Climatic zoning and viticulture in Galicia (North West Spain)

Zonage viticole et viticulture en Galice (Nord-ouest de l'Espagne)

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Abstract: Galicia is situated in the NW of the Iberian Peninsula, just north of Portugal and so sharing a mild, maritime climate, certain vine species and a number of long-standing viticultural traditions. In Galicia about 18,000 has are dedicated to wine growing, of which roughly half (46%) correspond to the 6 DOs in the area.
The Galician climate is marked by its great diversity that can be explained by the prevailing maritime and continental winds over this part of the world and also due to its topography where a series of N to S mountainous chains check rain-bearing fronts from the Atlantic. This factor gives rise to the appearance of rain shadows particularly suitable for vine growing.
A database was established with standardised 1971-2000 climatic data from 53 selected stations. Fourteen parameters and climatic indices commonly used in viticulture zoning studies were calculated. An analysis of principal components identified the main factors related to climatic variability as well as the climatic indices and parameters with major discriminating scores. These indices included those selected by the Geoviticulture Multicriteria Climatic Classification System (GMCCS). Results show that 13 out of the 36 worldwide viticulture climates specified by the GMCCS appear in Galicia confirming the diversity of viticultural climates present in the region. These results also demonstrate the efficacy of the GCCM system for the differentiation of climatic types on a regional level reinforcing the system's versatility.

Key words: mesoclimate, vine, Galicia, zonification

Introduction

Galicia is a Spanish region in the extreme northwest of the Iberian Peninsula just north of Portugal and so sharing both a cool maritime climate and some wine varieties (e.g. Albariño, Loureira…) as well as various aspects of traditional viticulture e.g. terracing, pergolas. Galicia also shares with Portugal certain viticultural areas such as the Támega valley and the estuary of the Miño valley which is, in fact, the frontier between the two countries.
Altogether there are more than 10,000 ha of vines that include wholly or in part all 6 denominations of origin (D.O.) which is the legal nomenclature used in Spain and Portugal for the recognition of quality in those particular areas presenting the most favourable conditions for the production of quality wines. These vineyards produce an average of more than 50 million kilos of grapes a year, the majority being white grapes (Albariño, Palomino, Treixadura, and Godello) although about 15% of red grapes are also produced: mainly Garnacha and Mencia.
From a strictly climatologic point of view, there are 3 factors that define this part of the Iberian Peninsula. The situation facing the Atlantic ocean with its rain-bearing winds, and the presence of a mountainous barrier running N-S (the Galician Dorsal reaching 1,000 m altitude at points and whose foothills cross the Miño valley about 50 Km, as the crow flies the coast) facilitate the precipitation of rain from the wet fronts in their course eastward inland and favours areas of rain shadow leewards (Föhen) very suitable for vine growing. The third factor is the general relief of the region giving rise to alternating low lying parts (« horts ») and higher areas which results in a stepped landscape where the higher blocks are located towards the East favouring the rains from the Atlantic fronts.
In Galicia, Atlantic and Mediterranean currents intertwine following dynamics whose results strongly depend on distance from the sea, the dominant slope of the mountain facet and altitude. In this way, it is possible to find as many Oceanic (cf) climate types (Köppen, 1931) as Mediterranean (cs) ones. Altitude is also important as Carbonneau (2003) indicates: when considering viticulture climates, plains and valleys often offer different macroclimates and this can be observed in many Galician viticultural areas where the lower

parts of the hills and the floodplains might be under mediterranean regime whereas the upper parts of the hills and the tableaux are under maritime regime, or continental in some occasions.
For a long time these climatic differences between the hills and the watersheds presented a serious difficulty when trying to define the climates of different viticultural areas. Although some evidence was available (personal experience, variety of flora, forms of vegetation, etc.) proving quite appreciable climatic differences, there were scarcely no weather stations situated on the slopes where the main viticultural fields are located. Fortunately, from 1999 the scarcity of this information began to be solved by setting up a new network of automatic weather stations, many of which (about 23) are installed in viticultural areas. Although the recorded series are still short, the data offered are extremely valuable in deeper investigation into more or less local variations of the climate within the viticultural zones especially in the identification and characterization of the eventual mesoclimates that can be present in the extensive viticultural areas.
Carbonneau (2003) indicates that mesoclimates are the result of variations brought to the regional climate (viticultural macroclimate) by gradients (height, aspect, distance from the sea or to a large mass of cold or hot water, etc.) or by the relief (slopes, sun exposure etc.). Many viticulture zonification studies include an introductory phase of identification and characterization of the mesoclimates that appear from variations that affect the intensity of certain selected climatic factors (temperature, rainfall, sunlight, frost, drought, etc.) which clearly influence vine's development. These factors are not usually used by themselves but combined into mathematical expressions or bioclimatic indices or integrals to quantify accumulation or final balance over a certain period of time, which in viticulture studies are usually the 6 or 7 months of the vine's growth (Fregoni, 2003). Recently, some studies (Tonietto, 1999; Carbonneau, 2003; Tonietto and Carbonneau, 2004) combine a reduced number of climatic indexes for the classification of viticulture climates in a series of climatic types that set up a classification with an aim to be universally valid. The promoters of this system gave it the name of Geoviticulture MCCS distinguishing 36 different climatic types, taking into account the possible combinations of 3 indexes, namely Huglin´s Heliothermic index (HI), cold night index (CI) and drought index (DI). To prove its efficacy, this classification was successfully tested to differentiate the climate of 97 worldwide viticulture zones (Tonietto and Carbonneau, 2004).
The idea of a widely valid classification of viticulture climates is certainly attractive and it's likely that studies will shortly appear proving their usefulness in different parts of the world. Amongst the attributes that support this universal application is the possibility of working on different levels and in different zones of the viticultural world. The variability and diversity of viticultural climates present in Galicia offer the opportunity of testing the application of the Geoviticulture MCC system in geographically reduced areas which is one of the aims of this study. We also want to identify which climatic indices from those commonly used in viticultural zoning are most suitable for the description of the mesoclimates present in wine-producing areas of Galicia.

Material and methods

Material

In order to carry out this study, we obtained meteorological data from 52 stations from 6 organizations i.e. The National Meteorological Institute of the Ministry of Environment (IMN), the System of Geographical Information for agricultural data of the Ministry of Agriculture, Fishing and Food (SIGA), the System of Environmental Information of the Council of Environment for the Galician government (SIAM), the Phytopathologic Station of Areeiro in the county of Pontevedra (AREEIRO), the hydrologic services of the north western electrical company FENOSA, and the Institute of higher agronomic studies of the technical University of Lisbon (ISAUL). Data from normalized summaries for the 1945-74 period were used on three locations along the Sil river canyon since the station networks available to us provided a scarce coverage for that area.

Methods

The termo-pluviometric figures from the selected weather stations formed a very heterogeneous group in so far as the variables with the length of time, periods oscillating from 5 to 30 years and quality with respect to the presence of artificial tendencies and anomalous data. With the purpose of setting up a trustworthy database, quality checks for the detection and elimination of anomalous data were carried out using frequency histograms (Aguilar *et al*., 2002), correction of artificial tendencies by means of the standard homogeneity test (Alexandersson and Moberg, 1997), and the filling in of gaps by the method of lineal adjustment (González-Hidalgo *et al.*, 2002). Finally the series were reduced to a period 1971-2000 applying the method for the differences in the temperature series and the coefficients for precipitations.

Having obtained the normalized data base for 1971-2000, the calculation of 14 parameters and climatic indices in common use in studies of climatic zoning in viticulture was undertaken (Amerine and Winkler, 1944; Branas *et al.*, 1946; Hidalgo, 2002; Huglin, 1978; Gladstones, 1992; Gómez-Miguel y Sotés, 2003). These include annual precipitation (Pa), rainfall during the growth period (Pe), summer rain (Pv), average annual temperature (Ta), average temperature over the growth period (Te), the frost free period (Hm), continentality (Ct), the Riou´s drought index (DI), the Hidalgo index (Hd), Brana´s hidrothermic index (HdB), the integral of effective temperatures or Winkler´s index (IW), Huglin´s index (HI), Brana´s heliothermic index (HB) and the night cold index (CI).
In order to identify the main factors of climatic variability in the wine producing areas under study, the data from the 52 stations were submitted for the realization of an analysis of principal components using Varimax rotation. The identification of the climatic indices and parameters with greater capacity to discriminate among local vine climates was carried out observing their weights in the PCA factors and the correlation matrix among variables.

Results

Table 1 shows descriptive statistics corresponding to the variables and climatic indices from the 52 meteorological stations consulted for this research. Figures relative to the altitude and distance from the sea are also included.

Table 1 - Statistics of climatic parameters and indices

	Al	Dm	Ta	Tas	IW	Hl	IH	Pe	Pa	Pv	HB	Hd	DI	Hm	CI	Ct
Mean	265	117	13.6	17.3	1341	3.5	2011	375	1174	111	4729	3.3	93.7	258	11.7	13.7
Dt	224	85	1.1	1.0	185	0.5	230	103	363	27	1347	1.1	35.1	52	1.4	2.1
Min	24	0.2	11.0	14.7	872	2.2	1474	217	628	70	2607	1.7	24	165	8.5	9.9
Max	800	286	15.3	19.1	1660	4.3	2512	581	1862	177	7277	5.9	170	365	14.6	17.8

Principal Components Analysis

On submitting the data set to principal component analysis it is found that the variability in the meteorological stations can be accounted by 3 main factors that on combination are able to explain 92.6% of the actual variability. As can be seen in table 2, the first component explains 41.2% of the variance including, above all, variables related to precipitation and indices which relate precipitation with the sum of effective temperatures.
The second component explains 37.7% of the variance and the dominant variables and indices are related to temperature i.e. effective temperature (Te), Winkler´s index (IW), Huglin´s index (HI) and Brana´s heliothermic product (HB) which are the data showing the highest values.
The third component explains 17.2% of the variance and includes variables related to the cold: fundamentally the nictothermic index (CI) and the average duration of the frost free period (Hm).
On comparing figures from the matrix of rotated components from table 2 it can be seen that some of the variables are strongly correlated therefore providing redundant information.
The indices which are part of the GMCCS systems are represented in all three components and are among those achieving the highest ACP scores. Because of this we could hypothesize that when we combine those indices we could reach a high capacity to discriminate and therefore, they could be adequate to discriminate the climatic types present in the Galician wine growing areas.

Table 2 - Matrix of rotated components

	Pas	Pa	HdB	DI	Pe	Hd	Ct	HlB	IW	Tas	IH	Ta	Hm	CI	%	Var.
Comun.	.97	.93	.96	.85	.85	.84	.85	1.00	1.00	1.00	.97	.97	.89	.90	Exp	Acc.
Comp 1	.961	.934	.927	.918	.912	-.831	-.656				-.166	.285	.264	.179	40.5	40.5
Comp 2		.117	.175			.355	.256	.975	.974	.974	.958	.786	.256	.453	35.0	75.5
Comp 3	.225	.217	.257		.145	-.150	-595	.211	.217	.219	-.148	.519	.866	.813	17.2	92.6

Heliothermic index

This is the classical index used to evaluate the heliothermic potential of the environment (HI heliothermal index) from average to maximum temperatures present during the vine’s growth period and then multiplied by a coefficient of correction which takes into account the average daylight period in the latitude studied.

The average HI of the stations researched in this study is 2,011, oscillating from the minimum 1,454 to a maximum 2,512. This signifies that in Galicia there are stations classifiable as 5 of the 6 HI classes described by Tonietto and Carbonneau (2004) in the GCCCM System.
Half of the stations (50%) are temperate warm with values greater than 2,100 and lower than 2,400 usually situated in the lower parts of the hills where vineyards are more profuse. There are also a significant number of stations (31%) classified as temperate (1,800 < HI ≤ 2,100) which are generally found at higher altitudes on higher slopes and watershed plateaux.

Drought index

Drought is a factor that can condition the vines growth, maturity and production and consequently the potential of viticulture zones. Tonietto and Carbonneau (2004) propose the use of the dryness index (DI) which is an adaptation of Riou´s index (Riou *et al.*, 1994) specifically designed for usage in vineyards. The final score is obtained adding up the scores corresponding to each of the 6 months of the vine's growth period. To do this, the estimate of water retained by the soil at the end of each period is taken into account. That is the reserve that vine's roots may tap fundamentally, precipitation, the potential transpiration of the vineyard and direct evaporation from the soil. The GCCCM system defines 4 viticulture climates with relation to scores that maybe reached on the DI index – those that are very dry, moderately dry, sub-humid or humid and of which the last three can be found in the wine growing areas of Galicia although the most abundant (84%) are stations classified as sub-humid.
In so far as to the spatial distribution we would only mention that the stations classified as humid (DI-2, which are 6% of all the stations), correspond to and some coastal areas affected by maritime wet fronts due to the presence of mountain barriers eastwards. The moderately dry class appears in the western areas belonging to Bierzo, Valdeorras and the proximities of Monterrey DO representing 10% of the dataset.

Night cool index

Following Kliewer and Torres (1972), it is known that daily thermal amplitude when grapes are maturing is a key factor to quality and often a decisive point in the quality of grape harvesting as it influences the synthesis of secondary metabolites such as polyphenols and aromas which are essential for the colour and aroma in wines.
Tonietto (1999) considers that the average air temperature minimums over September (March in the Southern Hemisphere) can be used as a reliable index for indications of potential quality in viticultural climates. He gives it the name of night cool index distinguishing four viticulture climates in relation to scores in this index i.e. climates with very cold nights, warm nights, and hot nights.
Among the stations within or close to the Galician wine growing areas, the majority (59%) belong to the very cool nights class (CI+2) and there is a 33% classified as cool night class (CI+1) which are located mainly in coastal areas to the west of the Galician Dorsal or inland areas close to dams. We can find temperate night class (CI-1) stations in the Salnés DO which is one of the most prestigious wine growing areas in Galicia.

Discussion

The combinations allowing for the different classes foreseen for the 3 indexes on which the GCCM system is based would show 96 different climatic types: although Tonietto and Carbonneau (2004) limit that variability indicating that of the 96 possible combinations only 36 really correspond to climates present in the actual wine growing areas of the planet. As it can be seen in table 3, on combining the 3 indexes in order to classify the weather stations situated in or near Galicia, we found that these could be categorized in 13 different climatic types of which 5 correspond to areas where no vineyards exist or their presence is marginal.
Thus it can be seen than in a space of scarcely 30.000 km^2 about third of all the different worldwide vineyard zone climates can be found. In the first place, this indicates that Galicia shows and outstanding diversity of viticulture climates and secondly, that the GCCM system is not only adequate for the distinguishing of worldwide climates but also allows the differentiation climatic types at finer scales which could strengthen the GCCM versatility. As for the abundance and distribution of the variety of the climatic types encountered in Galicia we may highlight as the most significant the following aspects:
The most abundant types (17% each) are established in areas were the climate is temperate (HI-1) or temperate warm (HI+1), sub-humid (DI-1) and of very cool nights (CI+2), which predominate in the central and western part of the Miño basin and where most of the Galician wine growing areas protected by a DO

are located. At an international level, to locate similar climates we would need to go to Perugia (Italy) or Bei Jing (China).

Table 3 - Viticultural climates found in Galicia according too the GCCCM System

GCCCM System	%	Stations	Wine growing intensity	Similar viticultural areas in the World
HI-2 DI-1 CI+1	2	Betanzos	Denomination of Origin	Napier (New Zealand)
HI-2 DI-1 CI+2	10	Mabegondo, Arbo, Xinzo, Marroxo, Maceda	Marginal	Tours, Nantes, Colmar (France)
HI-1 DI-2 CI+1	2	Herbón	Marginal	Pau (France)
HI-1 DI-1 CI+1	12	Ames, Salcedo, Lourizán, Rosal, Currás, Ribadumia	Denomination of Origin	Cognac, Bordeaux, Toulouse (France)
HI-1 DI-1 CI-1	8	Cambados, Vilagarcía, Vilariño, Padriñán	Denomination of Origin	------
HI-1 DI-2 CI+2	2	Caldas	Marginal	Macon (France)
HI+1 DI-1 CI+1	13	Monção, Frieira, Ponteareas, Páramos, Ourense, Peares, Sequeiros	Denomination of Origin	Modena, Treviso (Italy) Tong Chuan (China)
HI+1 DI-1 CI+2	17	Arnoia, Prado, Quinza, Vilamartín, Pumares, Barbantes, Fontefiz, Coles, Pinguela, Montefurado	Denomination of Origin	Bei Jing (China)
HI-1 DI-1 CI+2	17	Leiro, Mesiego, Belesar, Verín Coles, Conchada, Bóveda, Brollón, Castro C., Petarelas	Denomination of Origin	Perugia (Italy) Bratislava (Slovaquia)
HI+2 DI-1 CI+1	4	Castrelo, Velle	Denomination of Origin	Yi Couniy (China)
HI-3 DI-1 CI+2	2	Caldelas	No vine growing	Vancouver (Canada)
HI-1 DI+1 CI+2	8	Larouco, Villafranca, Ponferrada, Carucedo	Denomination of Origin	Viseu (Portugal) Valladolid (Spain)
HI-2 DI+1 CI+2	2	Castelo	No vine growing	Summerland (Canada)

In areas with higher elevation and closer to the altitudinal limit to grow vines at both sides of the Galician Dorsal, the vines are usually located in areas with temperate warm climate (HI+1), sub humid (DI-1) and of cool nights (CI+1) which represent about 13% of all of the stations considered in this work. At an international level we can find this climate in Modena and Treviso (Italy) and Tong Chuan (China).

In sectors to the west of the Galician Dorsal, proximity to the sea can be interpreted in an increase in both precipitation and minimum summer temperatures and vineyards are usually situated in the temperate climatic class (HI-1), sub humid (DI-1) and cool or temperate nights (CI+1, CI-1). To the first climate type belong 12% of the stations which tend to be located in coastal areas of the Rias Baixas DO which represent a climatic type similar to that of Cognac o Bordeaux (France). The second climatic type (with temperate nights) is less abundant (8% of all of the stations) but it is known by its typifying as the stations included belong to the Salnés district which is one of the districts included within the DO Rías Baixas and where Albariño variety is able to reach all of its potential for quality wine production. Curiously enough, there is no mention in Tonietto and Carbonneau (2004) of any other wine growing area at the international level within this category.

In the western sector (DO Bierzo and Valdeorras) there is a temperate climate type (HI-1), moderately dry (DI+1) and with very cool nights (CI+2) which comprises 8% of the stations and of the same type as that of Ribera del Duero (Valladolid, Spain) or Viseu (Portugal).

One of the less abundant climate types in the Galician wine growing areas is the cool type (HI-2), sub humid (DI-1) and with very cool nights (CI+2) which is only present in a very localized area to the west around the Betanzos town where wine growing has a long tradition. To find a comparable climatic type in the world we would need to go to Napier in New Zealand. It is also of low occurrence (4%) the warm type (HI+2), sub humid (DI-1) with cool nights (CI+1) which is found only in districts close to dams. We can find an equivalent climate type in Yi Couniy in China.

The rest of climatic types appear in areas close to wine growing areas but were the presence of vineyards is occasional or rare. This is the case of the cool climate (HI-2), sub humid (DI-1) and of very cool nights

(CI+2) which represents 10% of all of the stations included in this work. However, we can find French wine growing areas in these climatic types such as Tours, Nantes or Colmar. A similar thing occurs in the temperate districts (HI-1), humid (DI-2) and of cool nights (CI+1) which is represented by Herbón and which has a similar climate to that of Pau in France. Vineyards aren't common in temperate climates (HI-1), humid (DI-2) and of very cool nights (CI+2) despite there are wine growing areas such as Macon (France) with this climate class. The rest of climate types appear at very high elevations within wine growing areas: for example, Castro has an elevation of 800m and has a viticultural climate HI-3, DI-1, CI+2 whereas Castelo (at 740 m height) has a viticultural climate equivalent to that of Summerland in Canada. Vines aren't cultivated extensively at these locations in Galicia.

Conclusion

We demonstrated that the GMCCS is adequate to perform viticultural climate zoning and that is able to distinguish climatic types even when the study is performed at the regional level, as it is the case of Galicia. From the point of view of viticultural climates, Galicia has a rich diversity where a third part of all of the currently identified viticultural climates at an international level are present although not all of them are used extensively for vine growing.

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