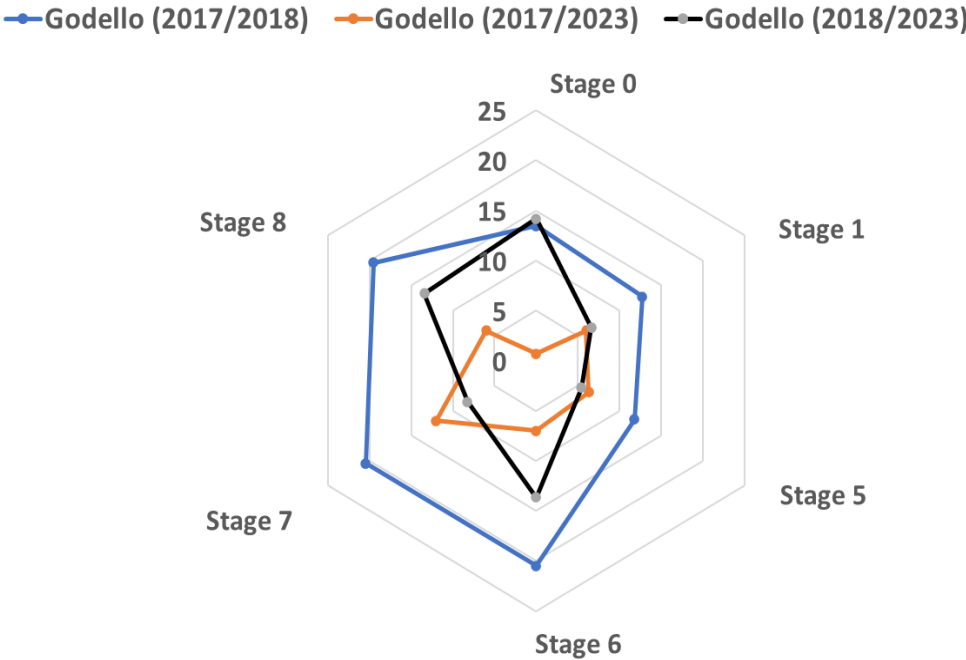
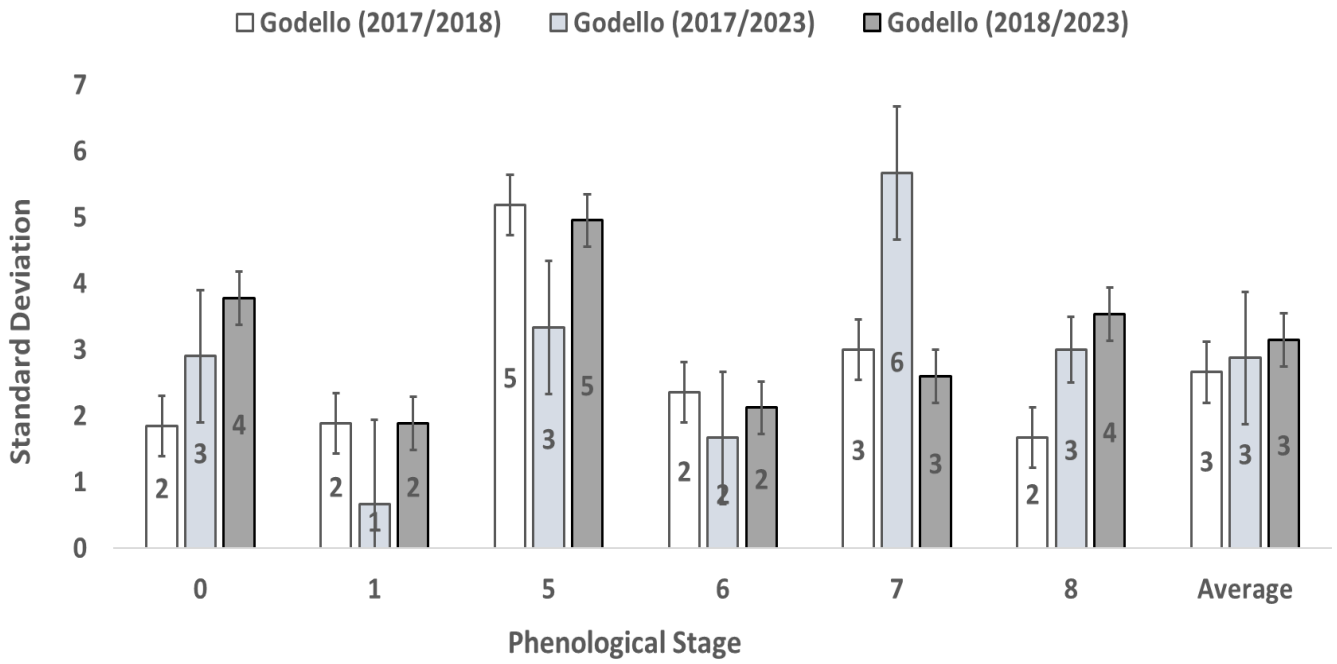


Fig. 2a. Start date of the Standard Deviation (S. D.) for each phenological stage with the average values (Error bars included in the first graph)

Godello Duration S.D.



Duration S.D.

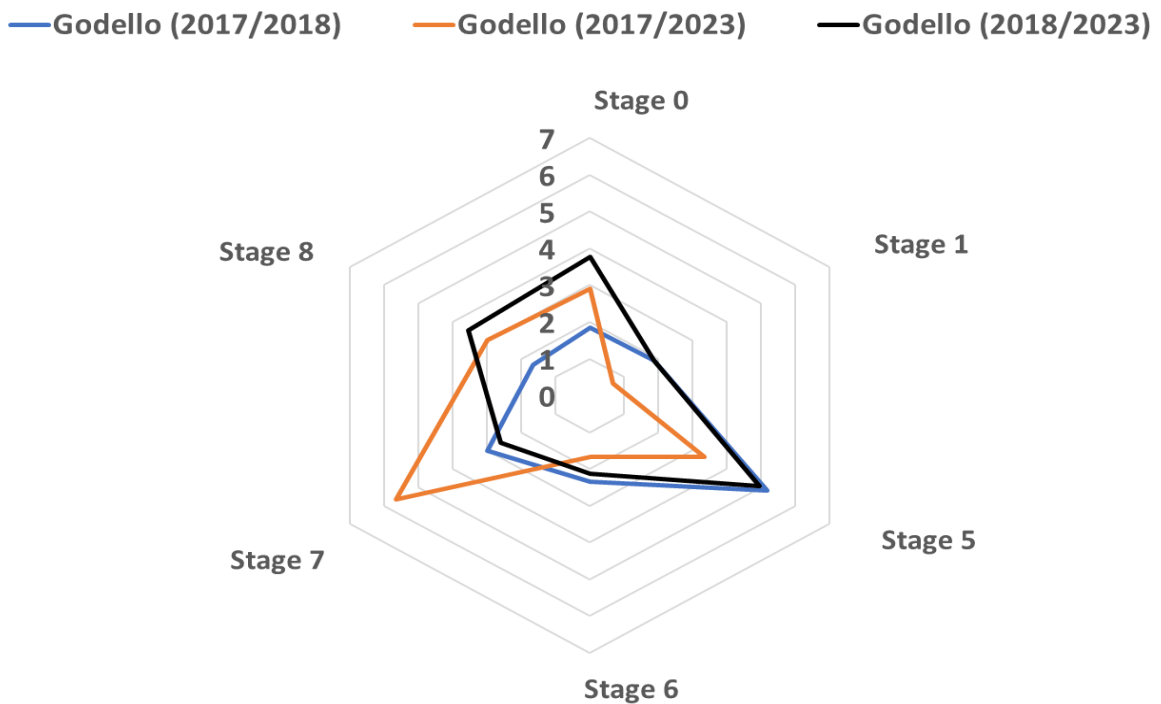


Fig. 2b.Duration of the Standard Deviation (S. D.) for each phenological stage with the average values. (Error bars included in the first graph)

Analysis of Meteorological Parameters

The phenological phases included in main stage 0 (St 0: Sprouting) take place this year from mid-March to the end of March. During this phase, the lowest average maximum and minimum temperatures (17.2°C and 6.6°C, respectively) were recorded. Stage 1 (St 1: Leaf development) takes place from mid-April to early May. From then until the beginning of June, stage 5 (St 5: Inflorescence emerge) took place.

The next stage 6 (St 6: Flowering) took place from the beginning to the middle of June. The highest rainfall value (19.1 mm of rainfall) was recorded at this stage, namely on 12 June. Stage 7 (St 7: Development of fruits), runs from June to the beginning of August. Finally, the last phenological stage of the vegetative cycle of the vine 8 (St 8: Ripening of berries), occurred between the beginning of August and the end of the same month, recording the highest average maximum, minimum and average temperatures (29.9°C, 14.8°C and 21.7°C, respectively) (Fig. 3).

The accumulated heat units for berry ripening (St 8) reached the levels of around 5000 GDD. Thus, the thermal requirements needed to overcome the different phenological stages ranged from 1175 GDD for stage 0 (St 0) to 4933 for stage 8 (St 8).(Table 3).

Heat requirements were determined by calculating the accumulated sum of daily maximum temperatures (in growing degree days, GDD) from the conclusion of the cold period until the onset of each phenological phase for the Godello Variety (*Vitisvinifera* L.) grown in the Souto Chao plot on the slopes of the Sil River, where the particular orography of this territory, with slopes of up to 80%, as well as the proximity to the river, determine the conditions for vine cultivation.

In these areas it is essential to conserve the scarce soil moisture and to reduce erosion processes. One of the techniques used by winegrowers is mulching, the main objective of which is to prevent the proliferation of weeds. Non-living mulches have a number of advantages. These include improved soil structure, disease and pest control, crop quality improvement, which reaps financial benefits. The primary benefits, however, are associated with weed control. Weed suppression can result in significant long-term labour and herbicide savings. It is critical to select the appropriate mulch for the situation. The effectiveness of the mulch will vary depending on the prevailing weed problems and the surrounding environment [18, 19](Fig. 4).

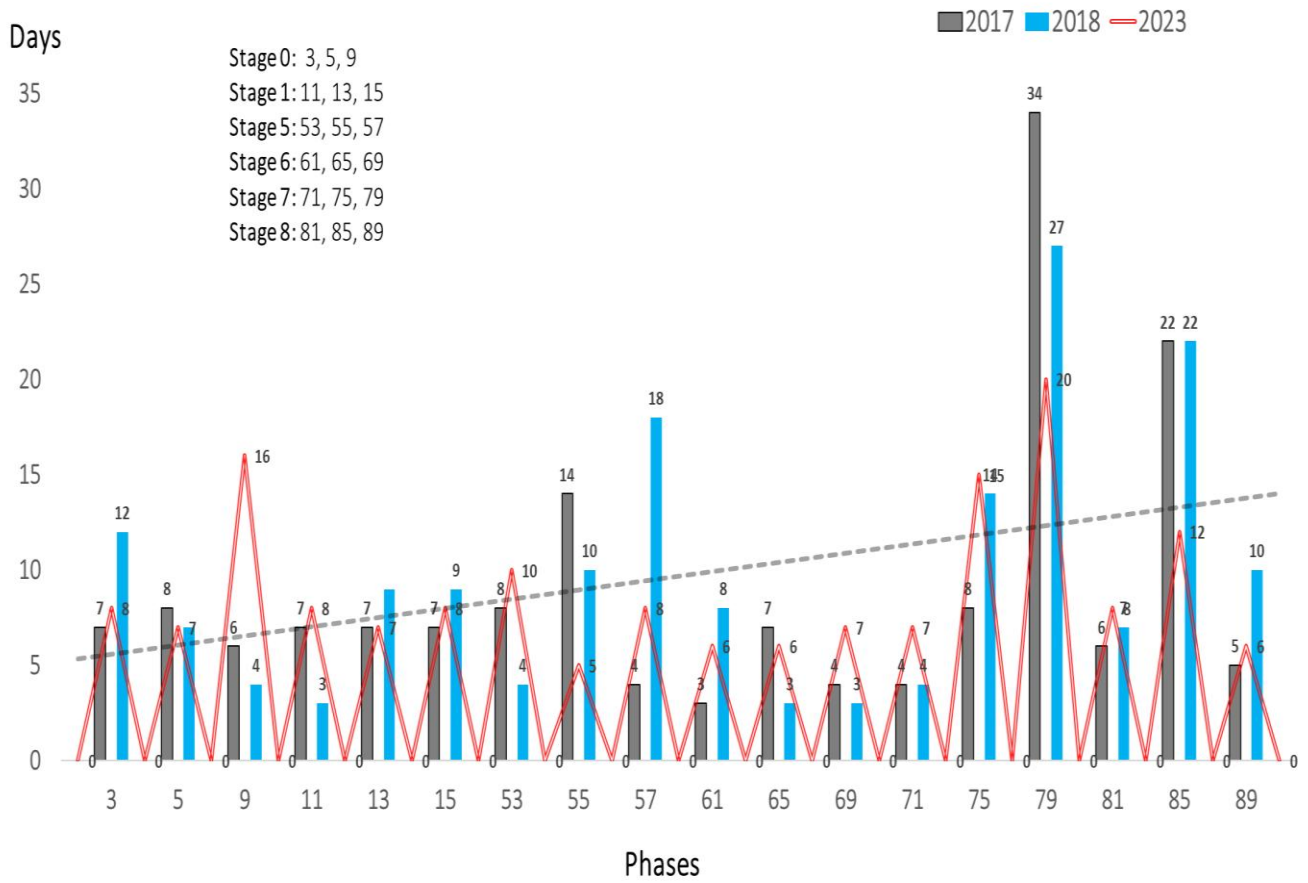


Fig. 3. Length of each phenological phase in the different years of study

UNDER PEER



Fig. 4. Vineyards in Ribeira Sacra. Godello variety in the Souto Chao plot

Statistical Analysis

The ANOVA test results show that no significant differences were found between the samples analysed in terms of the duration of each stage and phenological stage in the different years of the study.

The calculated F value was lower than the *critical F* value. The α value (0.05) is also lower than the p -value (0.93835). In the samples analysed, the value found is 0.06370, which is lower than the value of 3.17879.

This result has also been confirmed by the Tukey HSD/KRAMER Q test where the α value 0.05, is lower than the p -value calculated between the different groups with values of: 0.93804; 0.9965 and 0.96284 (Table 5).

Table 5.ANOVA test with values shown and calculated: Df=degrees of freedom; Sum Sq=sum of square; Mean Sq=mean square; F; P-value and F crit. The TUKEY HSD/KRAMER was calculated between the different groups (mean;std err; q-stat; lower; upper; p-value; mean-crit and Cohen d)

ANOVA Test

Groups	Count	Sum	Average	Variance
Souto Chao 2017	18	161	8,944444444	58,0555556
Souto Chao 2018	18	174	9,666666667	46,7058824
Souto Chao 2023	18	164	9,111111111	16,4575163

Source of Variation	Sum sq	df	Mean sq	F	P-value	F crit
Between groups	5,148148148	2	2,574074074	0,06370474	0,938356536	3,178799292
Whitin groups	2060,722222	51	40,40631808			
Total	2065,87037	53				

TUKEY HSD/KRAMER

alpha 0,05

group	mean	n	ss	df	q-crit
Souto Chao 2017	8,944444444	18	986,9444444		
Souto Chao 2018	9,666666667	18	794		
Souto Chao 2023	9,111111111	18	279,7777778		
		54	2060,722222	51	3,413823529

Q TEST

group 1	group 2	mean	std err	q-stat	lower	upper	p-value	mean-crit	Cohen d
Souto Chao 2017	Souto Chao 2018	0,7222222	1,498264145	0,48203931	-4,39258717	5,837031615	0,938045	5,11480939	0,11361776
Souto Chao 2017	Souto Chao 2023	0,1666667	1,498264145	0,11123984	-4,948142726	5,281476059	0,9965949	5,11480939	0,02621948
Souto Chao 2018	Souto Chao 2023	0,5555556	1,498264145	0,37079947	-4,559253837	5,670364948	0,9628401	5,11480939	0,08739827

DISCUSSION

The active vegetative period of the vine (considered from bud burst to harvest) was longer in 2018, while it was similar in the other two years (2017 and 2023). However, the length of the Godello cycle was 161, 174 and 164 days in 2017, 2018 and 2023 respectively. Previous studies carried out in this wine region on Mencía, the predominant variety, reported very similar results to those obtained here for Godello [9]. The fact that 2018 shows a significant difference compared to the other two years of study can be attributed to the higher minimum temperatures recorded throughout the vegetative cycle during that year, which leads to a longer development time of the different phenological phases. The lower minimum temperatures in 2018 would explain the longer Godello cycle in the Souto Chao vineyard. A study carried out by Queijeiro [20] in the Ribeiro area showed significantly higher values than those observed for Godello in Ribeira Sacra.

The longest cycle length was observed in parallel studies carried out in the same wine region with other red varieties, such as Brancellao and Merenzao, where a vegetative cycle length was reported to be of 200 days [4]. In other Spanish wine regions (Rioja DO), red varieties such as Tempranillo reported a vegetative cycle length very similar to Godello in Ribeira Sacra in 2018, which was an average of 174 days. In the same Rioja DO, minority red varieties such as Maturanatinta, MaturanatintaNavarrete and Monastel de Rioja reported vegetative cycle lengths of 158, 163 and 173 days, respectively [21]. The phenological cycles of some Turkish varieties have been reported to range from 120 to 176 days, with Trakyallkiren and Yalova being the earliest and Favli the latest [22].

The present study showed that the year 2023 was the driest as compared to other years of study in Ribeira Sacra and consequently, the beginning of the berries ripe for harvest (Ph 89) was early, which occurred in mid-August 2023. Regarding thermal heat requirements, the daily sum of maximum temperatures fluctuated from the sprouting phase (St 0: Sprouting) to berry ripening (St 8: Ripening of berries) stage, in values between 1175 GDD and 4933 GDD. In studies conducted in this geographical area, heat accumulation values recorded for the same variety and in the same plot reported similar values for sprouting (St 0: Sprouting), of 1425 and 1549 GDD, in the years 2017 and 2018, respectively. Values for berry ripening (St 8: Ripening of berries) were 5150 GDD in 2017 and 5233 GDD in 2018, values were in line with those obtained in this present year 2023 of study. The thermal requirements needed to induce flowering (St 6: Flowering) were 2881 GDD, also similar to those obtained in previous studies, which ranged from 2923 to 2939 GDD [4]. This suggests that we must consider the date of the beginning of the flowering stage (St 6: Flowering) because it is very important in determining the harvest date, as there is a constant number of accumulated temperature units between these events [21]. Finally, regarding the accumulated thermal units for berry ripening (St 8: Ripening of berries) the values achieved in 2023 were slightly lower than those recorded in 2017 and 2018 in the same plot. In the other viticultural regions also for the red grape cultivars such as Sangiovese and Cabernet Franc, the heat requirements of these varieties during the period between budbreak and flowering varied between 96 and 271 GDD, with the Cabernet Franc variety requiring the highest number of days and the highest sum of heat during the period [23]. These values were very distant from those achieved in the Souto Chao plot for Godello. Therefore, the knowledge of the different phenological stages of the vineyard and their identification is very important for cultural practices and the use of phytosanitary products to control pathogens [3, 24].

One aspect highlighted by climate change emerging pest monitoring units, technicians and winegrowers is that in addition to changes in the phenology of the vine, there is a significant increase in disease and pest patterns in this wine-growing region, which also have a substantial impact on both the quality and yield of the crop [25]. It is also worth highlighting notable differences within the

Ribeira Sacra area itself such as those reported by other studies similar to the present study. This includes great spatial and temporal variability in temperature and phenology within the same wine-growing area [26], which can lead to different conditions, such as drier periods during the grape ripening phase depending on the sub-area in which the vineyard is located.

Today it is difficult to understand the extent of climate change on viticulture as the literature on this topic is quite recent, with 2000 being the first year in the WoS dataset, and from this time onwards there has been a significant growth in the number of publications, indicating the importance and scientific interest in the effects of climate change on viticulture and wine production [27].

As a consequence of the higher temperatures during 2023 (Table 1), the shortest ripening period among the three years studied was observed, specifically 26 days; as opposed to 33 and 39 days in 2017 and 2018, respectively. The reported values closely resemble those documented by Hernandez et al. (2010) [28] for 'Moscatel de Jundiaí' and Madalena', both white grape varieties. When cultivated in the region of Jundiaí, those varieties exhibited a phenological stage duration of 30 days. For other white cultivars such as Prosecco, Vermentino and Verdichio, the ripening duration varied between 53 and 62 days, probably due to regional climatic conditions, as a consequence of low temperatures due to the high altitude, and to the genetic characteristics of the cultivar [29].

The increase in temperatures would also accelerate the vegetative cycle of the plant. Spring rains may coincide with flowering and fruit development, which would be detrimental to a process that needs drier environments. This fact occurred in our study area in 2017 and 2018, where the highest rainfall occurred during the month of March, while in the present study (2023), rainfall was less abundant (Table 1). Studies with similar findings have noted that high spring temperatures with high water availability in the soil as a result of rainfall, may cause the plant to favour vegetative development over grape production. This excess moisture could also increase the risk of disease outbreaks, including insect-borne diseases [25]. In this regard, as a consequence of the increase in temperature, vectors of emerging diseases such as grapevine flavescencedorée, a serious disease caused by a phytoplasma, have been detected in some vineyards in Galicia and northern Portugal. The bacterial agent has recently been named *CandidatusPhytoplasma vitis*, and its vector is the cycadellid of the Deltocephalinae subfamily, *Scaphoideus titanus*.

Infection can kill young vines and greatly reduce the productivity of old vines. The duration of the hatching period is related to diapause, the interruption of which does not require low temperatures. The length of this hatching period varies across regions with long hatching periods being typical for vineyards in areas with mild winters. Temperatures regulate the onset and duration of the incubation period, as well as the sex ratio. It is a clear example of a disease common in areas of the Mediterranean, with a much drier climate and milder temperatures, which starts to colonise previously pathogen-free territories as a consequence of climate change [30].

Jones and Davis [31] also pointed out that vine development occurs as a direct effect of climate and can be described by phenological events, and stated that the phenology of a crop is important in determining the ability of an area or region to produce crops within the scheme of its climatic regime. The phenological data obtained through a descriptive analysis of the means and standard deviations for the different stages of the vine, from Sprouting (St 0) to Ripening of fruits (St 8), show different values from those obtained in other similar studies for varieties such as Perlon, Red Globe, A. Lavalée, M. Palieri, Sultanina, etc., but the highest standard deviation was found to be for the variety Perlon. However, the highest standard deviation also coincides with our study in terms of the stages of Flowering (St 6) and Ripening of fruits (St 8) [32].

CONCLUSION

It can be concluded that the active vegetative cycle of the vine was generally longer in the year 2018. However, the significant differences were observed between the beginning and end of the different phenological phases for the three years. Both in 2017 and in the present year of study i.e., 2023, the beginning and the end of the vegetative cycle took place between March and August, while in 2018 it was from April to September. The phenological behaviour of the Godello variety is linked to climatic conditions, with temperature being the main meteorological parameter explaining the inter-annual differences in the vineyard, highlighting the advance recorded in most of the phenological phases in 2017 and 2023. The shortest phenological phase was Flowering (St 6) stage, while the longest was Fruit Development (St 7) stage. The period of low temperatures was necessary to overcome the cooling period in the vineyard studied, which ended in the second half of December month. The thermal requirements to complete berry ripening were around 5,000 heat units (GDD) in the year 2023, which was slightly lower than those required in the year 2017 and 2018. The main conclusion of this study is that high temperatures and drought have reduced the period for the grape harvest in the context of climate change. This is therefore also affecting the other crops and could worsen in the coming years, according to the Intergovernmental Panel on Climate Change (IPCC).

Disclaimer

This paper is an extended version of a preprint document of the same author.

The preprint document is available in this link: <https://www.biorxiv.org/content/10.1101/2023.12.25.573298v1.full.pdf> [As per journal policy, preprint article can be published as a journal article, provided it is not published in any other journal]

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. BOE No. 247 of 15 October 2021, pages 126250 to 126252. UNESCO Biosphere Reserve Declaration. Available from: www.boe.es/diario_boe/txt.php?id=BOE-A-2021-16794
2. Verdugo-Vásquez N, Acevedo-Opazo C, Valdés-Gómez H, Araya-Alman M, Ingram B, García de Cortázar-Ataurilet al. Spatial variability of phenology in two irrigated grapevine cultivar growing under semi-arid conditions. *Precis. Agric.* 2016;17(2):218-45. doi: 10.1007/s11119-015-9418-5.
3. Cortiñas Rodríguez JA, González-Fernández E, Fernández-González M, Vázquez-Ruiz RA, Aira MJ. Fungal diseases in two north-west Spain vineyards: relationship with meteorological conditions and predictive aerobiological model. *Agronomy.* 2020;10(2):219. doi: 10.3390/agronomy10020219.
4. Cortiñas JA, Fernández-González M, González-Fernández E, Vázquez-Ruiz RA, Rodríguez-Rajo FJ, Aira MJ. Phenological behaviour of the autochthonous Godello and mencia grapevine varieties in two designation origin areas of the NW Spain. *Scienciahorticulturae.* 2020;265:109-221. doi: 10.1016/j.scienta.2020.109221.
5. Cortiñas JA, Fernández-González M, Vázquez-Ruiz RA, Aira MJ, Rodríguez-Rajo FJ. The understanding of phytopathogens as a tool in the conservation of heroic viticulture areas. *Aerobiologia.* 2022;38(2):177-93. doi: 10.1007/s 10453-022-09741-y.

6. Sotés V. Vulnerability of vineyards to climate change and adaptation strategies. *Phytoma*. 2015;274:36-45.
7. Zamora F. Production and ageing of red wine: scientific and practical aspects. AMV ediciones y Mundi-Prensa. Madrid; 2015.
8. MartínezA, Aleixandre TudóJL, Aleixandre BenaventJL. Effects of climate change phenomena on wine quality. *Enovicultura*. 2016;42:4-26.
9. Cortiñas Rodríguez JA, Fernández-Conde ME. Phenology of the mencia variety cultivated in a territory included in the UNESCO world network of biosphere reserves. *Mod.Tech.Agric.Horti.Sci*. 2022;2(1):1-6. doi: 10.53902/MTAHS.2022.02.000503.
10. FerrerRM, 2015. Climate change effects on *Plasmoparaviticola* incidence in vineyards. [Biología ambiental. Universidad Autónoma de Barcelona. TFG – ddd.uab.cat].
11. Cortiñas Rodríguez JA, Fernández-Conde ME. Sustainable use of plant protection products in heroic viticulture areas. Reducing risks to the environment and winemaking. *Suntext Rev.Biotechnol*. 2021;2(2):125.
12. International Organization, 1987. OIV; Office International de la Vigne et du Vin. <https://www.cervim.org/en/about-us/cervim>
13. Martínez de Toda F. Keys to quality viticulture (2nd ed.) New techniques for stimulating and controlling grape quality in vineyards. Mundi-Prensa. Madrid (España). Vol. 253; 2011.
14. Rodríguez Guitián MA, Ramil-Rego P. Climatic classifications applied to Galicia: a review from a biogeographic perspective. *R.r*. 2007;1(3):31-53. doi: 10.15304/rr.id5318.
15. Mapama. Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente. Register of Commercial Varieties; 2017. Available from: <http://www.mapama.gob.es>.
16. Lorenz DH, Eichorn KW, Bleiholder H, Klose R, Meier U, Weber E. Phanologische Entwicklungsstadien der Weinrebe (*Vitis vinifera* L. ssp. *vinifera*). Codierung und Beschreibung nach der erweiterten BBCH-Skala. *Vitic. Enol. Sci*. 1994;49:66-70. doi: 10.1111/j.1755-0238.1995.tb00085.x.
17. GalánC, CariñanosP, García-MozoH. Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalucía. Spain. *Int. J. Biometeorol*. 2011;45:59-63.
18. PatilS, PawarA, BisaryaD, KumarV, KumarS, JadhavV, 2022. Mulching: A sustainable solution for soil and water conservation. *Biological Forum – An International Journal*. 14(4a), 619-23.
19. GrundyAC, BondB. Use of non-living mulches for weed control. *Nonchemical Weed Management*; 2007. p. 135-53.
20. Queijeiro J, Blanco D, Alvarez C. Climatic zoning and viticulture in Galicia (NW Spain). In: Van Leeuwen C, Roby JP, Marguerit E, Fanet J, editors. *Vie Congrès international Des Terroirs Vitivinicoles*; Jul 2-4. Bordeaux, Montpellier, France; 2006. p. 34-9.
21. Martínez J, Rubio P, Chavarri JB, Baroja E, García-Escudero E. Evaluation of red minority grape varieties (*Vitis vinifera* L.) in the DOC, Rioja, Spain. XXXVI. Available from: <http://hdl.handle.net/10261/147524> World Congress of Vine and Wine, 11th General Assembly of the OIV; 2013.
22. KöseB. Phenology and ripening of *Vitis vinifera* L. and *Vitis labrusca* L. varieties in the maritime climate of Samsun in Turkey's Black Sea Region. *S. Afr. J. Enol. Vitic*. 2014;35(1):90-102. doi: 10.21548/35-1-988.
23. GrisEF, BurinVM, BrighentiE, VieiraH, Bordignon-LuizMT. Phenology and ripening of *Vitis vinifera* L. grape varieties in São Joaquim, southern Brazil: a new South American wine growing region. *Cienc. Inv. Agr*. 2010;37(2):61-75. ISSN 0718-1620. doi:10.4067/S0718-16202010000200007.
24. MullinsMG, BouquetA, WilliamsLE. Biology of the grapevine. 239 p. New York: Cambridge University Press; 1992.

25. Santos JA, Fraga H, Malheiro AC, Moutinho-Pereira J, Dinis LT, Correia C, Moriondo M, Leolini L, Dibari C, Costafreda-Aumedes S, et al. A Review of the Potential Climate Change Impacts and Adaptation Options for European Viticulture. *Appl. Sci.* 2020, 10:3092. <https://doi.org/10.3390/app10093092>
26. Buesa I, Yeves A, Guerra D, Sanz F, Chirivella C, Intrigliolo DS. Testing field adaptation strategies for delaying grape ripening and improving wine composition in a cv. Macabeo Mediterranean vineyard. *Front Plant Sci.* 2023 Apr 25;14:1-14. <https://doi.org/10.3389/fpls.2023.1155888>, PMID 37180377.
27. Grazia D, Mazzocchi C, Ruggeri G, Corsi S. Grapes, wines, and changing times: A bibliometric analysis of climate change influence. *Aust. J. Grape Wine Res.* 2023 Sep 20;2023:1-19. doi: 10.1155/2023/9937930.
28. Hernandez JL, Pedro Júnior MJ, Santos AO, Tecchio MA. Phenology and production of American and hybrid wine grape cultivars in Jundiaí - SP. R. Brasil. *de Fruticultura.* 2010; 32:135-142.
29. Pedro Júnior MJ, Moura MF, Hernandez JL. Phenology, thermal requirements and maturation of the SR 0.501-17 white wine grape hybrid cultivated in contrasting climatic conditions. *Rev. Ceres.* 2020 Aug 28;67(4):247-55. doi: 10.1590/0034-737x202067040001.
30. Chucho J, Thiéry D. Biology and ecology of the Flavescence dorée vector *Scaphoideus titanus*: A review. *Agron. Sustain. Dev.* 2014;34:381-403.
31. Jones GV, Davis RE. Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. *Am. J. Enol. Vitic.* 2000;51(3):249-61. doi: 10.5344/ajev.2000.51.3.249.
32. Piña S, Bautista D. Phenological cycle of table grapevine (*Vitis vinifera* L.) cultivars in tropical conditions. *Bioagro.* 2004;16n:1. ISSN 1316-3361.